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ATHI WATER SERVICES BOARD (AWSB)

FEASIBILITY STUDY AND MASTER PLAN FOR DEVELOPING NEW WATER SOURCES FOR NAIROBI AND SATELLITE TOWNS

Volume 1: Master Plan Main Report

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Chapter 1 - Introduction

1 General

The Government of Kenya has received a credit from International Development Association (IDA) and the Agence Française de Développement (AFD), and intends to apply part of the proceeds for Consulting Services for Improving Water Security: Feasibility Study and Master Plan for Nairobi and Satellite Towns.

The present document is the Master Plan Report prepared by the Consultant Egis Bceom International in association with Mangat I.B. Patel & Partners according to the Contract with Athi Water Services Board (AWSB) for the consulting services related to the Feasibility Study and Master Plan for Developing New Water Sources for Nairobi and Satellite Towns.

To date, the following Reports / Working Papers have been submitted by Egis Bceom International / Mangat I.B. Patel & Partners.

- Inception Report, February 2011
- Working Paper No. 1 – Preliminary Review and Update of Scenarios for Water Supply to Nairobi – February 2011
- Working Paper No. 2 – Surface Water Hydrology – March 2011
- Working Paper No. 3 – Water Demand Report – April 2011
- Water Sources Options Review Report (Draft Version 01) – 23rd May 2011
- Water Demand Report - Satellite Towns - May 2011
- Review of Groundwater Resources – June 2011
- Water Sources Options Review report (Version 02) – August 2011
- Working Paper for Development of Water Sources for Satellite Towns – October 2011
- Preliminary EIA for the Selected Scenario: Nairobi Water Sources, Phases 1 & 2 - Version 04 - December 2011
- Preliminary Design Report - Northern Collector Phase 1 Project - Version 01 - March 2012
- Preliminary Design Report - Northern Collector Phase 1 Project - Version 02 - June 2012
- Long Term Development Strategies (Nairobi City and Satellite Towns) - 10th July 2012
- Report on Extended Yield Analysis of the Northern Collector System - July 2012
- Report on Thika Dam Safety Assessment - July 2012

Various discussion forums have been held jointly between AWSB, World Bank, AFD and other Stakeholders to discuss the Preliminary findings outlined in the above mentioned Working Papers and other Reports. Comments and suggestions on the Preliminary findings have been incorporated in the Final Reports.

After submission of the Water Sources Option Review Report (Version 02) further discussions were held with AWSB, WB and AFD regarding the potential yields of the contemplated water sources. Based on discussions, further modelling work for the existing and the contemplated systems was carried out. The outputs have been included in the present report. The results confirm the proposal made on the basis of the Water Sources Option Review Report; the recommended strategy for supply to Nairobi is Scenario 3A with the First Stage works to meet Nairobi City Water Demand Horizon 2017 comprising the following water schemes: (i) wellfields in Kiunyu (2014) and Ruiru (2015); and the Northern Collector Phase I (2016). The Preliminary Design of the Northern Collector Phase I Project has been prepared on this basis.

This Report also includes development strategies for water supply to the Satellite Towns. The strategies have been compared on Least Cost basis. A Multi-criteria Analysis carried out showed that the Mixed Water Supply Option ranked the best to meet the water demand of Nairobi and Satellite Towns upto Year 2035.

2 Content of the Master Plan Report

The document is presented in two separate volumes with:

- Volume 1: Master Plan Report
- Volume 2: Master Plan Report Appendices

Volume 1 of the present report is organised as follows:

- Present Water Sources for Nairobi and Satellite Towns
- Study Area, Land Use, Socio Economic and Demographic Trends
- Water Demand Forecast
- Surface Water Hydrology (updated with Satellite Towns)
- Groundwater Assessment (updated with Satellite Towns)
- Development Strategy and Water Balance Modelling for Nairobi City
- Phase I – Development for Supply to Nairobi City
  - Wellfield Development
  - Preliminary Design of Northern Collector Phase I System and Related Works
    - Northern Collector Tunnel
    - Water Treatment Facilities
    - Raw Water and Treated Waster Transmission Main
    - Environmental Impact Assessment
    - Project Costs and Implementation Schedule
    - Financial Analysis
    - Economic Analysis
- Development Strategy for Water Supply to Satellite Towns
  - Options for Water Supply to Satellite Towns
  - Least Cost Analysis for Water Supply to Satellite Towns
  - Environmental Impact Assessment
- Assets Management Plan
- Water Resources Management

- Risk Management
- Summary and Recommendations of the Master Plan

Volume 2 of the Master Plan Report provide the related Appendices.

3 Objectives of the Assignment

3.1 Terms of Reference

The reference documents to be used for carrying out the present assignment include: (i) the TOR related to Consultancy services for Improving Water Security: Feasibility Study and Master Plan for Developing New water Sources for Nairobi and Satellite Towns, issued in October 2009 by AWSB, (ii) the Clarifications to Consultants on RFP Document issued on January 11th, 2010, by AWSB and (iii) the Minutes of Negotiations all attached together with the Consultant's Proposal for the Contract.

The Location Plan for Nairobi City and Satellite Towns is given in **Figure 1-1 on Page 1-4.**

The clarifications issued subsequently by AWSB (ref Section 3.2 below) have significantly changed the objectives, the sequences of activities and the expected outputs indicated in TOR. It must be emphasized that the TOR document mentioned Two Phases as follows:

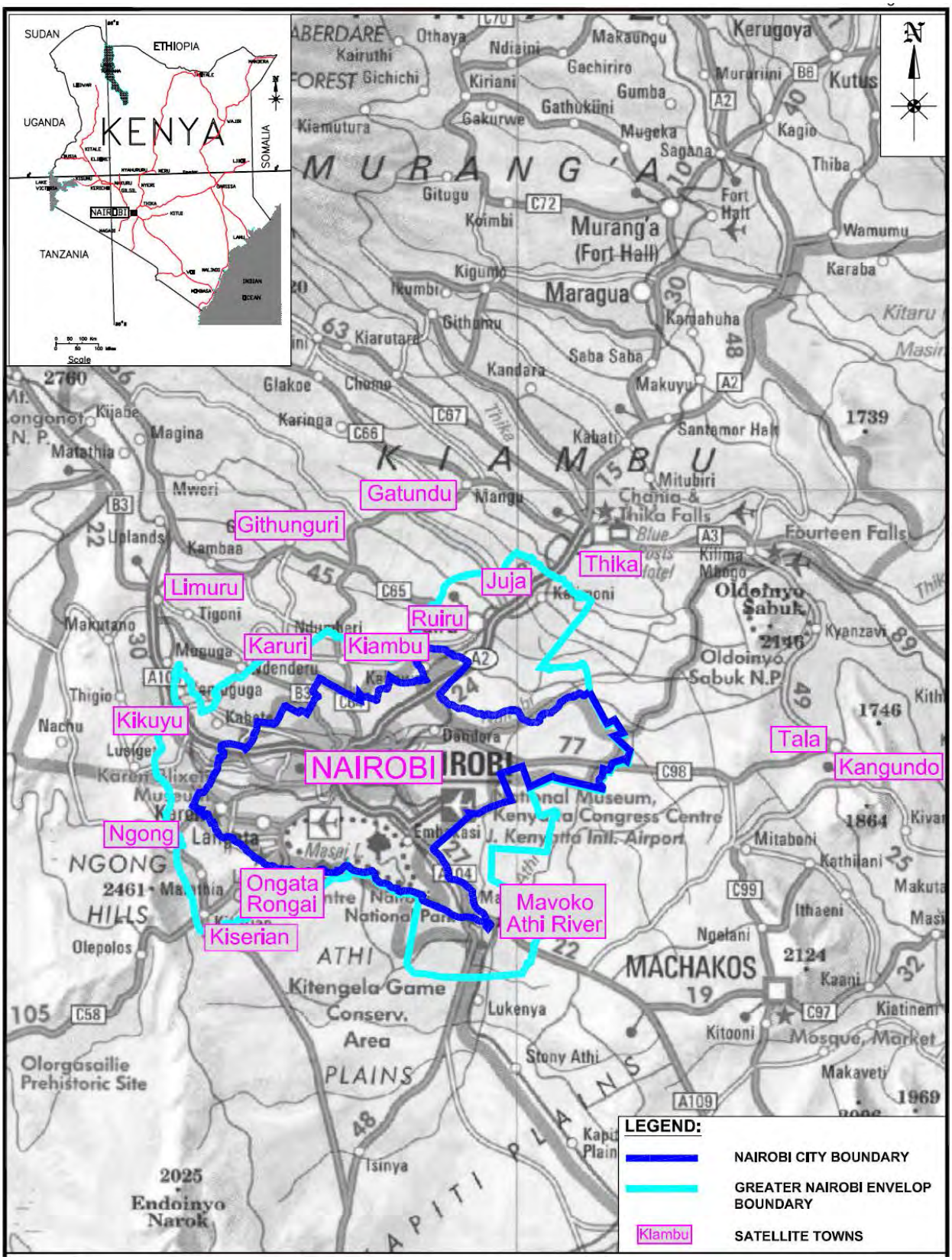
- Phase 1: including two steps:
  - Draft Feasibility Study considering all options and recommending 2-3 strategies to meet 2035 demand in the most cost effective option;
  - GOK reviews 2-3 strategies and selects one strategy which would be developed up to Full Feasibility Study Level.
- Phase 2: including two main sub-activities:
  - Master Plan for 25 years in 5 year increments (or stages).
  - Detailed Design and Bidding Documents for the first 5 year increment (stage 1) – This component was subsequently deleted in clarifications issued on 4th January 2010.

3.2 Clarification Issued on 11th January 2010

A letter related to "Clarifications to Consultant on RFP document" was issued by AWSB and addressed to all shortlisted consultants on 11 January 2010. The letter stated that further clarifications are as follows:

- "*The Consultant is not required to prepare any detailed design for Maragua and Gatamayu dams or any other detailed design. Detailed design will be part of another assignment which AWSB intends to procure as soon as the study is advanced enough to make a decision about specific investment needed.*"
- … "*as part of the activities for the services, the Consultant will be required to undertake a feasibility study and masterplan to meet the long term (25 years) needs for Nairobi and preliminary design for the short term measure to meet the demand for 2017. The preliminary design may include total water storage capacity of at least 100 million cubic meters, treatment works and transmission main. The preliminary design may include one or more dams, groundwater development and/or other options. The Consultant will undertake hydrological reviews, geotechnical investigations and topographical surveys at the feasibility level for potential dam sites and hydrogeological reviews for groundwater options.*"

Figure 1-1: Project Location Map - Nairobi City and Satellite Towns



4 Water Sector Organisation

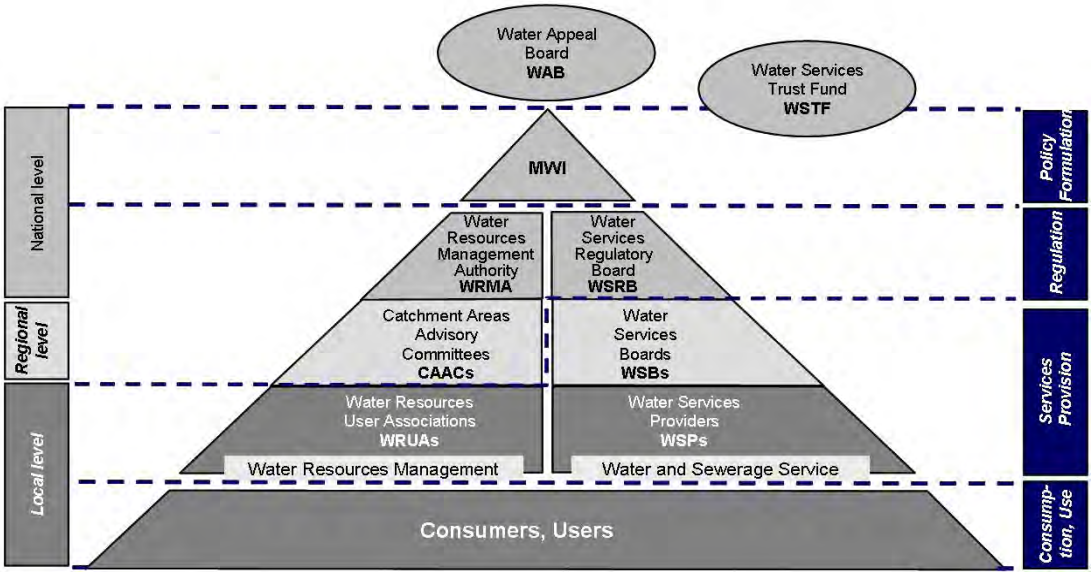
4.1 Key Legislation and Policies

Key legislation and policies for the water sector in Kenya include:

- The National Policy on Water Resources Management and Development, Sessional Paper No. 1 of 1999, and
- The Water Act, 2002, which was aimed at providing for a harmonized and streamlined management of water resources, water supply and sewerage services.

The institutional arrangements and authorities in charge are shown in Figure 1-2 and described in the sections below.

Figure 1-2: Functions and Roles of Institutions set up under Water Act, 2002



4.2 Ministry of Water and Irrigation (MWI)

The Ministry of Water and Irrigation (MWI) is the ministry in charge of the water sector and is therefore responsible for the overall management of water resources and general government policy on the water sector in the country. The Ministry was established in January 2003 with the goal of conserving, managing and protecting water resources for socio-economic development.

Under the water sector reforms, the Ministry transferred management of and operation of water services to the Water Services Regulatory Board (WASREB) from mid 2005. The Director of water was the person in charge of water services in the ministry but these powers and duties were transferred to the regional water service boards that are now licensed by the WASREB to provide water services in different regions across the country. The ministry and other state corporations that were involved in water supply such as the National Water Conservation and Pipeline Corporation also transferred their water supply facilities to these regional water service boards. NGOs, CBOs and any other community self help groups are required to enter into agreements with the respective regional water service boards with regard to use of water supply facilities owned by the community organisations.

4.3 Water Resources Management Authority (WRMA)

The Water Resources Management Authority (WRMA) was formed as one of the water sector bodies under the water sector reforms; the body was established under the Water Act 2002. The

overall mandate of WRMA is to protect and conserve water resources. Water resources for purposes of the Water Act include lakes, ponds, swamps, streams, marshes, watercourses or any body of flowing or standing water both below and above the ground.

The functions of the WRMA include planning, management, protection and conservation of water resources. The WRMA is also authorized to receive and determine applications for water permits and monitor their compliance. There are currently six established regional offices in Kenya, these are Athi catchment area in Machakos, Tana catchment area in Embu, Rift Valley catchment area in Nakuru, Lake Victoria South catchment area in Kisumu, Lake Victoria North catchment area in Kakamega and Ewaso Nyiro North catchment area in Nanyuki.

The WRMA responsibilities extend to the management of water catchments. The Water Act establishes the Catchment Area Advisory Committees whose principal functions are to advise the WRMA on water resources conservation, use and apportionment at the catchment levels.

4.4 Water Services Regulatory Board (WASREB)

The Water Services Regulatory Board is established under the Water Act and was operationalised in March 2003. The functions of the WASREB include the issuance of licences to Water Service Boards and to approve service provision agreements concluded between Water Service Boards and Water Service Providers. The Water Service Providers are the agencies that directly provide water and sanitation services to consumers. The WASREB is responsible for ensuring that water services and supply are efficient and meet expectations of consumers through regulation and monitoring of Water Service Boards and Water Service Providers. To standardize service provision, the Board has the responsibility of developing among others, tariff guidelines.

The Board is therefore supposed to oversee the implementation of policies and strategies relating to provision of water and sanitation services, these policies include the National Water Services Strategy (2007 -2015), Pro-Poor Implementation Plan for Water Supply and Sanitation (refer to the popular versions of these documents prepared by COHRE & Hakijamii Trust), the specific functions of the WASREB include:

- Providing information about water and sanitation services.
- Regulating the provision of water and sanitation services; this is done through such methods as setting standards for the provision of water services, monitor compliance of facilities for water supply with the set standards.
- Licensing Water Service Boards such as the Athi Water Services Board and other regional water service boards and approving their appointed Water Service Providers through service provision agreements.
- Setting the rules, establishing standard guidelines and monitoring the performance of Water Service Boards and Water Service Providers and enforcing regulations.
- Establishing technical, water quality and effluent disposal standards.

4.5 Water Services Trust Fund (WSTF)

The Government of Kenya, through the Ministry of Water and Irrigation established the Water Services Trust Fund (WSTF) under the Water Act 2002 to channel funding for its long-term objectives of developing water and sanitation services in areas of Kenya without adequate water. The main objective of the WSTF is to assist in financing capital costs of providing services to communities without adequate water and sanitation services. The WSTF focuses on reaching

those areas that are underserved or not served at all such as informal settlements, the priority being given to poor and disadvantaged groups. The projects are funded through direct allocation by the Government and donations and grants that may be received from bilateral and multilateral development partners, organisations and individuals.

4.6 Water Appeals Board

The Water Appeals Board is established under the Water Act to adjudicate disputes within the water sector. The Appeals Board is made up of three persons, one appointed by the President on advice of the Chief Justice and two others appointed by the Minister for Water and Irrigation. The Water Appeals Board can hear and determine appeals arising from the decision of the Minister of Water and Irrigation, the WASREB and the Water Resources Management Authority (WRMA) with respect to the issuance of permits or licensees under the Water Act.

4.7 Water Services Boards (WSB)

Water Services Boards (WSBs) are constituted under the Water Act 2002. The WSBs are responsible for the provision of water and sewerage services within their areas of coverage and are licensed by the WASREB. The WSBs are also responsible for contracting Water Services Providers (WSPs) for the provision of water services.

WSB and WSP enter into service provision agreements that include but not limited to the supply area, development, rehabilitation and maintenance of water and sewerage facilities of the WSBs. The WSBs are responsible for the review of the water services tariffs proposals from WSP before submission to WASREB for consideration.

There are currently eight (8) established WSBs namely: Athi Water Services Board, Tana Water Services Board, Coast Water Services Board, Lake Victoria South Water Services Board, Lake Victoria North Water Services Board, Northern Water Services Board, Rift Valley Water Services Board and Tanathi Water Services Board.

4.8 Athi Water Services Board (AWSB)

The Athi Water Services Board serves Nairobi City and the surrounding districts of Kiambu East, Kiambu West, Gatundu and Thika. The main responsibilities of AWSB are to:

- Expand coverage with strong focus on improving access to water services in urban informal settlements and to the rural poor.
- Contribute to poverty reduction, promote gender equity, sensitize communities on good health and hygiene practices, promote HIV/AIDS awareness and conserve the environment.
- Appoint viable and well managed Water Service Providers and ensure they have appropriate systems by undertaking the following:
  - Enforce water quality monitoring.
  - Ensure they have maintenance systems and procedures to minimise interruptions to water supplies.
  - Ensure they have an accurate and efficient billing system.
  - Ensure they are customer focused in all their activities.
  - Monitor and evaluate performances against targets for the Board and Water Service Providers.
  - Build Capacities of Water Service Providers to embrace efficiency, accountability and responsibility in service delivery.

5 Previous and On-going Studies

Previous and On-going Studies which have been reviewed critically are as follows:

5.1 Third Nairobi Water Supply Project

The study was carried out by Howard Humphreys & Partners, England, in association with Howard Humphreys (Kenya) Ltd, Kenya, for the Nairobi City Commission. In this context, two Study Reports are particularly relevant for carrying out the present study:

- Long-Term Development Plan (Regional studies), June 1986
- Northern Collector Scheme, Feasibility Report, July 1998

5.1.1 Long-term Development Plan (Regional Studies)

The Report was issued in June 1986. The Long Term Plan was to be aimed at satisfying the needs of Nairobi and its environs to 2010.

The study area covered the drainage area of the upper catchments of the Tana and Athi Rivers; it included the whole of the upper Athi catchment but only the Thika catchment of the Upper Tana system. The study area included Nairobi, the whole of Kiambu District and parts of Muranga, Machakos, Kajiado and Nyandarua Districts[1] with a total covered area of 7,500 km^2. The area lies within the Athi River catchment within the exception of Muranga which is within Tana River catchment.

After investigating additional water resources and making the required analyses, the study concluded that following the completion of the Thika 6 Scheme (Ndakaini Dam) which would transfer water per gravity to Nairobi via Mwagu intake and Ngethu Treatment Works, the Northern Collector should be extended to the North Mathioya river and additional supplies are gravitated to Nairobi via a new high level treatment works[2] to a service reservoir at Kabete. Selected minor surface and groundwater sources will be developed at the same time to augment supplies to the areas outside Nairobi.

5.1.2 Northern Collector Feasibility Study

The Draft Report was issued in June 1998, and the Feasibility Study Report in July 1998. Based on the conclusions of the previous studies for the Third Nairobi Project, the principal objective of the study was to identify sufficient sources of water to meet the demand for water of Nairobi until Year 2010, and to propose an integrated implementation plan.

The previous studies confirmed that Thika Dam was the preferred choice of water for the Third Nairobi Project with a yield of 3.8 m^3/s. The Northern Collector was to constitute an extension of the existing water resource system encompassing Thika Reservoir, Sasumua Dam, and Intakes on the Kimakia, Kiama and Chania Rivers.

[1] The study area was different from that targeted under the present study which is limited to Nairobi and thirteen (13) satellite towns: Thika, Ruiru-Juja, Kikuyu, Limuru, Kiambu, Githunguri, Karuri, Lari, Gatundu, Mavoko Municipality, Ongata Rongai, Ngong Township and Tala-Kangundo, w/o rural schemes

[2] Ngorongo

The broad objective of the Northern Collector was to intercept a proportion of the flow in rivers to the North of Thika reservoir sufficient to allow the water resource system that supplies Nairobi to increase in yield in two phases:

- Phase I: 1.50 m^3/s
- Phase II: 2.77 m^3/s
- Total: 4.27 m^3/s

The study recommendations were as follows:

Phase I

The required yield for Phase I of 1.50 m^3/s can be achieved with a reliability of 90% by a 13 km long tunnel diverting flows from the Irati, Gikigie and Maragua rivers. The diversion capacities and compensation flows[3] required are summarized in Table 1-1.

Table 1-1: Phase I Configuration for the Northern Collector

Diversion No	River	Compensation Flow (m^3/s)	Diversion Capacity (m^3/s)
1	**Irati**	**0.332**	**2.0**
2	**Gikigie**	**0.076**	**1.0**
3	**Maragua**	**0.502**	**3.0**

Source: Howard Humphreys & Partners, Northern Collector Scheme, Draft report, June 1998

If compensations flows are set in such a manner as to minimize the impact on hydropower generation by the run-of-river schemes in Muranga District, the required yield for Phase 1 of 1.50m^3/s could only be met by an extended 23 km long tunnel with additional diversions from the South Mathioya, Hembe and Githugi Rivers.

Phase II

84% of the required for phase II, 2.32 m^3/s, can be achieved with a tunnel of total length 25 km by diverting flows from the South Mathioya, Hembe, Githugi and North Mathioya rivers in addition to the Phase I diversions. The diversion capacities and compensation flows required are summarized in Table 1-2.

Table 1-2: Phase II Configuration for the Northern Collector

Diversion No	River	Compensation Flow (m^3/s)	Diversion Capacity (m^3/s)
4	**S.Mathioya**	**0.665**	**1.5**
5	**Hembe**	**0.484**	**1.0**
6	**Githugi**	**0.411**	**1.5**
7	**N. Mathioya**	**1.093**	**2.5**

Source: Howard Humphreys & Partners, Northern Collector Scheme, Draft report, June 1998

The study concluded that it was not realistic to consider setting the compensation flows to minimize impact on the generation of hydropower within the District.

[3] Without considering the downstream hydropower generation

Phase III

The analysis made by Howard Humphreys' study showed that the yield of the project could be increased if additional storage can be introduced into the configuration.

Proposed Next Stage

The Consultant noted that the construction of the Northern Collector will constitute the completion of the Long Term Development Plan as envisaged in 1986. Howard Humphreys' study added that there was (in 1998) a need to establish a future plan for provision of water supply to the city. Some options for increasing the yield were already identified at a preliminary level mainly in the form of provision of new storage reservoirs.

5.2 Nairobi Water and Sewerage Emergency Physical Investments Project

Due to the great need to improve water supply and sanitation services in Nairobi, the "Nairobi Water and Sewerage Emergency Physical Investments Project (NWSEPIP)", financed by the Agence Française de Développement (AFD) was initiated by the Ministry of Water and Irrigation on behalf of the Athi Water Services Board. It aimed at providing investments opportunities to complement the Nairobi Water and Sewerage Institutional Restructuring Project (financed by World Bank) that aimed at strengthening the institutional framework for water and sanitation services in Nairobi.

The NWSEPIP Study carried out by the Consultant SOGREAH, France, in association with CAPE Consult, Kenya (2003), included two components:

- Component A: Emergency Rehabilitation of the Sasumua Dam, damaged during the rains at the beginning of 2003
- Component B: other emergency physical investments related to the water and sanitation installations of Nairobi.

The following data review are related to the report for Component 2, "Feasibility Study of the Final Scenario", submitted by the Consultant in October 2005.

The diagnosis of the Nairobi water supply system led to the following main observations:

- Measurements showed that the actual flow measured in 2004 at Ngethu Treatment Plant is 110,000 m^3/d less than originally designed, with the following main reasons:
  - Mwagu intake no longer had the capacity to divert the target discharge from Chania river
  - The transmission line from Maatara and Ngethu was not able to carry the required discharge
  - Ngethu Treatment Plant required some rehabilitation to produce the design capacity
  - Transmission line from Ngethu to Gigiri no longer had the required capacity
- There was an unbalanced deficit with estimates of 49% for Kabete System and 13% for Gigiri System.

As a result, the Conclusions of the SOGREAH-Cape's Report were as follows:

- The Emergency Physical Investments Programme should focus on increasing the volume of water supply to Nairobi
- The programme should participate in reducing imbalance in water distribution within the City
- A Water Supply Master Plan in view to define a 4th Nairobi Water Supply Project is required as an emergency

5.3 Hydrological Study and Water Management for the Ngethu – Sasumua System (BRLi/Seureca Final Report (Draft), June 2011)

The Consultant BRL Ingénierie in association with Seureca, France, have carried out the Hydrological Study and Water Management for the Ngethu – Sasumua system for Athi Water Services Board (AWSB), with funds from Agence Française de Développement (AFD), aiming at maximizing the water production from the existing water system composed principally of three dams (Sasumua, Thika and Ruiru) and three water treatment plants (Ngethu, Sasumua and Kabete). Sections 5.3.1 and 5.3.2 below are abstracts from the BRLi/Seureca Final Report (draft) dated June 2011.

5.3.1 Yield Analysis

The 90% reliable yields are given in Table 1-3 below for individual dam / weir

Table 1-3: Reliable Yield in m^3/s

River / Structure	Gross Yield	Compensation Flow	Water Available
Sasumua Dam	1.01		1.01
Thika Dam	2.69	0.25	2.44
Kiama Weir	0.21	0.05	0.16
Kimakia Weir	0.41	0.14	0.27
Chania between Sasumua & Mwagu Intake	1.08	0.158	0.92
Total Thika + Kiama+Kimakia+Chania (Sasumua Dam & release from the dam not included)	4.39	0.598	3.79
Total system Thika-Kiama-Kimakia-Chania (Sasumua Dam not included) taking into account joint management			5.5

It can be noted that the whole system yield is 5.5 m^3/s with 90% reliability, i.e. significantly higher than the total of the individual yields.

In Howard Humphreys study (1986) the 90% reliable yield of the Thika-Kiama-Kimakia-Chania system is estimated at 3.8 m^3/s. However in another report "Hydrological Review Howard Humphreys 1995" it is stated that "this is the yield influenced by the releases that are made from Thika Dam for the benefit of downstream users". It is possible that estimation in 1986 was based on the maximum compensation flow downstream Thika Dam.

For the Sasumua Dam the 90% reliable yield is 1.01 m^3/s or 87,260 m^3/day, higher than the expected Sasumua WTP capacity (68,400 m^3/day in raw water). In fact the water demand at 68,400 m^3/day is guaranteed with a reliability of 98%.

5.3.2 Simulation of the System Operation

A day-by-day simulation was carried out by taking into consideration the rehabilitated capacities of the two water Treatment Plants.

- Sasumua WTP: 68,400 m^3/day (raw water)
- Ngethu WTP: 457,920 m^3/day

The results are summarised in Table 1-4, Table 1-5 and Table 1-6 on 1-12.

Table 1-4: Water Balance at Sasumua Dam Over the Simulated Period

Average Characteristics	Operation Data (2006-2010)	Simulation with long Time Series (1946-2010)
Inflow	0.64m³/s (Rainfall-runoff model for the same period: 0.67m³/s)	1.26m³/s
Net losses (evaporation – direct rainfall)	-0.01m³/s (evaporation < direct rainfall)	-0.017m³/s
Outflow	0.62m³/s (different from inflow because of the storage variation in the dam between beginning and end of the period)	0.73m³/s
Spilled Water	Unknown	0.54m³/s

Table 1-5: Water Balance at Thika Dam Over the Simulated Period

Average Characteristics	Operation Data (1997-2010)	Simulation with long Time Series (1946-2010)
Inflow	2.4m³/s (estimation from observation at 4CB5: 1.76m³/s)	2.66m³/s
Net losses (evaporation – direct rainfall)	-0.03m³/s (evaporation < direct rainfall)	-0.02m³/s
Compensation Flow	0.25m³/s	0.25m³/s
Release for Ngethu WTP	1.33m³/s	1.91m³/s
Spilled Water	0.86m³/s	0.56m³/s

Table 1-6: Simulated Abstractions compared to the Inflows (averages over the Period)

Site	Inflow (m³/s)	Abstraction Nairobi Water Supply (m³/s)	Remark
Sasumua Dam	1.26	0.74	
Thika Dam	2.66	1.91	
Kiama Intake	0.79	0.72	
Kimakia Intake	1.49	0.71	Limited by Kimakia Intake capacity (1m³/s)
Chania River (lateral flow + release from Sasumua Dam)	3.12 (2.58 +0.54)	1.79	
Total River runs at Mwagu Intake (Kiama, Kimakia + Chania)	5.40	3.22	Taking into account compensation flow (0.158m³/s) and spilled water
Thika Dam + River Runs	8.06	5.13	

The total abstraction for Ngethu WTP is 5.13m³/s for the simulated period with 1.91 m³/s from Thika Dam and 3.22 m³/s from other Rivers. The average is lightly inferior to the water treatment capacity (5.3 m³/s in raw water), because of the deficit in dry years. The water demand at Ngethu WTP is satisfied with a reliability of 92% (daily time step).

5.3.3 Addendum Nr 1 - Flow Measurement and Assessment of the Raw Water Transmission Capacity From Mwagu Weir to Ngethu WTP (BRLi/Seureca Draft Report, March 2012)

The Report has concluded and recommended the following:

The current water diversion capacity at Mwagu Intake is about 4 m^3/s without any fuse raise on the crest of the Mwagu central weir before spilling downstream the weir.

The flow would be around 4.3 m^3/s with an 8cm height fuse raise as it is currently the case with a metal bar installed on the crest of the ogee weir before spilling downstream the weir.

The capacity of Mwagu Intake could be easily increased to the aimed objective (4.8 m^3/s as optimal abstraction, and 5.3 m^3/s as maximum instantaneous capacity) by:

- Installation of a 25cm height fuse raise (metal bar or timber); in this case the fuse raise should be removed before flood periods otherwise it would increase the siltation in the reservoir.
- Levelling off the sill on the bottom of the channel intake (near the entry of the outlet chamber, height - 0.5m) which is not useful.

The second solution is strongly recommended by the Consultant.

The real capacity of the Mwagu - Mataara Tunnel (not to be confused with the Mwagu Intake) is seemingly near its designed capacity, i.e. 5.3 m^3/s. No direct measurement was undertaken in the Tunnel because of bad accessibility.

The current capacity of the Mataara Chamber / Mataara Raw Water Mains is around 5.1 m^3/s before spilling at Mataara Chamber.

The raw flow meters existing at Ngethu WTP have acceptable accuracy.

A regular maintenance at Mwagu Intake will be necessary since the debris accumulated at the screens can considerably reduce the water diversion capacity.

5.4 Other Study Reports

5.4.1 Reports related to Groundwater

During their assignments in Nairobi for the Inception Report preparation, the Consultant Hydrogeologists made a review of available Study Reports. A detailed review of the report mentioned below is presented in Volume Annexes, Section 2.5:

- Hydrogeology of the Nairobi Area

The report prepared by Gevaerts, in 1964, is a basis for all other studies in the field.

Water Resources Assessment Study in Kiambu District, Kenya

- Third Nairobi Water Supply Project - Long Term Development Plan – Regional Studies – Hydrogeology

The report is part of the study reports prepared by Howard Humphreys in 1986. The report identified areas for future developments.

- Geology of the Nairobi Area

The report prepared in 1991 by Saggerson described among other the stratigraphic succession in Nairobi area.

- The Study on the National Water Resources Master Plan

The National Water Resources Master Plan was submitted by JICA in 1992[4]. In the Volume of Annexes to the present report there is a detailed review of the parts of JICA National Water Master Plan relating to groundwater resources.

- The Athi River Basin Integrated Water Resources Management Programme

The Report prepared by BCEOM, 1998, was related to Phase 1 of the project "Management of the aquifers underlying the Greater Nairobi Area". This report collated and integrated surface and groundwater information concerning the Athi River Basin into a groundwater model.

- The Role of Groundwater in the Water Supply of Greater Nairobi - Kenya

The report prepared by S. Foster et al, 2005, summarized the status of Nairobi water supply, with assessment on contribution, potentials of underground resources and management weaknesses.

- Preliminary Allocation Plan of the Nairobi Aquifer Suite

The Report prepared by Norken (I) Ltd., for WRMA, 2009, presents the results of a Rapid Appraisal of Groundwater Abstractions in Five Areas (Hotspots): Westlands, Karen, Thika Town, Kikuyu Town and Ongata Rongai.

- Report for proposed Groundwater Borehole Drilling to Enhance Water Supply in Nairobi Area

The report prepared by Earthview Geoconsultants, year 2009, was issued as a conclusion of a study in view to identify potentially high yielding aquifers mainly in eastern Nairobi. Buried paleo valleys were identified and preliminary location for field works selected. Maps were not available.

- Climate Variability and Water Resources Degradation in Kenya - *Improving Water Resources Development and Management* (The World Bank - Hezron Mogaka, Samuel Gichere, Richard Davis and Rafik Hirji)
- Inventory of all Boreholes Drilled within Nairobi Metropolitan (Water Resources Management Authority - Rural Focus Ltd. - 27th June 2011)
- Towards a Strategic Analysis of Water Resources Investments in Kenya - Hydrological, Economic, and Institutional Assessment for Storage Development (The World Bank - Water Resources Management (AFTWR), June 30, 2011)
- Draft of The National Water Policy 2012 (The Republic of Kenya, March 2012)
- National Land Reclamation Policy (The Republic of Kenya, April 21st, 2011)
- Draft Water Bill 2012
- The Future of Water in African Cities: Why Waste Water? (The World Bank - Michael Jacobsen, Michael Webster, Kala Vairavamoorthy (eds.)

5.4.2 Reports Related to Projects Planned by Tana Water Services Board

Reports prepared by the Consultant Howard Humphreys related to the development of water abstraction schemes from Maragua, South and North Mathioya Rivers were collected from TWSB (Nyeri) and were reviewed by the Consultant and assessment of water demand incorporated under the on-going study.

[4] Also the "Aftercare Study Report" which was issued year 1998

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Appendix 2.2 - Commercial data for the Water Company.

Chapter 2 - Present Water Sources For Nairobi & Satellite Towns

1 Existing Water Sources for Nairobi City

1.1 Existing Production Systems

Nairobi City is presently supplied with water from four main sources as follows:

- **Kikuyu Springs** – comprising of 3 Nr Springs located 18km west of the City, yielding a total of 4,800m^3/d (0.056m^3/s). The Springs were the first source of potable water for Nairobi, developed between 1900 and 1906.
- **Ruiru Dam** on Ruiru River, located 25km North of the City. The Dam was constructed in 1950 and has a safe yield of 21,700m^3/d (0.25m^3/s)
- **Sasumua Dam** on Sasumua River, located 60km North of the City. The Dam was constructed in between 1956 and 1968. It has a safe yield of 68,400m^3/d (0.79m^3/s)
- **Thika Dam – Mwagu Intake System**:- This System comprises of the following sources:
    - Mwagu Intake Weir on the Chania River, located 40km North of Nairobi
    - Thika Dam, located 50km North of Nairobi. The Dam impounds water from Thika River, supplemented by flows diverted from the Kiama and Kimakia Rivers. The Dam was constructed between 1989 and 1994.

The design capacity of the Thika Dam-Mwagu System is 460,000m^3/d (5.3m^3/s). Due to various operational constraints, average production from the System is 415,000m^3/d (4.8m^3/s).

Along with the surface water sources listed above there are many wells and boreholes supplying water supply to Nairobi City. Except a few boreholes managed by NWSSC (30Nr. of which 12Nr. are operational) and operated in case of shortage from other sources most of the wells are privately owned and run. The total present contribution was estimated to be 45,000 m^3/day year 2010. Number of wells is increasing and it was assumed that the total Groundwater production will increase by 1,000m^3/day every year during the project life.

Figure 2-1 on page 2-3 shows a Schematic Plan of the existing Sources and Transmission Pipelines to Nairobi City and a Layout Plan is given in **Figure 2-2** on page 2-4.

2 Production and Transmission Systems

2.1 Kikuyu Springs System

The Kikuyu Springs Source was the original source of potable water for Nairobi and was developed at the beginning of the last century to supply water to what is now the City Centre. It was the principle source of water until the mid 1930's.

The spring source comprises three springs yielding a total of about 4800m^3/day, located 18 km to the west of the city at an elevation of 1960m. Although the output is now considered small compared with Nairobi's present demand, its high elevation and good water quality provides a valuable low-cost water supply in the city particularly during water rationing. Measurement of the flows carried out in 1998 indicated that the Kikuyu Springs system produced 9,000 m^3/day.

The two principal springs supply presently local small distribution zones through 250 m^3 service reservoir built under the Third Nairobi Water Supply Project. The third spring which is a minor source is only used for local supply.

2.2 Ruiru – Kabete System

Ruiru Dam

Originally an intake on the Ruiru River, a tributary of Nairobi River (Athi River basin), located about 25 kilometres north of Nairobi City, constructed in 1938, connected to a 225mm steel pipe and later to a 300mm pipe; the Ruiru Dam is a concrete gravity dam which was constructed in year 1950 and connected to a third 400mm pipe. Ruiru Dam main components and characteristics are listed in Table 2-1.

Table 2-1: Ruiru Dam Characteristics

Dam Component	Characteristics
Type	Concrete gravity and masonry parapet and wing wall
Dam crest length	155 m
Reservoir Normal Water Level	1 959.86m AOD
Reservoir Maximum Water Level	1 962.59m AOD
Total capacity of reservoir	2.9 million m^3
Reservoir surface area	35 ha
Reservoir safe yield	0.189 – 0.263 m^3/s
Catchment area	6 680 ha
Spillway discharge capacity at maximum water level	255 m^3/s
Spillway type	Over weir channel
Spillway crest length	48.75m
Spillway crest elevation	1 959.86m
Bottom outlet scour pipes discharge capacity	2 no. 36" and 24" ND
Outlet Draw off Pipes	6 no. 12" ND
Maximum height above foundation	18.3m

Kabete Treatment Plant

The Kabete Water Treatment Works, located 8 km west of the city centre, was built in 1939. It has been expanded several times in the 1940s and the 1950s. If sufficient raw water is supplied it can produce 20,000m^3/day; however, its current production is only half this figure. It is reported that mechanical and electrical equipment need replacement.

Figure 2-1: Nairobi Water Supply – Schematic of Existing Main Systems

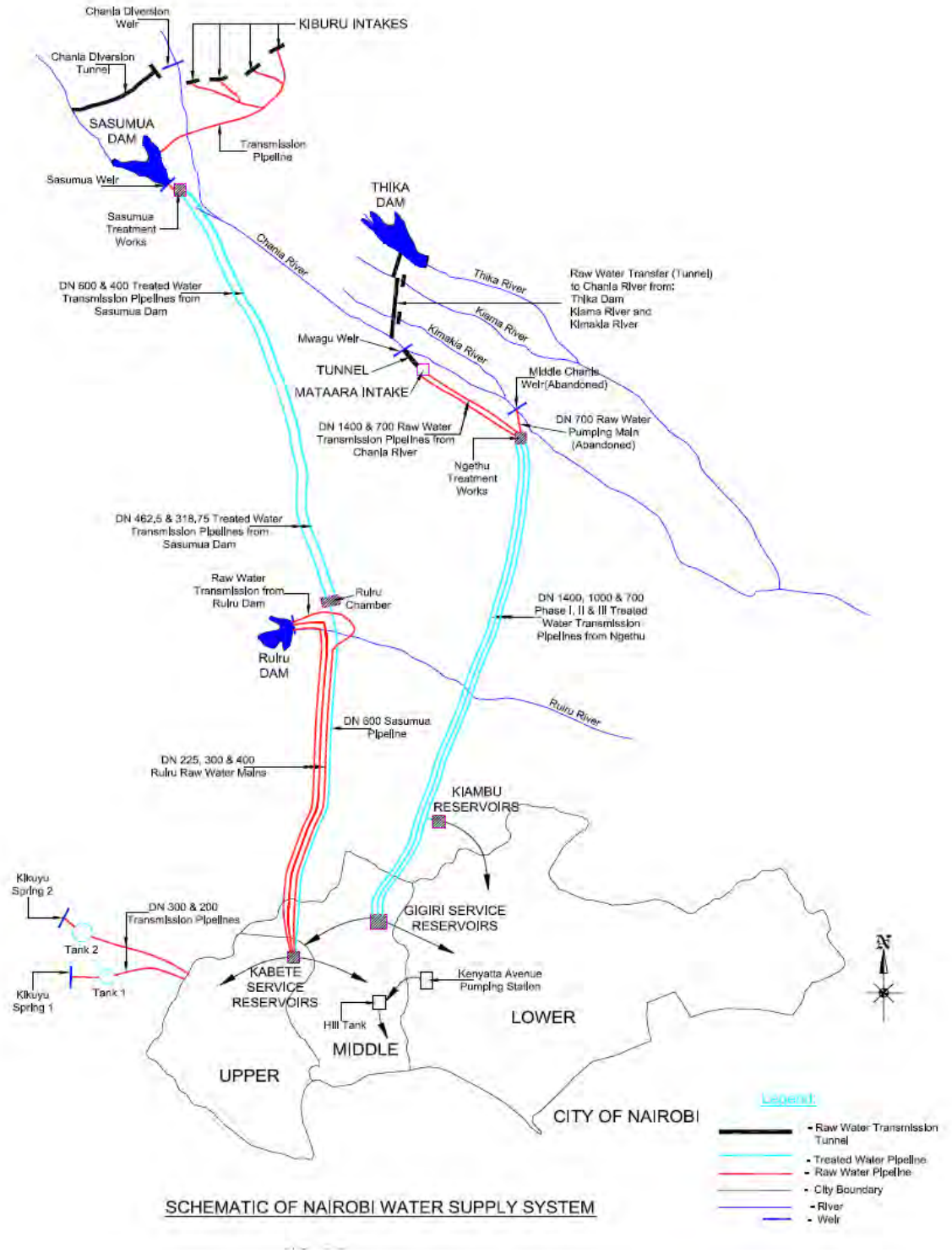
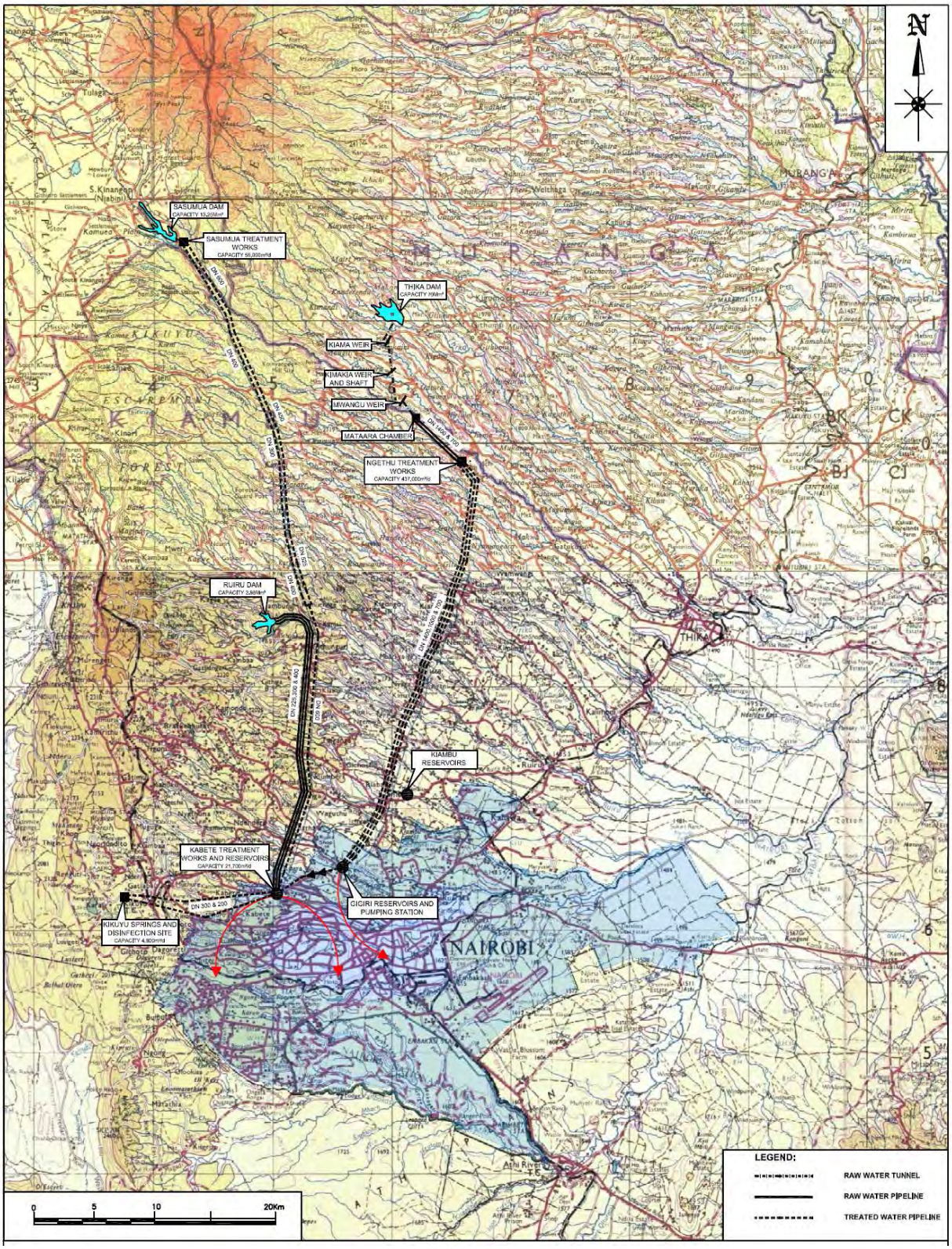


Figure 2-2: Existing Nairobi City Water Supply System



Kabete Pumping Stations

There are eight (8) pumps with unit discharge of 400 m^3/h pumping treated water to Nairobi:

- 3 pumps to Dagoretti Forest Reservoir, 4 days a week
- 5 pumps to Uthiru Reservoir, the other 3 days of the week

2.3 Sasumua – Kabete System

Sasumua Dam

The Sasumua Dam is located on the Sasumua stream, a tributary of the Chania River (Tana River basin). It is located about 6 km from the Njabini Market at the southern end of the Aberdare Ranges. It has been in operation since year 1956.

The main characteristics of the dam are listed in Table 2-2.

Table 2-2: Sasumua Dam Characteristics

Dam Component	Characteristics
Height of the dam	41.5 m
Full Water Supply Level	2 496.4m AOD
Spillway Crest length	427m
Total capacity of reservoir	15.9 million m^3
Catchment area	128 km^2
Spillway discharge capacity	452 m^3/s

The initial height of the dam was 33.5 m; it was raised between 1963 and 1968 to 41.5m.

Three streams (Chania River, Kiburu East and Kiburu West) are diverted into Sasumua Reservoir in order to increase the natural inflow.

Raw Water Main

The raw water transmission from the Dam consists of a pipeline, split in three segments, all totalling a length of 685.8 m. The description of the distinctive sections is as follows:

- **Section 1**: From the tunnel outlet for a distance of about 80.66 m, the pipe is made of bitumen-lined steel pipe nominal diameter DN800. This section terminates in the first junction, in which also is installed an air valve. At this junction, the pipe is branched into two lines of bitumen – lined steel sections.
- **Section 2**: This section has two pipes running in parallel. The first branch is of DN450 nominal diameter and the other is of DN 600 nominal diameter. This section terminates just before the inlet to the works.
- **Section 3:** This section begins just outside the inlet to the treatment plant and ends at the power generating turbines. In this section, the DN600 pipe is reduced in diameter from DN600 to DN 450 and both pipes deliver raw water for the hydro-turbines.

The 1996 report by Howard Humphreys & Partners (Nairobi Water Supply Operating Philosophy) estimated that the carrying capacity of this raw water main has been reduced progressively by slime deposits in the pipeline from initial 63,000 m^3/day to about 58,000 m^3/day.

Sasumua Treatment Plant

Situated about 1km downstream of the Dam the Sasumua Treatment Plant is an old plant that has been developed over three phases. According to Third Nairobi Water Project Reports, the first stage was commissioned in 1956. Phase 2 was commissioned in 1961, while the Phase 3

was commissioned in 1963. The total stated raw water design capacity of the plant is approximately 63,700 m^3/day. Raw water from the transmission mains is delivered to the plant via three (3) impulse electrical power generating turbines each of rating 37.5 kW, operated as 2 duty and one standby. From the hydro-turbines, the water is conveyed into a flow-division chamber with two sharp-crested weirs. The smaller weir delivers flows to the phase one plant, while the larger one delivers flows to the phase two and three plants through a DN900 culvert.

From the flow measurements carried out at the inlet weirs by NCWSC, the total raw water delivered into the works is around 54,000 m^3/day. The losses within the treatment plant have been assessed as 10%.

Rehabilitation of the Sasumua Treatment Works has been completed recently.

2.4 Thika – Ngethu – Gigiri System

The system was developed through the three phases of the Nairobi Water Supply Project with:

- **Phase 1** included the construction of a river intake and pumping station on the Chania River, North of the existing site of Ngethu Treatment Plant
- **Phase 2** included the construction of a second intake at Mwagu, 7km upstream of phase 1 intake in order to feed Ngethu treatment plant by gravity. The first intake became a standby source. Sasumua dam was then intended to regulate flow in the Chania River and to enhance flow at Mwagu intake from 104,000 to 121,000 m^3/day
- **Phase 3** included the construction of Thika Dam on the Thika River. A system of transmission tunnels picking up extra flows from Kiama and Kimakia Rivers delivers water to Mwagu intake

Thika Dam

The Thika Dam located about 50 km north of Nairobi, close to Ndakaini village, was constructed between 1989 and 1994 under the Third Nairobi Water Supply Project. It is a river regulating reservoir to augment water supply to Nairobi by ensuring adequate flows at Ngethu Treatment works.

The main characteristics of the reservoir are listed in Table 2.3.

Table 2-3: Thika Dam Characteristics

Dam Component	Characteristics
Height of the dam	65 m
Reservoir water surface	2.8 km^2
Full Water Supply Level	2 041m AOD
Spillway Crest length	420m
Capacity of reservoir	70 million m^3
Catchment area	75 km^2
Tunnel length	340m
Tunnel diameter	3m
Draw-off pipe	1 400mm with 6 draw-off valves
Spillway characteristics	H= 65m, shaft diameter: 5.5m
Tunnel	Discharge: 390 m^3/s, length: 180m
Emergency spillway	Qmax=120 m^3/s
Thika-Kiama tunnel	L= 1km, D= 2.5m, Q= 6 m^3/s
Kimakia – Chania tunnel	L= 3km, D= 2.5m, Q= 6 m^3/s

The intake shaft is located on the southern edge of the reservoir. A discharge valve regulates the outflow to the Thika – Kiama transmission tunnel.

The 1,400mm intake has been designed for a maximum flow of 5.7m^3/s. A second draw off structure has been constructed to supply irrigation, compensation and demand from a future high-level treatment works.

Kiama Weir

Located 450m downstream of the Thika – Kiama tunnel outfall it includes a weir (4.0 m high with an 8.0 m long ogee-crested section creating a pool from which water flows through a penstock-controlled inlet to the Kiama – Chania tunnel which is about 3.4 km long with a 2.5 m diameter. A 500mm scour outlet allows for silt flushing.

Kimakia Weir

The Kimakia weir comprises a 10 m long and 1.0 m high concrete section constructed across the Kimakia River to abstract a portion of the river flow to complement releases from Thika dam. From the pool the water flows to the Kimakia – Chania transmission tunnel. The settings of the tunnel are such that no flow enters the tunnel until compensation flows in the downstream reaches 0.14 m^3/day. The stated maximum capacity in this section of the tunnel can reach 6.3 m^3/s.

Chania Outfall

The Kiama-Chania tunnel emerges into a short channel in which is installed a weir to measure the total discharge delivered by the tunnel. A gabion-lined channel carries water to an outfall structure some 80m above the bed of the receiving Chania River. The stated design of the structure is 6.3 m^3/s which is the stated maximum tunnel design discharge.

Mwagu Intake

The intake was completed year 1982. The 14m high weir has three crest levels to facilitate flow measurement. Two 900mm scour pipes cross the central weir section. Compensation flow was expected to be released via a 300mm pipe which clogged with silt. No compensation flow is released anymore during dry season.

The intake discharges water into the Mataara tunnel with a maximum capacity of 5.3 m^3/s controlled by penstock valves.

Mwagu Transmission System to Ngethu

From Mwagu intake a 2.7km long 3.0m diameter tunnel connects to Mataraa Chamber in the Mataraa River valley. The tunnel leads to a horseshoe profile. For approximately 50% of its length the tunnel crown is lined either with a reinforced concrete arch or reinforced shotcrete; the other 50% is unlined. Mataraa Chamber acts as a header tank for raw water pipelines to Ngethu. In year 1983, the chamber was connected to a 1,400mm pipeline with overflow level 1,841m. It was extended in 1992 for connecting an extra 1,200mm diameter pipeline with a new overflow raised to elevation 1,841.8m.

Table 2-4: Design Capacity of the Mwagu - Mataara - Ngethu System

Component	Design Capacity (m^3/day)
Mwagu intake	460,000
Mataara tunnel	460,000
Raw water main diam. 1400 mm	270,000
Raw water main diam. 1200 mm	195,000

The combined design capacity of the pipes is 465,000 m³/day. According to the SOGREAH – Cape Consult assessment the combined flow reaching Ngethu treatment works was estimated to be 360,000 m³/day.

Ngethu Water Treatment Works

The site was developed in early 1970s in three phases to receive raw water from Mwagu and transfer treated water to Gigiri, Nairobi, wholly by gravity. Works were completed in 1978. In 1984 and 1994 capacity was increased and the treatment process rehabilitated. The treatment processes and the equipment for phases 1, 2A and 3 are proprietary Degremont Plants with two "Pulsator" Clarifiers and 4 Constant Rate Gravity Filters "Aquazure" Type. The Phase 2 comprising of 3 clari-flocculators and 8 filter units are proprietary WABAG Plants. The maximum total installed capacity of the three plants is said to be 450,000 m³/day.

Table 2-5: Capacity of Ngethu Water Treatment Works

Phase	Year	Input (m^3/s)	Output (m^3/s)
1 + 1A	1974 / 78	0.74	0.71
2	1984	1.41	1.36
2A	1994	0.47	0.45
3	1996	2.68	2.57
	Total	**5.30**	**5.09**

Ngethu to Gigiri Transmission Line

The treated water transmission system was developed in three phases as follows. The treated water is stored in head reservoirs. Three pipelines, inter-connected at Ruiru, Gatundu, Kiambu and Gigiri for optimizing flow distribution are controlled by flow valves at Gigiri Reservoirs.

Table 2-6: Treated Water Transmission Pipelines Ngethu - Gigiri

Phase	Steel Pipe	Length (Km)	Design Capacity (m^3/day)
1	700 mm	36.3	49,600
2	1000 mm	36.3	128,000
3	1200 mm	6.0	265,000
	1400 mm	13.8	265,000
	1200 mm	11.0	225,000
	1000 mm	5.5	108,000

2.5 Others

Groundwater is used as a supplementary water source for Nairobi since 1930s. Several groundwater schemes have been locally developed mostly in recent years and the TOR suggested that groundwater could contribute a high proportion[1] of the total supply. Within the satellite towns, some schemes supplied from groundwater were identified during the field visits and related data available in Volume II.

Nairobi City Water Supply and Sanitation Company (NCWSC) is managing about thirty boreholes within its service area out of which twelve are presently operated for about twelve hours a day.

[1] The figure of 25% has been mentioned

3 Storages and Main Distribution Zoning

Water supply in Nairobi can be broadly divided into three areas: Upper Supply Area, Middle Supply Area and Lower Supply Area as shown on **Figure 2-3** on **Page 2-10**. Detailed Layout Plan showing Nairobi Water Supply Pressure Zones, Service Reservoirs, Distribution Principles and water supplied at present to the zones is given in **Appendix 2.1.**

3.1 Upper Supply Area

It comprises four (4) Distribution Zones:

- Zone 1 is supplied by gravity from Kikuyu Springs with excess flows being discharged into Zone 2
- Zone 2 is headed by Dagoretti Forest Reservoir which is supplied by three 118 l/s units in Kabete Pumping Station via a 10.2 km long 500mm rising main
- Zone 3 is sub-divided into two major sub-zones. Zone 3 North is headed by Uthiru Service Reservoir which is supplied by three 118 l/s units in Kabete Pumping Station via a 4.5 km long 500 mm rising main. Zone 3 South is fed from the Zone 2 distribution network.
- Zone 4 is headed by Loresho Water Tower which is supplied from two 37 l/s pumps in Kyuna Pumping Station.

Table 2-7: Nairobi Upper Supply Area

Zone	Name	Storage Capacity (m^3)	Sources
1	Kikuyu Springs Tank 1	250 m^3	Spring No 1
	Kikuyu Springs Tank 2	250m^3	Spring No 2
2	Dagoretti Forest	11,000m^3	Pumped from Kabete
3	Uthiru	11,000m^3	Pumped from Kabete
4	Loresho Tower	450m^3	Pumped from Kyuna

3.2 Middle Supply Area

It comprises of Zones 5, 6 and 7:

- Zone 5 is headed by Kyuna Service Reservoir which is supplied by a connection of the Sasumua transmission main through a pressure sustaining valve.
- Zone 6 is supplied by gravity from Kabete Service Reservoir complex
- Zone 7 is headed by Hill Tank which is fed through a 450 mm main direct from Kabete

Table 2-8: Nairobi Middle Supply Area

Zone	Name	Storage Capacity (m^3)	Sources
5	Kyuna	9,000	Gravity from Sasumua
6	Kiambu	59,000	Gravity from Sasumua and Ruiru
7	Hill Tank	18,000	Gravity from Kabete

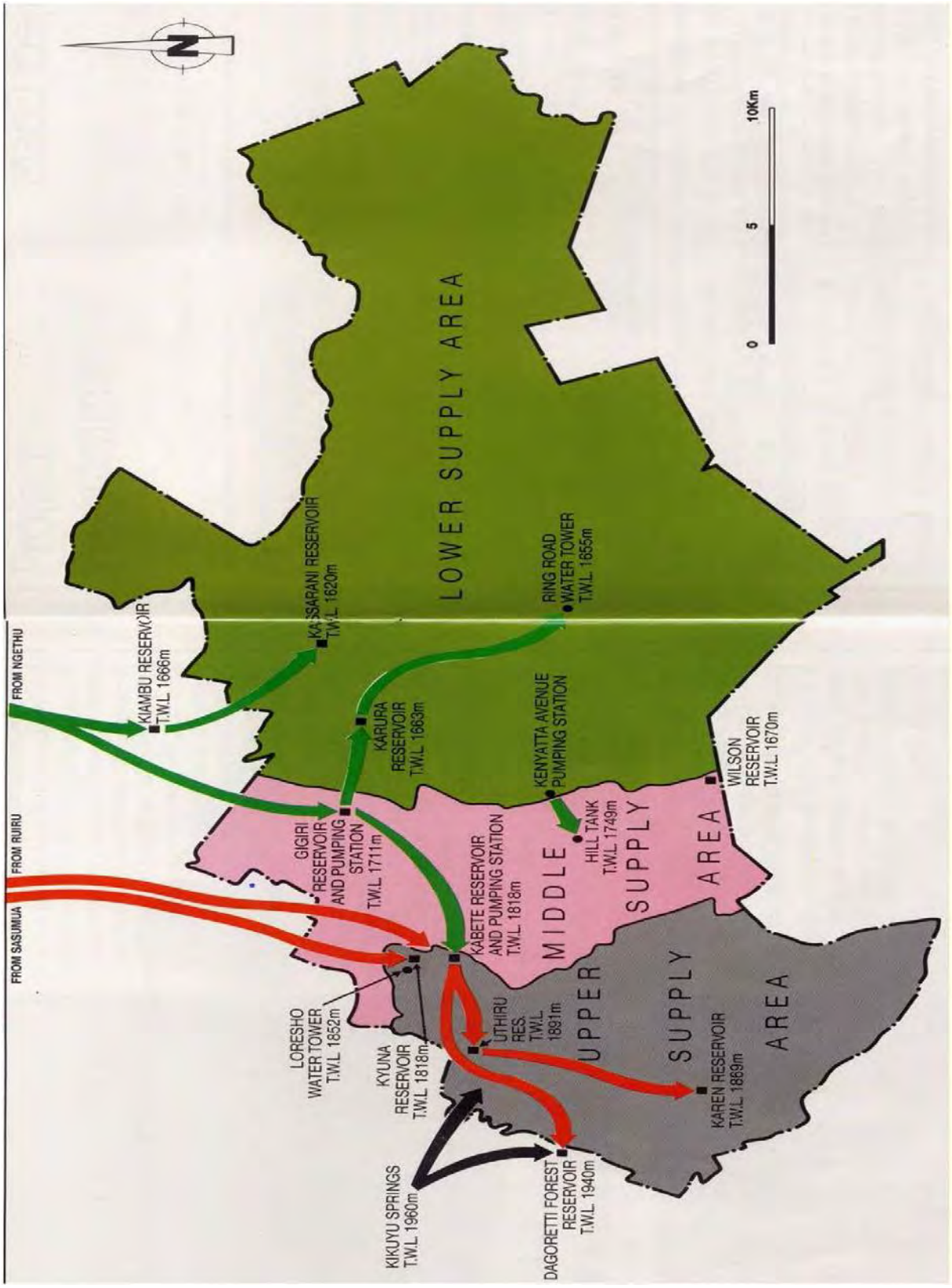
3.3 Lower Supply Area

The Lower Supply Area is fed by gravity from Gigiri Service Reservoirs, and comprises four Distribution Zones: 8, 9, 10 and 11.

Table 2-9: Nairobi Lower Supply Area

Zone	Name	Storage Capacity (m^3)	Sources
8	Gigiri	61,000	Ngethu
9	Kabete	42,000	Ngethu
	Karura	9,000	Ngethu
	Wilson	11,000	Ngethu
10	Outering	450	Ngethu
11	Kasarani	11,000	Ngethu

Figure 2-3: Nairobi Three Water Supply Areas



4 Existing Water Supply Systems for Satellite Towns

4.1 Kikuyu Urban Centre

4.1.1 Water Service Provider

Kikuyu Water Supply is currently operated by Kikuyu Water Co Ltd., established as a private Company under the Companies Act, Cap 486 and wholly owned by the Municipal Council of Kikuyu.

The water company's designated area of supply is 118.8km² but currently supplies water to only 30% of this area. The present population under the mandate of the company is estimated at 143,930 persons, but only a total of 23,518 persons are currently supplied with water (16.3%). The Locations within the Company's area of jurisdiction are as follows:

- Muguga
- Gitaru
- Thogoto
- Gitiba
- Gikambura
- Karai
- Kiambaa
- Wangige

Within the Kikuyu Water Company's area of jurisdiction, there exists 36 small Self- Help Water Schemes, which fall under the relevant District Water Officers.

4.1.2 Existing Infrastructure – Kikuyu Water Supply System

Source

The source of water is ground water comprising of 12nr. Boreholes. The yield of the Boreholes ranges between 3.2 m^3/hr to 35 m^3/hr with a total production of 4,202 m^3/day. The locations of the existing Boreholes are shown on **Figure 2-4 on Page 2-13**. Details of the existing Boreholes are given in Table 2.10.

Table 2.10: Details of Existing Boreholes

Borehole No.	Borehole Name	Year Drilled	Drilled Depth (m)	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
C483	Wangige Market	**Nov-46**	96	4.09	4.00	4	16
Not Assigned	Dagoreti Market	**Feb-02**	150	6.1	3.20	6	19.2
C4328	Thamanda	Mar-76	214	9.09	12.00	20	240
C4909	Kamangu	Apr-81	300	Details not available	4.00	24	96
C4974	Nduma	Sep-81	320	Details not available	10.00	24	240
C6019	Ondiri 1	Nov-84	49	20	22.00	16	352
C6020	Campus	Nov-84	58	20	30.00	16	480
C93	Riu	May-40	150	20.5	35.00	24	840
Not Assigned	Corporation	No Details	250	20	Not Operational-not fully		

Borehole No.	Borehole Name	Year Drilled	Drilled Depth (m)	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
					equipped		
C537	Twin	Apr-47	69.5	9.1	20.40	16	326.4
C540	Twin	Jun-47	80	21.9	35.00	16	560
Not Assigned	Ruku	Jan-04	220	22	7.00	24	168
C3170	Muguga	May-62	202	15	16.00	24	384
C89	Thogoto	Apr-40	Details not available	10.9	20.00	24	480
Not Assigned	Kamwita	Jan-02	203	18	Not Operational		
					Total Daily Present Production m^3/d		**4,202**

Treatment Works

Water is only subjected to disinfection by chlorination at the storage tanks.

Distribution System

The Distribution System covers 30% of the area of supply and comprises of GMS / uPVC pipes diameter ranging in size from 25mm to 150mm. The first Distribution System was developed in the 1950s, however, over the years the system has been expanded. The Storage comprises of 14nr. storage tanks capacity ranging in size from 48m^3 to 225m^3.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2-4 - Location of Kikuyu Urban Centre and its Administrative Units at Sub-Locations level

4.2 Ruiru – Juja Urban Centres

4.2.1 Water Service Provider

The Water Service Provider for Ruiru Municipality and Juja Division is the Ruiru-Juja Water and Sewerage Co Ltd. (RUJWASCO). RUJWASCO was incorporated in 2007 as a private company under the Companies Act, Cap 486. It is jointly owned by the Ruiru Municipal Council and the Thika County Council, each with a 50% shareholding.

The Company's designated area of supply is approximately 259km^2, comprising of the whole of Ruiru Municipality and part of Thika County Council Area. The company currently supplies approximately 35% of its mandated area i.e. 90km^2.

Approximately 116km^2 of the area under RUJWASCO jurisdiction is presently served by the Nairobi City Water and Sewerage Co. Ltd (NCWSC). These areas include Kahawa Sukari and Githurai Locations. Plans are underway for RUJWASCO to take over the areas under its jurisdiction presently supplied by NCWSC.

4.2.2 Existing Infrastructure – Ruiru and Juja Water Supply System

Source

i. **Ruiru Water Supply**: The main source of water is a Surface Water System based on pumping from Ruiru River. Raw Water is abstracted via a Reinforced Concrete Weir on the River and pumped to an adjacent Treatment Works. The Ruiru River source supplies approximately 1,500m^3/d of water to Ruiru Town.

   In addition to the Ruiru River supply, there are 3 Nr Boreholes in Ruiru Town. Each borehole has an average production of 8m^3/h. The Boreholes are pumped for 20 hours per day, giving a total production of 480m^3/d.

ii. **Juja Water Supply**: The main source of water is a Surface Water System based on pumping from Ndarugu River. Raw Water is abstracted via a Reinforced Concrete Weir on the River and pumped to an adjacent Treatment Works. The Ndarugu River source supplies approximately 2,000m^3/d of water to Juja Town.

iii. **Bulk Water Supply from Ngethu Pipeline –** the areas presently being served by the Nairobi City Water and Sewerage Co. Ltd (NCWSC) i.e. Kahawa Sukari and Githurai Locations draw water from the Ngethu Pipeline serving Nairobi. Amount of water consumed from Ngethu Pipeline is about 2,500m^3/d.

Details of the existing sources are shown in Table 2-11 on Page 2-15.

Table 2-11: Details of Existing Water Sources

RUIRU & JUJA WATER COMPANY, DETAILS OF EXISTING WATER SOURCES

Borehole No.	Borehole Name	Year Drilled	Drilled Depth (m)	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Dumping Hours	Present Production (m^3/day)
Data not available	Mugutha Borehole	Data not available			8 m^3/hr	20	160 m^3/d
	Ruiru East Borehole				8 m^3/hr	20	160 m^3/d
	Murera Borehole				8 m^3/hr	20	160 m^3/d
					Data not available		
Total Present Daily Production from Boreholes							**480 m^3/d**

Surface Water Sources

1. Existing Ruiru River Intake and Treatment Works:
   - Location: 0273500/9873500
   - Elevation: 1520 m
   - Capacity: 1500 m^3
2. Existing Ndarugu River Intake and Treatment Works:
   - Location: 0281500/9789800
   - Elevation: 1520 m
   - Capacity: 2000 m^3

Treatment Works

Both Ruiru and Juja Water Supply Systems have conventional Treatment Works, with capacities 1,500m^3/d for Ruiru and 2,000m^3/d for Juja respectively. Both Treatment Works consist of Chemical Mixing & Dosing facilities, Composite Treatment Units, Chlorination Facilities, and Treated Water Pump Houses. Water from the Treatment Works is pumped to Storage Tanks located in Ruiru and Juja Towns respectively.

Distribution System

The Ruiru Town Distribution System covers approximately 40km^2 and comprises of GI and uPVC pipes, diameter ranging in size from 50mm to 150mm, total length approximately 60km.

The Juja Town Distribution System covers approximately 50km^2 and comprises of GI and uPVC pipes, diameter ranging in size from 50mm to 300mm, total length approximately 70km.

Figure 2-5 on Page 2-16 shows the Location of Juja Municipality and Juja Division and their Administrative Units at Sub-Locations Level.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2-5 - Location of Juja Municipality and Juja Division and their Administrative Units at Sub-Locations Level

4.3 Kiambu Municipality

4.3.1 Water Service Provider

The Water Service Provider for Kiambu Municipality is the Kiambu Water and Sewerage Co Ltd. (KIWASCO). KIWASCO is established as a private company under the Companies Act, Cap 486 and is wholly owned by the Municipal Council of Kiambu.

The Company's designated area of supply is Kiambu Municipality, covering an area of approximately 59km^2. The company currently supplies approximately 30% of its mandated area i.e. 17km^2.

4.3.2 Existing Infrastructure – Kiambu Water Supply System

Source

The main source of water for Kiambu Municipality is a Ground Water System comprising of 11 Nr. Boreholes with a total production capacity of approximately 3,060m^3/day.

In addition, the Municipality receives 230 m^3/d bulk water supply from the Ngethu Pipeline serving Nairobi. Details of the existing sources are shown in Table 2-12 below.

Table 2-12: Details of Existing Water Sources

Borehole No.	Borehole Name	Year Drilled	Drilled Depth (m)	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
C11270	Ndumberi BH	1996	202	Data not available	2.5 m^3/hr	24	60
No Data	Waithaka BH	2006	No Data		14 m^3/hr	24	336
C3875	BH No. 5	1971	165.5		9 m^3/hr	24	216
C2819	BH No. 4	1971	236		8 m^3/hr	24	192
C11597	Town Hall BH	1997	207		18 m^3/hr	24	432
C2057	BH No. 3	1953	147		20 m^3/hr	24	480
C6708	Thuku BH	1986	No Data		72 m^3/hr	9	648
C3892	BH No. 6	1973	170		17 m^3/hr	24	408
C12816	Kangoya Market	2000	223		9 m^3/hr	24	216
C11271	Kangoya Primary	1996	175		3 m^3/hr	24	72
No Data	Kihingo	No Data			No Data	24	No Data
					Total Present Daily Production from Boreholes		**3,060 m^3/d**

Treatment Works

Treatment of Water is carried out for only one borehole known as the Thuku Borehole. Water from all other boreholes is distributed to consumers without any treatment.

The Treatment Plant for the Thuku Borehole water is a full conventional Treatment Plant of capacity 1,800m^3/d. It comprises of a Cascade Aerator, 2 Nr Horizontal Flow Sedimentation Tanks, 3 Nr Rapid Gravity Sand Filters, Chlorination Facilities, Pump House with 2 Nr Pumps, Elevated Backwash Tank (40m^3 capacity), Office Building and 4 Nr. Grade 9 Staff Houses

Distribution System

The Distribution System covers approximately 17km^2 and comprises of GI and uPVC pipes diameter ranging in size from 25mm to 110mm. Total Length of the Distribution Mains is approximately 27km. **Figure 2-6** on **page 2-18** shows the location of Kiambu Urban Centre.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2-6 - Location of Kiambu Municipality & its Administrative Units

4.4 Karuri Town

4.4.1 Water Service Provider

The Water Service Provider for Karuri Town is the Karuri Water and Sanitation Co Ltd. (KAWASCO). KAWASCO is established as a private company under the Companies Act, Cap 486. The Company was incorporated in 2008.

The Company's designated area of supply is approximately 49km^2, comprising of Kiambaa, Kihara and Ruaka Locations of Kiambu East District. The company currently supplies approximately 75% of its mandated area i.e. 36km^2.

4.4.2 Existing Infrastructure – Karuri Water Supply System

Source

Karuri Town and its environs are served by a Ground Water System comprising of 13 Nr. Boreholes. Currently, the boreholes and springs have a total production of approximately 1,667 m^3/d.

In addition, Karuri receives about 1,100m^3/d bulk water supply from the Sasumua Pipeline serving Nairobi. Details of the existing sources are shown in Table 2-13 below.

Table 2-13: Details of Existing Water Sources

Karuri Spring Water & Sanitation co. Ltd, Details of Existing Water Sources						
Borehole Name	**Year Drilled**	**Drilled Depth (m)**	**Tested Yield (m^3/hr)**	**Present Yield (m^3/hr)**	**Daily Pumping Hours**	**Present Production(m^3/hr)**
Karuri Marks	21-5-1939	159	9.58	7.60	13	98.8
Mombasa BH	13-2-1978	117	18.24	17	13	221
Kimuga	No Data	No Data	11.5	12	13	156
Mucatha		138		3.80	7	26.6
Ruaka	30-1-2007	225	9	7.4	13	96.2
Gacharage	Data not available	280	19.2	17	13	221
Cannon		226	5.4	3.6	13	46.8
Thairu		200		2.5	10	25
Wangunyu	Data not available	Data not available	Data not available	6	13	78
ACK Karuri				1	2	2
Karura Primary				5	13	65
Ndenderu			5	Data not available		
Total Present Daily Production (m^3/d)						**1,036**

Surface Water

- Gathiri Springs
- Sun Springs

Details of production from the above Springs are not available

Treatment Works

No treatment is carried out for the borehole and spring water.

Distribution System

The Distribution System covers about 36km^2 and comprises of GMS / uPVC pipes, diameter ranging in size from 25mm to 150mm.

Figure 2.7 on **page 2-20** shows the Location of Karuri Town and its Administrative Units at Sub-Locations Level. The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2-7 - Location of Karuri Town and its Administrative Units at Sub-Locations Level

4.5 Githunguri Town

4.5.1 Water Service Provider

The Water Service Provider for Githunguri Town is Githunguri Water and Sanitation Co Ltd.

Githunguri Water and Sanitation Co. Ltd. is established as a private company under the Companies Act, Cap 486 and is wholly owned by the Kiambu County Council.

The Company's designated area of supply is approximately 265km^{2}comprising of the entire Githunguri District and part of Lari District. The company currently supplies approximately 47% of its mandated area i.e. 125km^2.

4.5.2 Existing Infrastructure – Githunguri Water Supply System

Source

The source of water for the area under the Githunguri Water and Sanitation Co. Ltd. is a Ground Water System comprising of 9 Nr. Boreholes with a total production capacity of approximately 1,000 m^3/day. The ground water is supplemented by 2 Nr Surface Water Gravity Systems with sources at Komothai River and Githiga River with a total production of approximately 800m^3/day.

Githunguri Town is served by 3 Nro. boreholes (out of the total 9 Nr. boreholes in the larger Githunguri District) with a total production of 936m^3/day. In addition, the Town receives 400m^3/day bulk water supply from the transmission pipelines serving Nairobi (Ngethu and Sasumua Pipelines).

The combined water supply to Githunguri Town from the boreholes and Nairobi bulk water supply is 1,336m^3/day. Details of the existing sources are shown in Table 2-14 below.

Table 2-14: Githunguri Water Company, Details of existing Water Sources

Borehole No.	Borehole Name	Year Drilled	Drilled Depth (m)	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
C1939	Githunguri 1	1939	Data not available		16	24	384
Data not available	Githunguri 2	2007		Data not available	10	24	240
	Githunguri 3	2007			13	24	312
	Giathieko	2007	220	355 litres/min	14	12	168
	Gathaithi	2007	Data not available	Data not available	14	12	168
	Thuita	2007	160	167 litres/min	8	12	96
	Kiratina	2007	Data not available	Data not available	20	12	240
	Mihuko	2007			13	12	156
	Kiairia	2009	240	200 litres/min	12	12	144
Total Present Daily Production from Boreholes							**1,908 m^3/d**
Surface Water Source • Intake on Gatamaiyu River, not easily accessible (in Forest) • Production Capacity:-9,000 m^3/d • Intake on Kamiti River • Production: 600 m^3/d • From Ng'ethu and Sasumua Pipelines:- 400 m^3/d							

Treatment Works

No treatment is carried out for the water from Boreholes serving Githunguri Town.

For the Surface Water from Komothai and Githiga Rivers, only chlorination is carried out. A Conventional Full Treatment Works of capacity 2,400m^3/day is currently under construction for the Komothai Water System, expected to be complete by August 2011. This will, however, not serve Githunguri Town but other parts of Githunguri District.

Distribution System

The Distribution System in the Water Service Provider's area covers approximately 125km^2 and comprises of GMS / uPVC pipes, diameter ranging in size from 25mm to 110mm.

Figure 2-8 on **page 2-23** shows the Location of Githunguri Town and its Administrative Units at Sub-Locations Level.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2-8 - Location of Githunguri Town and its Administrative Units at Sub-Locations Level

4.6 Mavoko Municipality

4.6.1 Water Service Provider

Mavoko Municipality and Kitengela town areas are presently served by Mavoko Water & Sewerage Company (MAVWASCO). The Company was established in 2006 within the Water Act 2002 sector reforms as a legal entity under the companies Act Cap. 486 (Laws of Kenya) with the mandate to provide water and sanitation services to the entire population within a defined service area in Mavoko Municipality and the neighbouring Kitengela Town in Kajiado North District.

The total mandated area coverage is 860km^2 with a total population of approximately 167,000 but the area presently being served is 70km^2 with approximately a population of 80,000.

4.6.2 Existing Water Supply System

Source

The study area has no independent water sources and relies on bulk supplies from NCWSC and Nol Turesh water supply systems. The area has only one surface water production facility at Athi River which is dilapidated and in disuse although rehabilitation work is on-going.

Water presently distributed in Mavoko Municipality is from three sources as listed in Table 2-15 below.

Table 2-15: Water Sources

Source	Current Production (m^3/d)	Design Capacity (m^3/d)
NCWSC	7,500	20,000
Nol Turesh System	970	4,000
MAVWASCO Boreholes	700	-
Private Boreholes	Unknown	-

The Nairobi City Water & Sewerage Company source is the present Nairobi City source and is supplied through the Export Processing Zone (EPZ) line.

The Nol Turesh water supply scheme (capacity 4,000 m^3/d) was implemented in 1990 and consists of a 550 mm dia. steel pipe, taking water from the Nol Turesh springs in the foothills of Mt. Kilimanjaro to the towns of Sultan Hamud, Kajiado, Athi River and Machakos. The Nol Turesh source is very unreliable with water being supplied twice a week.

There are 6nr boreholes in the area which are operated by the Company. The borehole yields are also unreliable.

A layout Plan showing the location of existing water sources is shown in **Figure 2.9** on **Page 2-26**. Details of the existing borehole water sources are shown in Table 2-16 on page 2-25:

Table 2-16: Details of Existing Borehole Sources

Borehole Name	Year Drilled	Drilled Depth	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping hours	Present Production (m^3/day)
Utawala II BH	2010					
Syokimau BH	2010					
Athi River Water Works BH		200		24	16	380
Mavoko Tanks BH		180		20	16	320
Borehole '2'	2009					
Borehole '1'	2009					

Some of the data could not be obtained from the Water Operator

Treatment Works

Water supplied by the Nairobi Water & Sewerage Company and by the Nolturesh line is normally treated water. No form of treatment is carried out on the water from the 6nr boreholes.

Distribution System

The Distribution System only covers approximately 10% of the mandated area of supply and comprises of GMS / uPVC. The transmission main from Nairobi ranges from 600mm dia. to 900mm dia. while the Nol Turesh line is 250mm dia. the Nairobi line was constructed in 1996 while the Nol Turesh line was constructed in 1992.

Figure 2-9 on **page 2-26** shows the Location of Mavoko Municipality and its Administrative Units at Sub-Locations Level.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2-9 - Location of Mavoko Municipality and its Administrative Units at Sub-Locations Level

4.7 Ongata Rongai / Ngong / Kiserian Urban Centres

4.7.1 Water Service Provider

The Ongata Rongai and Ngong Township water supply systems are presently operated by Oloolaiser Water and Sewerage Company. The Company is a limited liability company wholly owned by Olkejuado County Council and was incorporated on 30th June 2006 and commenced operations in October 2006. The mandated water service provision area falls under Tanathi Water Services Board area of jurisdiction.

The company currently manages the following three water supply schemes, which were formerly operated by the Ministry of Water and Irrigation and the National Water Conservation and Pipeline Corporation:

- Ongata Rongai Water Supply
- Ngong Water Supply
- Kiserian Water Supply

The total mandated area coverage is 733km^2 with a total population of approximately 289,800 but the area presently being served is 82km^2 with a population of approximately 215,535, approximately 74% of the total population.

The water supply and sanitation systems presently being operated by the company for the three schemes are briefly discussed below.

4.7.2 Ngong Area

The Ngong water supply system covers the Ngong and Bulbul Sub-locations of Kajiado District. The system covers an estimated area of about 22km^2 and has a current human population of about 31,728. Ngong town which is also covered by the system is the divisional headquarters of Ngong Division. It is located approximately 20km to the South of Nairobi and has an estimated human population of 18,091.

Source

The source is ground water consisting of 10nr boreholes and a spring located at the Ngong Hills. The boreholes give an average yield of 12m^3/hr. The total present production from all the boreholes and spring supplying Ngong area is reported to be 414m^3/d by the Water Operator. Details of the existing borehole water sources are shown in Table 2-17 below.

Table 2-17: Details of Existing Borehole Sources in Ngong Area

Borehole No.	Borehole Name	Year Drilled	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
	Shilanga BH	2006		9	16	144
	Kihara BH			2	16	32
	Booster Pump Station BH	2006				
C2500	Ngong Main BH			15	16	240
C4967	Scheme 305 BH			22	16	352
	Roadside Bulbul BH	2008				
	Bulbul School BH					
C11083	Bulbul BH					
C14911	Ololual BH			16.5		
C4967	Olkeri BH					

Some of the data could not be obtained from the Water Operator

Treatment

No disinfection is done to water abstracted from the eight boreholes.

Distribution System

There are 5no. Storage Tanks in Ngong of capacities varying from 35m^3 to 90m^3. The total storage capacity is 310m^3. The total length of the distribution system is approximately 9km and comprises of 50mm dia to 100mm dia. uPVC diameter mains.

4.7.3 Ongata Rongai Area

The Ongata Rongai system serves Ongata Rongai Town and its environs with a total population of approximately 122,777 residents. The existing water supply system is only able to serve about 33% of the area given with the other areas being mainly supplied by privately owned systems.

Source

The source to the Ongata Rongai water supply system consists of a surface water supply system from Mbagathi River and 2nr boreholes. Water from Mbagathi River is pumped from the Intake to a Treatment Works before being pumped again to a high level storage for distribution.

No abstraction license has been granted by WRMA but an application to abstract 3,000m^3/d has been made. The 2nr boreholes are licensed by WRMA and each produce approximately 5m^3/h. Details of the existing borehole water sources are shown in Table 2-18 below.

Table 2-18: Details of Existing Borehole Sources

Borehole Name	Year Drilled	Drilled Depth	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
Health Center	2006	240		5	16	80
Olekasasi BH '1'	2006	230		5	16	80
Olekasasi BH '2'	2010	240		20		

Some of the data could not be obtained from the Water Operator

Treatment

The surface water source has a full treatment system of capacity 3,000m^3/d but currently treats 2,200m^3/d. After full treatment, treated water is pumped to a high level storage before being distributed. No disinfection is done to water abstracted from the two boreholes.

Distribution System

Ongata Rongai Water Supply has 8nr water storage tanks with a total storage capacity of 2,800m^3. The distribution pipelines totals to a length of 30km and comprises mainly of uPVC pipes. There are a total of 1,537 connections in Ongata Rongai.

4.7.4 Kiserian Area

Kiserian water supply system is located on the foot of Ngong Hills in Kajiado District, Ngong Division in Kiserian Location.

The water supply system serves Kiserian Township and its environs. It covers as area of approximately 47km^2 with a population of approximately 22,000 residents.

Source

The system was started in the 1930s when the then East African Railways and Harbours developed 12nr springs at the Ngong Hills source works for the Magadi Railway Line. The springs design capacity was 19.08m³/hr but at present only 3nr springs are being utilized. Additional water sources were later developed through drilling of boreholes in 1950's and 1970's and a new borehole drilled in 2009.

The three sources combined produce an average of 870m³/d which is below the demand of water for the area approximated at 2,500m³/d. Details of the existing borehole water sources are shown in Table 2-19 below:

Table 2-19: Details of Existing Borehole Sources

Borehole No.	Borehole Name	Year Drilled	Drilled Depth	Tested Yield (m³/hr)	Present Yield (m³/hr)	Daily Pumping Hours	Present Production (m³/day)
C1259	Head Works Borehole				19	16	304
C4199	Borehole '2'				23	16	368

Some of the data could not be obtained from the Water Operator

Treatment

Water from the springs is only subjected to disinfection by chlorination at the storage tanks.

Distribution System

There are 5nr. Storage Tanks in Kiserian, of capacities varying from 45m³ to 300m³. The Total Storage capacity is 612m³.

Figure 2-10 on **page 2-30** shows the location of existing water sources for Ongata Rongai / Ngong / Kiserian Urban Centres.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2-10 - Location of Existing Water Sources for Ongata Rongai / Ngong / Kiserian Urban Centres

4.8 Thika Municipality

4.8.1 Water Service Provider

The Water Service Provider for Thika Municipality is the Thika Water and Sewerage Co Ltd. The company was incorporated in July 2009 as a private company under the Companies Act, Cap 486. It is wholly owned by the Thika Municipal Council.

The Company's designated area of supply is approximately 254km^2, comprising of the whole of Thika Municipality and parts of Thika East District. The company currently supplies approximately 100km^2 about 38% of its mandated area.

4.8.2 Existing Infrastructure – Thika Water Supply System

Source

Thika Municipality is served by a Surface Water System with two sources – Chania River and Thika River. The main source is the Chania River. Raw Water is abstracted via Reinforced Concrete Weirs on both Rivers and pumped to a common Treatment Works.

Presently, about 26,000 m^3/d is abstracted from the Chania River.

The Raw Water Pumping Mains from the two intakes are of sizes 300mm dia length 600m (from Thika River) and 375mm dia length 100m from Chania River.

Treatment Works

Raw Water is treated in a conventional Treatment Works, capacity 36,000m^3/d. The Treatment Works consists of Chemical Mixing & Dosing facilities, 12 Nr Vertical Flow Sedimentation Tanks, 24Nr Rapid Sand Gravity Filters, Chlorination Facilities, 4 Nr Treated Water Tanks total capacity 11,362m^3 and a Treated Water Pumping Station with 14 Nr. Treated Water Pumps.

Distribution System

The Thika Municipality Distribution System covers approximately 100km^2 and comprises of GI and uPVC pipes diameter ranging in size from 50mm to 150mm.

Figure 2-11 on **page 2-32** shows the Location of Thika Municipality and its Administrative Units at Sub-Locations Level.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2.11 - Location of Thika Municipality and its Administrative Units at Sub-Locations Level

4.9 Limuru Town

4.9.1 Water Service Provider

Limuru Water Co Ltd. is established as a private company under the Companies Act, Cap 486 wholly owned by the Municipal Council of Limuru and was incorporated on 13th March 2006.

The Water Company's designated area of supply is 555km². The company currently supplies water to only 40% of the area. The present population under the mandate of the Company is estimated at 119,201 persons, but only a total of 40,230 persons about 34% of the total population, are currently supplied with water. The Locations within the Company's area of jurisdiction are as follows:

- Limuru
- Karambaini
- Ngecha
- Rironi
- Kamae
- Kinale
- Kijabe
- Gitithia
- Lari
- Kirenga
- Gatamiyu
- Nyanduma

Within the Limuru Water Company area of jurisdiction there exists the following

- 17 small Self Help Water Schemes, which falls under the relevant District Water Officers.
- Bathi Water Supply Scheme, which serves the main Trading Centres of Magina, Kimende, Lari and Uplands.
- Limuru Water Supply Scheme for the Town of Limuru.
- Kijabe Springs which serves part of Kijabe Location

4.9.2 Existing Infrastructure – Limuru Water Supply System

Source

The sources of water are as follows:

- Ground water / Springs for Self Help Water Schemes
- Bathi Dam for Bathi Water Supply. The Dam capacity is 20,000m³/day
- 14nr. Boreholes for Limuru Water Supply Scheme. The total yield from the Boreholes is approximately 3,070 m³/day.

Water from Bathi Dam does not reach the Study Area and a gate valve has been closed, within Guathuamba Sub-location, as the existing infrastructure cannot meet the present water demand of the intended area of supply.

Details of existing water sources are given in Table 2.20 on page 2-34:

Table 2.20: Details of Existing Water Sources

Borehole No.	Borehole Name	Year Drilled	Drilled Depth (m)	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
Details not available	Kibarage	Oct-07	250	3.9	3	12	36
C128	Uplands	May-05	128	27.4	22.5	20	450
C94	Ruhia	Details not available		14	14	12	168
C4587	BH No. 5	Aug-08	144	30	25	16	400
C4550	BH No. 3	Details not available	190	24	20	16	320
C4578	BH No. 4		103.75	23	20	16	320
C5787	DC Residence		144	6	6	16	96
Details not available	Tigoni		Details not available		4	16	64
C5561	BH No. 6		110	18	20	16	320
Details not available	Water Supply		Details not available		20	16	320
	Tutu				4	12	48
	Nguirubi				30	16	480
	Boroti				4	12	48
					Total Daily Present Production m^3/d		**3,070**

Surface Water Sources

- Bathi Dam, Capacity: 20,000 m^3/d
- Kijabu Springs
- Details of Production are not available

Treatment Works

- The Bathi Water Supply Scheme comprises of a full Conventional Treatment Works, with an installed capacity of 2,500m^3/day.
- Only disinfection by chlorination is carried out on Borehole Water,
- Water for Self Help Water Schemes is not subjected to any form of Treatment
- Water from Kijabe Springs is subjected to disinfection by Chlorination

Distribution System

The Distribution System only covers 40% of the area of supply and comprises of GMS / uPVC pipes, diameter ranging in size from 25mm to 150mm.

Figure 2.12 on **page 2-35** shows the Location of Limuru Town and its Administrative Units at Sub-Locations Level.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2.12 - Location of Limuru Town and its Administrative Units at Sub-Locations Level

4.10 Gatundu Town

4.10.1 Water Service Provider

Gatundu Town Water Supply System is currently operated by the Gatundu Water and Sewerage Co Ltd. (GAWASCO) incorporated in April 2006 as a private company under the Companies Act, Cap 486. The Company's mandated area of supply is approximately 300km², comprising Gatundu South District, part of Gatundu North District and part of Githunguri District. The company currently supplies approximately 240km² of its mandated area.

Gatundu Water and Sewerage Co Ltd. operates three Water Supply Schemes, namely: Ndarugu, Thiririka and Ruabora Water Supply Schemes

Ndarugu Water Supply Scheme is the only scheme which serves Gatundu Town in addition to enroute water demands from the intake.

4.10.2 Existing Infrastructure – Gatundu Water Supply System

Source

Gatundu is served by a combination of Surface and Ground Water Systems. There are 3nr Surface Water Sources namely:- Ndarugu River serving Ndarugu Water Supply Scheme, Thiririka River serving Thiririka Water Supply Scheme and Ruabora River serving Ruabora Water Supply Scheme. Water is abstracted from the 3 rivers via reinforced concrete weirs. The Groundwater System comprises of 4nr Boreholes. Details of the existing borehole water sources are shown in Table 2.21 below:

Table 2.21 : Details of Existing Borehole Sources

Borehole No.	Borehole Name	Year Drilled	Drilled Depth (m)	Water Struck Level (m)	Water Rest Level (m)	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/hr)
C1955	Gatundu Town BH	1953	173	Data not available			16.3	Data not available	
Data not available	Kiganjo BH	2008	Data not available						
C3486	Kimunyu BH	2008	183	Data not available			30	Data not available	
Data not available	Gatitu BH	2007	Data not available				Data not available		

Some of the data could not be obtained from the Water Operator

Treatment Works

Presently, the only form of treatment carried out is chlorination of water from the Ndarugu River Source. Raw Water from the other sources is supplied directly to consumers without any form of treatment.

Construction of 3 Nr. Conventional Treatment Plants for each of the surface water sources is currently ongoing. The capacities of the Treatment Plants being constructed are as follows:

- Thiririka River - 9,000 m^3/d
- Ndarugu River - 4,000 m^3/d
- Ruabora River - 1,200 m^3/d

Distribution System

The Distribution System in Gatundu covers approximately 240km² and comprises of GI and uPVC pipes, diameter ranging in size from 50mm to 150mm. **Figure 2.13** on **page 2-37** shows the Location of Gatundu Towns and its Administrative Units to Sub-Location Level.

Figure 2.13 - Location of Gatundu Town and its Administrative Units at Sub-Locations Level

4.11 Tala & Kangundo Towns

4.11.1 Water Service Provider

Tala and Kangundo Towns' water supply systems are presently operated by Matungulu Kangundo Water & Sewerage Company (MAKAWASCO). The Company is a limited liability company wholly owned by Kangundo Town Council.

The mandated areas of coverage are Kangundo and Matungulu Districts in Eastern Province and falls under Tanathi Water Services Board area of jurisdiction. The total of mandated area of coverage is about 755km^2 with an estimated population of 219,100 persons. Only a total of about 14,000 persons are currently being served only 6% of the total population, mainly within the Tala, Kangundo and Nguluni urban centres.

Within the Water Company area of jurisdiction there are small Self Help and Private Water Supply Schemes which offer water in competition the Water Company in addition to meeting the huge water demand deficit.

Source

The source of water is ground water comprising of 5nr. boreholes which fall within the study area. The yield of the Boreholes range from 5m^3/hr to 18m^3/hr with a total production of 900m^3/day against a present estimated demand of 9,500m^3/day. Details of the existing borehole water sources are shown in Table 2.22 below.

Table 2.22: Details of Existing Borehole Sources

Borehole No.	Borehole Name	Year Drilled	Drilled Depth	Tested Yield (m^3/hr)	Present Yield (m^3/hr)	Daily Pumping Hours	Present Production (m^3/day)
C436	Thika BH	1949	160		12	16	192
C13682	Katine BH		150		5		
	Kyamulendu BH	2007	123		8.4	16	134
C3780	Nguluni BH	1972	114		12	16	192
C16332	Isinga BH	2007	140	5			
	Ndovoini 'B' BH	1978		22			
	Ndovoini 'A' BH	1946	24		18	16	288
						TOTAL	**806**

Some of the data could not be obtained from the Water Operator

Treatment

Water is only subjected to disinfection by chlorination at each of the borehole sites.

Distribution System

The Distribution System only covers approximately 10% of the mandated area of supply and comprises of GMS / uPVC pipes. Some of the water pipes were laid in the 1950s and have rusted and broken up leading to frequent bursts and water losses.

Figure 2.14 on **page 2-39** shows the location of existing Water sources.

The Commercial data for the Water Company is given in **Appendix 2.2.**

Figure 2.14 - Location of Existing Water Sources for Tala & Kangundo Towns

5 Summary of Present Water Sources for Nairobi and Satellite Towns

A summary of the present Water Sources for Nairobi City and Satellite Towns is given in Table 2.23.

Table 2.23: Summary of Present Water Sources for Nairobi and Satellite Towns

TOWN	EXISTING SOURCES	No. of Operational Boreholes	Total No. of Boreholes	CAPACITY (m^3/day)
NAIROBI	Kikuyu Springs			4,800
	Ruiru Dam			21,700
	Sasumua Dam			56,200
	Thika / Chania / Ngethu System			414,700
	Groundwater Sources, including 2,700 individual domestic boreholes			45,000
KIKUYU	Groundwater Sources (Boreholes)	13	15	4,202
KIAMBU	Groundwater Sources (Boreholes)	10	11	3,060
	NCWSC Bulk Supply			230
KARURI	Groundwater Sources (Boreholes)	11	12	1,667
	NCWSC Bulk Supply			1,100
RUIRU-JUJA	Ruiru Water Supply / Ruiru River			1,500
	Juja Water Supply / Ndarugu River			2,000
	Groundwater Sources (Boreholes)	3	3	480
	NCWSC Bulk Supply (Ngethu Pipeline)			2,500
MAVOKO	Nol Turesh Water Supply System			970
	Groundwater Sources (Boreholes)	2	6	700
	NCWSC Bulk Supply			7,500
NGONG, ONGATA RONGAI & KISERIAN	Ngong Water Supply - Boreholes & Springs	4	10	414
	Ongata Rongai Water Supply - Boreholes	2	3	160
	- Mbagathi River Intake			3,000
	Kiserian Water Supply - Boreholes & Springs	2	2	672
LIMURU TOWN	Groundwater Sources (Boreholes)	13	13	1,776
GITHUNGURI TOWN	Groundwater Sources (Boreholes)	9	9	936
	NCWSC Bulk Supply (Sasumua Pipeline)			400
GATUNDU TOWN	Ndarugu Water Supply Scheme / Ndarugu River			3,000
	Groundwater Sources (Boreholes)	2	4	740
THIKA TOWN	Chania River Intake			26,000
	Thika River Intake - Standby Source			10,368
TALA-KANGUNDO TOWNS	Groundwater Sources (Boreholes)	4	7	250

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Chapter 3 - Study Area, Land Use, Socio Economic and Demographic Trends

1 Study Area Presentation

The Objective of the Study is to identify strategies for bulk supply of water to Nairobi City and 13 Satellite Towns to initially meet the Short Term Year 2017 water demand and eventually the Long Term upto Year 2035 water demand. The task involves review of previous studies which have been carried out, but the proposed interventions have not been implemented to date.

The initial aim is to identify priority strategy to meet the 2017 water demand for which Preliminary Design has to be carried out. A Master Plan to meet the 2035 water demand of Nairobi City and 13 Satellite Towns has to be prepared under the Study. The development of bulk water sources to supply Nairobi and 13 Satellite Towns will impact on the general resource water balance in the region.

The Water Demand estimate must therefore be done at two levels:

- At Study Area Level which includes the River Basins from which water is abstracted to supply Nairobi and Satellite Towns
- At Town Area Level for Nairobi City and Satellite Towns

The Study Area covers the river basins used to supply Nairobi and Satellite Towns (Tana, Thika and Athi River Basins). Table 3-1 indicates the Districts within the Study Area and their population as enumerated in the 2009 Census.

Table 3-1 : Study Area - List of Districts and 2009 Population

Province	District	Population (2009)
Nairobi		3,138,369
Central	Muranga North	346,283
	Muranga South	335,460
	Kiambu East (Kiambaa)	253,751
	Kikuyu	265,829
	Kiambu West	131,132
	Lari	123,895
	Thika East	77,073
	Thika West	218,544
	Ruiru	241,007
	Gatanga	113,094
	Gatundu	214,791
Rift Valley	Kajiado North	263,256
Eastern	Machakos	442,930
	Kagundo	219,103
	Total	**6,532,280**

2 Nairobi and Satellite Towns

The list of the Satellite Towns as per the Request for Proposal (RFP) is given in Table 2 below and their locations with respect to Nairobi City are shown in **Figure 3-1 on Page 3-3.**

Table 3-2 : List of Satellite Towns

No.	Satellite Town	District
1	Gatundu	Gatundu
2	Thika	Thika West
3	Kikuyu	Kikuyu
4	Limuru	Kiambu West
5	Kiambu	Kiambu East
6	Karuri	Kiambu East (Kiambaa)
7	Githunguri	Githunguri
8	Ruiru	Ruiru
9	Juja	Thika West
10	Ongata Rongai	Kajiado North
11	Ngong Township	Kajiado North
12	Mavoko Municipality (Athi River)	Machakos
13	Tala-Kangundo	Kangundo

When studying the Satellite Towns, it appears that some of the Towns are located in the vicinity of Nairobi and are becoming part of the Greater Nairobi. The population growth is not occurring within the Municipal Boundaries but is infilling all the land available between Satellite Towns and the Nairobi District Boundary. These present trends in physical development i.e. population growth, optimum housing densities, infrastructure development and the Study of Kenya Government Vision 2030 Strategy etc. have all been considered in ascertaining the "Effective Envelop of Nairobi Water Demand".

Figure 3-2 on Page 3-4 shows the Nairobi City and the effective demand Envelop. This Envelop was approved by AWSB on 27 December 2010. It includes some of the Satellite Towns under the present study for mobilization of bulk resources (i.e. Kikuyu, Karuri, Kiambu, Ruiru, Juja, Athi River, Ongata Rongai and Ngong).

The area between Nairobi City Boundary and the Envelop Boundary is a contiguous part of Nairobi. Although this area lacks planned infrastructure, the development pattern is similar to Nairobi City and most residents in this area commute to Nairobi daily for work, schooling, etc.

In terms of water resources, these Towns will have their own resources wherever possible. Connections to the main transmission lines to Nairobi will only be allowed if there is no other resource available.

For the others Satellites Towns, outside the Nairobi Envelope (i.e. Limuru, Kimende, Githunguri, Gatundu, Thika, Tala, Kangundo), only the core urban centre will be taken into consideration for the water demand estimate. Rural areas are excluded from the present study except for ascertaining the water demand to be used in the Water Balance Model.

This Report presents a summary of the Land Use Analysis within the Nairobi Metropolitan Region (NMR) and the water demand forecast for Nairobi City and the Satellite Towns. In addition, the water demand forecast for the Region has been assessed where the existing and proposed sources emanate. This will be used in the preparation of the Water Balance Model.

Figure 3-1: Project Location Plan – Nairobi City and Satellite Towns

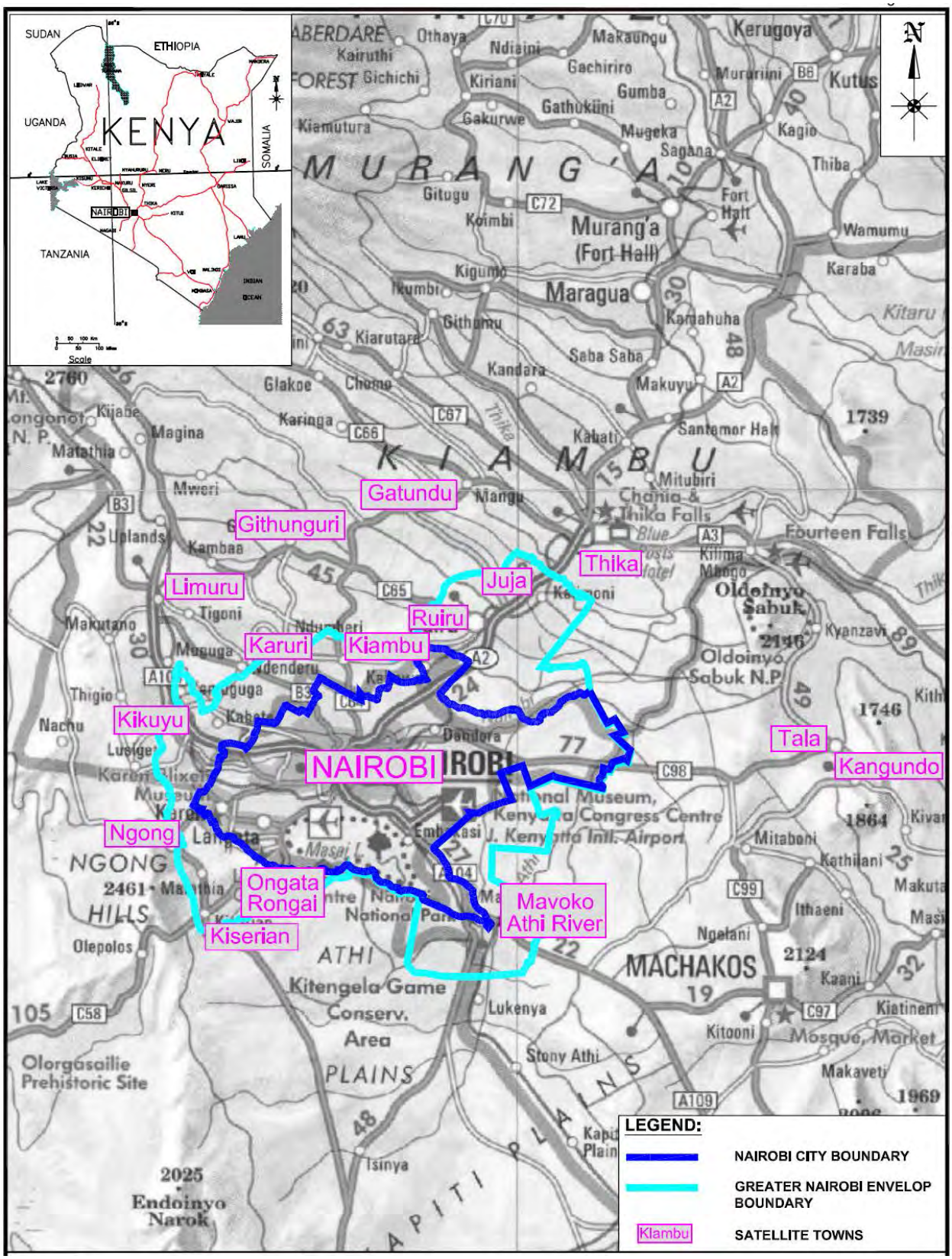


Figure 3-2: Nairobi City and the Effective Demand Envelop

2.1 Geology, Topography, Drainage And Climate

2.1.1 Geology

The Study Area is overlain with an ancient core of crystalline rocks of the Basement Complex which underlies the greater part of the plateau areas of Africa which have been affected by the extensive faulting, displacement and volcanic activity associated with the Rift Valley System. The eroded surface of the pre-Cambrian basement rocks outcrops only on the southern and eastern margins of the area. Elsewhere it is overlain by a variable thickness of volcanic and pyroclastic rocks of Tertiary age.

The Tertiary succession comprises various lava flows, pyroclastic rocks or their weathered derivatives, and also palaesoils, developed intervening periods sub-aerial weathering. Upthrusting and concentration of volcanic activity at the margins of Rift Valley has resulted in a general alignment of lava flows and associated deposits in a southeasterly direction. The sporadic character of the volcanic events both in space and time has dictated the lateral and vertical variability of geological succession.

2.1.2 Topography and Drainage

The Tertiary volcanic uplands on the margin of the Rift Valley are the source areas of the present drainage network. The highest land occurs in the Nyandarua Mountains where elevations of over 3,500m are reached within the Study Area. From the vicinity of Mt. Kinangop, the highest point, rise four major tributaries of the River Tana; the most Southerly, the River Chania, which provides the greater part of Nairobi's present water supply and the Rivers Thika, Maragua and Mathioya.

At the southern end of the Nyandarua Range the watershed to the internal drainage system of the Rift Valley becomes an undulating plateau and from this area originate several tributaries of the River Athi including from north to south the Ndarugu, Thiririka, Ruiru and Nairobi Rivers.

The rivers within both the Tana and Athi drainage system form a parallel drainage density, oriented generally southeasterly, and following the dip direction of the underlying lava flows. They have formed deeply incised valleys in long narrow catchments with steep side slopes and longitudinal profiles. The valley sides as well as the headwaters generally have a thick mantle of weathered rock and soil and only rarely is bedrock seen except within the river channel. This weathered mantle and the forest vegetation which covers elevations above 2200m, dampen the flood response of the rivers to intense rainfall and sustain dry weather flows.

The rivers emerge from their incised valleys onto a flat piedmont zone (at an elevation of approximately 1500m) which is without significant perennial tributaries and join up with the main Athi and Tana rivers.

With exception of the Ngong Hills which rise to 2460m, the character of the landscape changes to the South of Nairobi. The headwaters on the Rift Valley margin are both flatter and lower in elevation and in their middle courses the widely spaced tributaries of the Athi flow through a rolling plateau, with occasionally rocky hills standing above the general level. Of the three tributaries of the Athi meeting at the Athi River Township, only the Upper Embakasi (or Mbagathi) is perennial, although its dry weather flow is small.

Downstream, the course of the Athi approaches that of the lower Thika and at one point they are separated by a distance of only 1.5 km and an intervening relief of 50m. Subsequently their courses diverge, the Thika turning northwards to join the Tana at Masinga reservoir and Athi continuing southeastward along the margin of the Yatta plateau.

2.1.3 Climate

The climate of the area is predominantly controlled by its equatorial position and the large scale pressure systems of the African Continent and the Indian Ocean. However, topography strongly influences the magnitude of the climatic elements and to a lesser extent their seasonal distribution.

The seasonal distribution of rainfall is dominated by the movement of the Inter Tropical Convergence Zone (ITCZ) which separates the Northeastern and Southeastern trade wind systems and the belt of maximum rainfall follows the position of the overhead sun with a time lag of about 4 to 6 weeks. The two rainy seasons are therefore centered around April-May (The Long Rains) and October-November (The Short Rains). During the intervening dry seasons monsoonal systems bring rather dry air masses. From December to March the persistent Northeasterly monsoon brings clear sunny weather with only occasional showers. During the period of Southeasterly monsoon from June to October the weather is duller and cooler with occasional drizzle which is more persistent at higher elevations.

Rainfall is the climatological element of greatest water resource significance. The highest annual totals of over 2600mm occur at the windward side of summit of the Nyandarua Mountains and there is a decline with elevation which is much more rapid on the leeward slope towards the Rift Valley than on the windward side.

Indeed further south in the headwaters of the Thiririka and Ruiru rivers the rainfall divide is some distance to the east of the topographic divide. In general also there is a decrease towards the south in the rainfall at a given altitude.

At the edge of the piedmont zone between Nairobi and Thika, the annual rainfall values decline to 800 to 900 mm but there is little further decline towards the east. However, to the South within the Upper Athi catchment there is a further reduction to less than 600mm. Associated with these lower totals is a higher coefficient of variation.

Other climatic elements have a significant influence on water resources, especially in their effect on the rate of evapotranspiration loss. Throughout the area mean daily temperature varies little with season and the diurnal variation is greater than the seasonal variation. With increasing altitude, daily minimum temperature values decrease more rapidly than the daily maximum. Typically the annual average diurnal range at elevations of 1500m is 13°C to 25°C whilst at 2500m the range is from 6°C to 22°C.

Mean annual relative humidity values range from 65% at lower elevations to 80% or more above 2500m. Humidity is greatest at dawn and lowest in the early afternoon when the temperature reaches the diurnal maximum.

Below 1500m the mean daily duration of bright sunshine ranges from 4 hours during July and August to 9 hours during the Northern Monsoon season with an annual mean of 6.8 hours. Sunshine shows a decrease with altitude, with an annual mean of 5 hours at 2500m.

Mean annual free water surface evaporation as calculated by Woodhead using Penman's ranges from around 1800mm in piedmont zone to less than 1400mm in the Nyandarua Range Potential evapotranspiration is estimated to be about 75% of free water evaporation in the highlands and 80% or more in dryer lying areas.

2.2 Water Sources in the Project Area

There are two main rivers in the project area, Athi and Tana Rivers. Nairobi City and its neighbouring Towns are located within the Athi River catchment. Part of the waste water from these Towns flows into the Athi River deteriorating its water quality and reducing its potential as a new water source for Nairobi.

The first recorded water source for Nairobi was commissioned in 1899, based on the Ngong River (Nairobi Dam) in the Athi catchment. This produced small quantities of poor quality water and was later abandoned.

During the period 1900 to 1906 the Kikuyu Springs located 18 km from the city (refer to Figure 3.1, page 31) were developed to produce approximately 4500 m^3/ day which was sufficient for Nairobi's needs until the late 1930's.

In 1938 the first phase of development of a source based on the Ruiru River- an intake weir and pipeline. This source was further developed by commissioning a second pipeline in 1946, and a third pipeline then Ruiru Dam in 1949.

The next major source, Sasumua Dam was initially fed by Sasumua River, supplemented by water diverted from the head - waters of the Chania River. The Project included a water treatment plant works adjacent to the dam and a pipeline which delivers treated water to the terminal reservoir at Kabete in Nairobi. This project was completed in 1956. Subsequent developments have included raising the dam, diverting the Kiburu River into Sasumua and increasing the capacity of the treatment works, pipelines and terminal reservoirs.

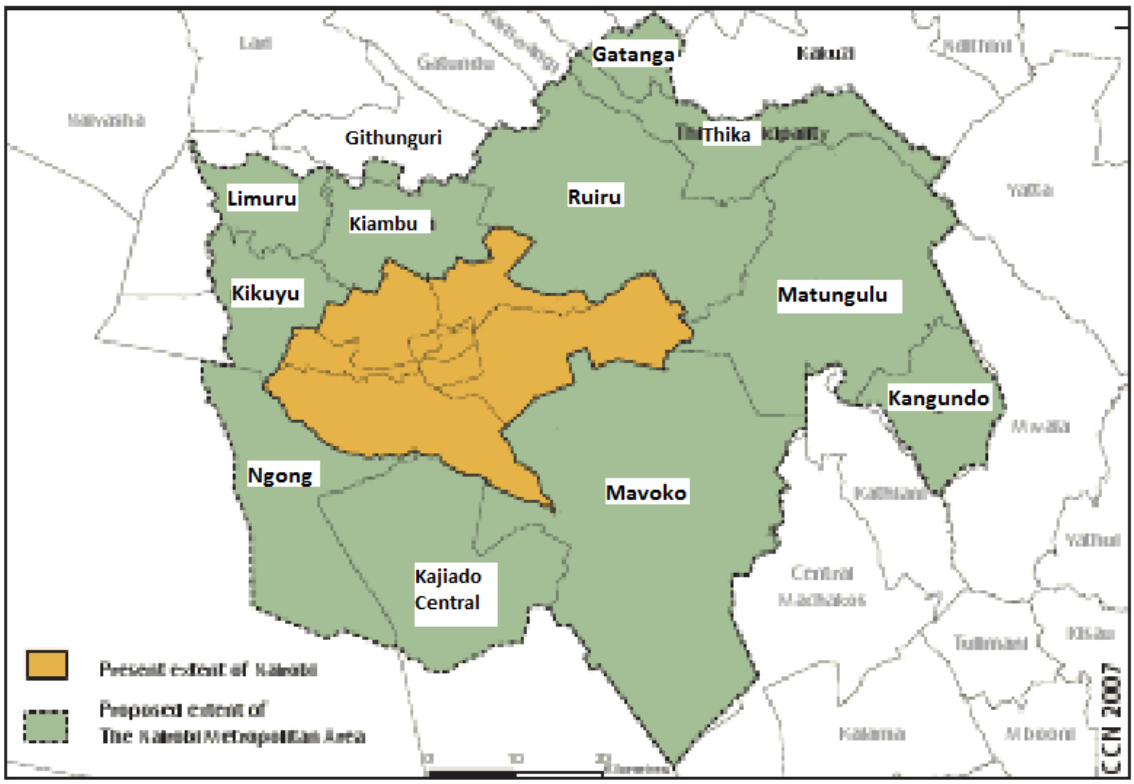
When Sasumua yield was fully exploited, the next source of water which was developed is the Chania River, initially by pumping from the river at Ngethu, followed by a diversion dam, at Mwagu which transfers water to Ngethu treatment works by gravity via a three metre diameter tunnel and a 1400 mm pipeline. This project was completed in 1984. After completion of the Mwagu Diversion Dam, the associated tunnel and pipeline conveying raw water to Ngethu, the total available water to Nairobi was close to the demand. Then Thika Dam was developed and commissioned in 1994 to feed the Mwagu / Ngethu system.

In order to ensure that Nairobi City does not suffer from chronic water shortage, the Northern Collector Phase 1 and Phase 2 were planned to be implemented in 2001 and 2006 respectively. However the implementation of this project stalled and Nairobi is faced with chronic water shortage resulting to water rationing in most parts of the City.

3 Land Use, Socio Economic and Demographic Trends - Nairobi City and the Metropolitan Area

The Nairobi Metropolitan Region (NMR) covers Nairobi City, Parts of Kiambu County, Thika, Kajiado and Machakos. Nairobi is spread over 696 sq km which is about 2% of the NMR area, it accommodates 3.13 million people according to the 2009 National census figures. **Figure 3-3 on Page 3-8** highlights the region occupied by Nairobi City (yellow) in relation to the rest of the metro region.

Figure 3-3: Metro Region in Relation to Nairobi

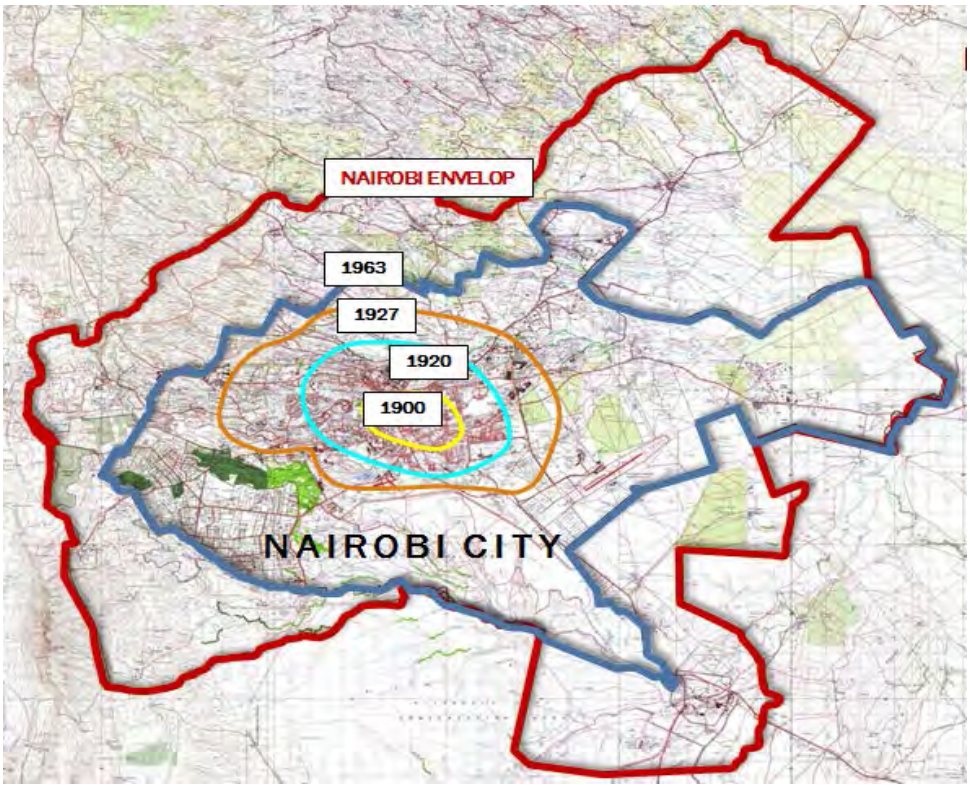


3.1 Nairobi City Boundary

In the last 100yrs, the City Boundary has been extended to cover a greater region as shown by map above. It has been extended to include rich agricultural and livestock area in Kiambu, Kajiado and Machakos District. The City Boundary has also been extended to include the Nairobi National Park. Initially the City covered 77sq.km. in 1927 and it was expanded to 686sq.km in 1963. At present the entire Nairobi Metropolitan Region area is 32,000sq km. **Figure 3.4** on **Page 3-9** shows how the city boundary has expanded over the years with the ever increasing competition among different land uses.

Nairobi City has expanded to accommodate different functions that compete for space within its boundaries. It is from this premise that the Metropolitan Region was mooted. The urban centres within the Metropolitan Region almost share the same pattern with the CBD occupying the central or the core of the Towns.

Figure 3-4: Map Showing the Expansion of Nairobi City 1900 – 2009



3.2 Nairobi City

3.2.1 Land Use

Nairobi's Land Use contains the zoned areas of Urban and Suburban areas such as CBD, City Centre, Urbanized Area, Urban Area and Sub Urban Area. The road network in the core Nairobi is mainly international and national passing through the City Centre.

The old town as the CBD today has the main administration offices and commercial centre including shopping malls, City Council of Nairobi, Nairobi Railway Station, an International Convention Centre and Government Offices. The road network is highly dense regular grid type and limited road space for widening.

Buru Buru has emerged as centre of the Eastlands, with supermarkets and entertainment outlets being the main attraction at the shopping centre, the surrounding areas are mainly medium to high density residential areas.

The Hill Area represents the administration area to the western part of the city. These include the State House, Government Offices, Embassies, World Bank, Jica, Nairobi University, Uhuru Park, Hotels (Serena) and residential apartments.

Westlands exhibits the true reflection of a City within a City with every component of a full-fledged City: shopping malls, five star hotels, casinos and office blocks that are developing at a very high rate. These developments, especially the office blocks must be consistent with infrastructural components like road network systems to avoid the traffic congestion.

The area outside the City Centre covering 5 to 7km radius from the CBD is classified as urbanized area and is surrounded by ring roads. The Land use in these regions is mainly industrial, commercial and residential. The road network here is incomplete and can be

described as the missing links to the core and other regions with the wider City Boundary. The bypasses under construction are earmarked to solve part of these bottlenecks and ease congestion to the CBD.

The area outside the urbanized ring is classified as Urban and the land use is mainly residential sub-divisions, industrial estates and commercial centres including air ports and Nairobi National park. The road network is mainly radial arterial roads leading to the CBD.

The out-most ring is classified as sub-urban and its land use characteristics are Agricultural and pasturage, sub-urban towns and residential developments. The road network is less developed except the western area where coffee/ tea feeder roads have been developed on the ridges.

3.2.2 Transport

Transport is an important component of a spatial development plan because it determines the direction and growth. It affects the economic viability and social mobility of the region and its people.

In NRM, the road system is the most predominant. The road network is of radial pattern with Nairobi city as the focus. Orbital roads are missing. This has led to concentration of activities within and intense traffic to and from the city. Radial road corridors traverse Nairobi city and extend into the region and beyond. Nairobi-Thika road (A-2), Nairobi-Eldoret-Uganda) (A-104) and Nairobi-Mombasa (A-109) are important international trunk roads carrying large volume of traffic. The major concentration of people and activities are along these road corridors. Nairobi city contains nearly 67% of the motor vehicles in Kenya.

The traffic characteristics of the regional towns indicate a high intensity of walk trips, long trip lengths by vehicles, high share of work trips and high dependence on public transport modes, primarily the matatus.

A number of road development programs are under implementation. At the regional level upgrading of Nairobi-Thika Road is a major one with financial assistance from African Development Bank and the Government of China. Within Nairobi City Southern and Northern Bypasses are under construction. Plans are under preparation for improvement of Ngong Road an important radial corridor.

The role of railway in enabling regional commuter movement is very limited though a recent feasibility study has identified a number of corridors in the city and the region for development of high technology public mass transport systems comprising mass rapid transit system (MRTS) and light Rail Transit Systems (LRTS). The geography of NMR poses a challenge to the development of telecommunication network. There are certain areas that are lacking in infrastructure facility and telecommunication network.

The completion of these road projects is going to witness more people moving to Satellite Towns forming the Nairobi Metro Region. Thika, Ruiru and Limuru have been acting as dormitory towns of Nairobi, but have been constrained by the major traffic snarl ups during the peak hours.

Besides being the political and administrative center, Nairobi's strategic location has made it an important regional hub for commercial, financial, industrial, education and communication in Eastern Africa.

Most of the road-based traffic from Municipal Council of Mavoko to Nairobi utilizes the Mombasa Road. As the Mombasa Rail line also passes through that area, commuters into the city of Nairobi are, able to travel in the trains that stops at Athi River Railway Station.

3.2.3 Residential

Residential patterns in the metropolitan region are largely segregated. Its origin in the Kenyan Towns especially Nairobi and its Satellite Towns can be traced back to the emergence of colonization. One of the most striking features of residential segregation in the city is its dynamics that involves transformation into different socio-spatial manifestations. For instance, currently an estimated 55% of the total population of Nairobi lives in the spatially segregated informal settlements that occupy only 5% of Nairobi's residential area. One such settlement is Kibera whose high density of about 2000 people per hectare makes it one of the most densely populated informal settlements in sub-Saharan Africa.

Like any other metropolis there are a lot of apartments and big bungalow type housing in Nairobi and low rise residential development in other parts of the region. Nairobi and NMR have a very low household size of 3.2 and 3.4 as compared to the county's average household size of 4.4.

3.2.4 Social Amenities

Social amenities in NMR are also not evenly distributed over the region with Nairobi forming the Hub of both educational and health facilities and in other parts of the region which have social amenities spread from 5km to 30km between facilities.

3.2.5 Industrial

This is the region between the CBD and the greater East Land. It is flanked by mostly the city council estates like Makongeni, Maringo, Bahati along Jogoo Road and the informal settlements of Mukuru Kwa Njenga and Mukuru Nyayo and Lunga Lunga. The industrial area is the major employment centre for casual labourers hence deemed to have the highest employment rates at any time of the day. The structures here are mostly storage Godowns and small manufacturing plants with the major roads being Enterprise Road and Mombasa road. It is the main railway terminus in Nairobi since all offloading and loading of manufacturing materials and loading of finished goods is done here.

Light industrial plants have spread towards Mlolongo along Mombasa road in the mixed use land use area. Kitengela has emerged as the prime residential area for factory workers from the cement factories and the EPZ Zone.

3.2.6 Commercial

This is a function that is mostly dominant in the CBD of the core Nairobi City. It is a feature that has spread to every estate shopping centre to ease shopping. The term commercial implies a lot of functions:

Neighbourhood Commercial

This is designated to encourage the organized concentration of retail goods and services for the convenience of the immediately adjacent residential neighbourhood. Typical uses found in neighbourhood centres include: grocery stores, pharmacies, restaurants, dry cleaners, service stations, beauty parlours, professional office and financial services.

Community Commercial

This designation is meant to encourage organized concentration of wide variety of retail goods and services for the residents. In addition to the uses specified in the neighbourhood commercial designation, the uses found in community shopping centres include, but not limited

merchandise sales, movie theatres and furniture sales. These include the areas along the outer ring road, Donholm and Fox Drive-in.

Business Commercial

This category is mainly developed to serve the employees of the surrounding industrial parks. They are characterized by high level of design to complement adjacent industrial and office development. Typical uses are similar to those specified in the neighbourhood commercial but with an added emphasis on uses that serve the business community. Employment generating uses are provided with range of retail and service uses. These are areas occupying Mombasa Road from Nyayo National Stadium to Mlolongo.

Specialized Commercial

These are mostly commercial uses that are more suitable for individual auto access than for general shopping area developments. The uses include auto sales and service, car washes, furniture, appliance and building supply stores and rental businesses. In Nairobi, these are areas along Ngong road, Langata road and Yaya Centre.

Commercial Recreation

This accommodates facilities for residents and visitors. Mamba Village, Splash Water World, Carnivore are the best examples.

Visitor Commercial

This accommodates hotels and motels. Besides these speciality shops, restaurants, entertainment and other uses catering to visitors may also be provided. The area around Museum Hill, Westlands and Bomas of Kenya.

Office Commercial

This is an area for professional and financial services in locations served by primary access, yet inappropriate for commercial or high-employment office centre because of the proximity to residential uses. Related uses may include lodges and clubs, medical clinics and convalescent homes. In Nairobi, these are areas around Hill Area, Community, Westlands and Kilimani.

3.2.7 Airport Overlay

Intended to ensure the development of properties that are subject to high noise levels or accident potential from aircraft operations. Jomo Kenyatta Airport and Wilson Airport areas fall in this category.

3.2.8 Environmental Status

The environmental status in NMR consisting of geological features, drainage, hydrology, climate, rainfall, temperature, drought and flood pattern. There is a need for an integrated approach for environmental planning in NMR. Environmental issues of the region have to be identified and integrated in the development of the region.

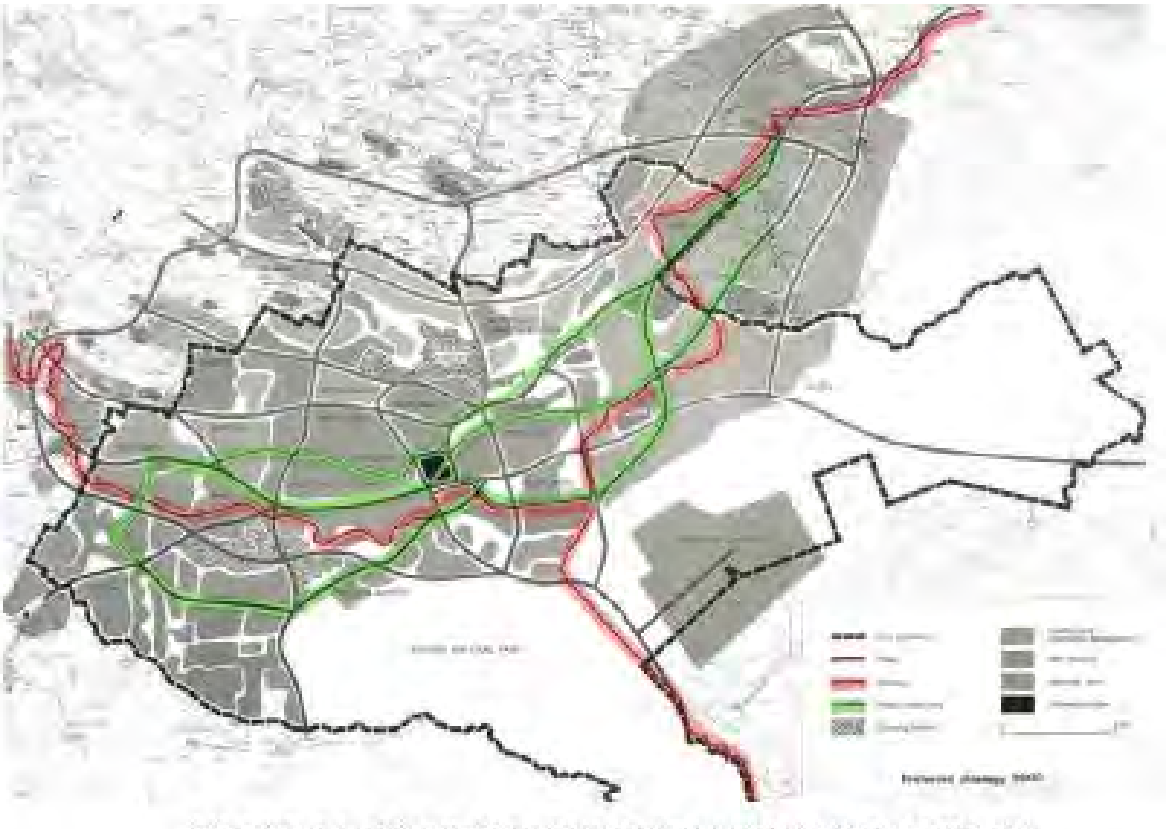
NMR has widespread forest lands, hills, national parks, numerous water bodies and other green/open areas. Due to increase in urbanization, particularly Nairobi City and surroundings, there are more requirements of housing and other economic development that can provide more employment in the region as shown by the Land Use Map **Figure 3.9 on Page 3-23**.

3.3 The Nairobi Metropolitan Region Growth Strategies

There have been various strategies in intervening years since 1973 that have been geared towards the development of the metropolitan region.

Presently Nairobi City does not have a strategic development and/or master plan. The first strategic policy for the City is contained in the 1948 Nairobi Master Plan. The second and last strategic plan was the 1973 Nairobi Metropolitan Growth Strategy. There has been several subsequent development plans for the City but short term and Adhoc. The same plans have been prepared by different agencies hence not integrated and coordinated. **Figure 3-5** shows the NMR growth strategy interventions since 1948 up to 2009.

Figure 3-5: Map Showing Nairobi Metropolitan Growth Strategy



3.3.1 The 1948 Nairobi Master Plan

This was the first comprehensive development plan for the City. The plan catered for the old small colonial city covering about 10sq.km.

3.3.2 The 1973 NRM Growth Strategy

This 1973-2000 Metropolitan Growth Strategy covered the City of Nairobi and its environs. The plan covered the population issues, economic activities, land use, transportation, housing and revenue and expenditure patterns.

Though the plan was prepared by the City Council itself, the plan was not effectively implemented and policies measured were not enforced. Unfortunately this is still the document which the City Council still relies on. However, the plan is not valid under the current physical legislation.

3.3.3 The 1992 Hill Area Zoning Plan

This plan covers the Upper Hill and Community Area just outside the CBD. The focus of this policy document was to decongest the CBD by transferring new office space to Upper Hill, formerly low density, high income residential neighbourhood. The implementation of the policy is however poor. Expansion of roads and support infrastructure has not been incorporated in the plan.

3.3.4 The 1998 Karen-Langata Structure Plan

This plan covered the most exclusive and high income and low density residential areas of Nairobi. The focus of the policy was to convert the area that was formerly under agricultural and low residential development to smaller plot size of I hectare (2.5 acres).

3.3.5 The 2006 Karen Langata Local Physical Development Plan

This was a first attempt by Ministry of Lands to prepare plan document under new Physical Planning Act. The key focus was to make provision for more housing for increased population demand. The minimum residential plot size was reduced to 0.5 acres.

3.3.6 The 2006 Local Physical Development Plan for Zone 3, 4 &5

This policy review document covers high income residential area of Kileleshwa, Kilimani, Woodley, Parklands, Westlands, Lavington, Thompson, Loresho, River Side and Spring Valley. The policy intervention looks at the development of highrise block of multi-family residential flat units.

3.3.7 The Nairobi We Want Initiation

In this policy document the City Council of Nairobi initiated the process of having greater public participation in formulating City Council policy. The implementation of the document was however poor because of conflicting political interests.

3.3.8 The 2006 Nairobi Metropolitan Transport Master Plan

Nairobi Metropolitan Transport Master Plan is focussed on addressing transport problems/challenges in the city. This plan document is however not effective as it is not related to any comprehensive and overall development plan for the city

3.3.9 The Redevelopment of the Eastlands

Majority of low income and middle-income population in Nairobi live in Eastlands. This policy document is focussed on redevelopment of housing for the low and middle-income population in Nairobi. The introduction of high rise blocks in Umoja, Tena, Kayole, Dandora and pipeline has witnessed unprecedented population increase among the low and middle income earners.

3.3.10 Machakos –Mlolongo-Isinya-Kitengela-Ngong Corridor Zoning Plans

This zoning policy plans are addressed to the Satellite Towns of Nairobi that lie in Machakos and Kajiado Districts. These policy documents have been initiated by the Ministry of Lands but do not relate to City Council of Nairobi Development Plan.

3.3.11 Kikuyu-Kiambu-Ruiru-Thika Corridor Zoning Plans

These are also policy efforts by The Ministry of Lands centred on the Satellite Towns of Nairobi in Kiambu District. The same policy efforts do not fully relate to City Council policy efforts.

3.4 Population in Nairobi Metropolitan Region (NMR)

According to the 2009 population census, the population within Nairobi Metropolitan Region (NMR) was 6,822,924 .Nairobi City alone had a population of 3,138,369. The population growth rate in Nairobi City was approximately 3.9% while that of the entire NMR was approximately 6.7%.**Table 3.3 below** presents the population distribution in the NMR based on the 1999 and 2009 National Housing Census.

Table 3-3 : Population Distribution in NMR Based on 1999 – 2009 National Housing Census

District	TC/MC/CC	Area (Sq. Km)	Enumerated population			Population density /sq.km)	
			1999	2009	CAGR	1999	2009
Nairobi	City Council	696	2,143,254	3,138,369	3.92%	3079	4,509
Kiambu		1,324	744,010	922,370	2.20%	562	697
	Kikuyu TC	137	156,131			1,140	
	Karuri TC	46	71,475			1,540	
	Limuru MC	156	68,326	104,745	5.3%	439	667
	Kiambu MC	98	60,605	94,833	5.6%	618	968
	Kiambu CC	887	387,473			437	
Thika		1,960	645,713	864,509	2.94%	329	441
	Ruiru MC	291	109,574	241,007	11.9%	377	825
	Thika MC	94	106,707	218,544	10.4%	1,141	668
	Thika CC	1,576	429,432			272	
Kajiado		21,903	406,054	687,312	5.43%	19	31
	Kajiado TC	288	9,165			32	
	Olkejuado CC	21,615	396,889			18	
Machakos		6,281	906,644	1,098,584	1.85%	144	175
	Machakos MC	349	143,274			410	
	Mavoko MC	957	27,168			28	
	Kangundo TC	178	179,952			1,010	
	Masaku CC	4,797	556,250			116	
NMR		32,164	4,845,675	6,711,144	3.31%	151	207
Kenya		581,677	28,686,607	40,406,412	3.16%	49	69

3.5 Population Dynamics in Nairobi City.

3.5.1 Population Growth

Population is a major driver of environmental change in Nairobi and as such is a determinant of other parameters such as solid-waste-generation rates, land-use patterns and settlement, and water consumption. The population of Nairobi grew from 8,000 in 1901 to 118,579 in 1948 (Rakodi 1997). By 1962, the City had a population of 343,500 people, although some of this could be attributed to extension of the City's Boundaries .Between the 1948 and 1962 censuses, the population grew at an average rate of 5.9 per cent per annum, compared with 7.6 per cent in the previous 12-year period. Taking the 2009 census figures as a baseline, it is projected that the City's population will be 3.8 million by 2015 (CBS 2001). This increase will put even more pressure on the available resources. Although it covers only 0.1 per cent of Kenya's total surface area, Nairobi already has about 8 per cent of the country's total population (CBS 2001) and 25 per cent of Kenya's urban population (UN-Habitat 2001). In 1962, there were over twice as many adult males as females.

3.5.2 Factors Affecting Population Growth in Nairobi

Fertility is one of the principal components of population dynamics, the others being mortality and migration (UN 1973 in CBS et al. 2004). Fertility reduction became the thrust of the country's population policy as early as 1967. This underlines the deliberate efforts by the Government to contain population growth (CBS et al. 2004). Indeed, the total fertility rate in Nairobi fell from 4.6 in 1989 to 2.6 in 1998 and is currently 2.7 (CBS et al. 2004). One of the targets of the National Population Policy for Sustainable Development is to stabilize the fertility rate at 2.1 by 2010 (CBS et al. 2004). Population growth is partly explained by net migration into the City. The net immigration flow into the city between 1979 and 1989 was 772,624 (NEMA, 2003). The forces motivating rural-urban migration to Nairobi include better economic prospects, opportunities for higher education and higher wage employment, and the attraction of Nairobi as a market for goods and services. But there is also the phenomenon of diurnal migration of people from the environs who commute daily into Nairobi for purposes of employment, education or trade. Projections are that diurnal migration will continue unless deliberate efforts are made to develop satellite towns and employ strategies to reduce the daily influx of people to the city. For instance, universities could be established at regional levels so that higher education opportunities are taken closer to people in the countryside. In order to adequately tackle these problems, however, diurnal migration first needs to be quantified and factored into the City development policies.

3.5.3 Population Distribution in Nairobi City.

The other feature of Nairobi's population is its distribution. In some areas of the City, the population density is quite high. The City's overall population density is 3,079 people per square kilometre (CBS 2001), but, this varies significantly across the different divisions. For instance, Central Division is the most densely populated with 22,164 persons per square kilometre, while Kibera Division has 1,284 people per square kilometre (CBS 2001). Even within divisions, there are differences. Some areas of Kibera Division have extremely high densities, especially in the slum areas. **Figure 3-6** on **Page 3-17** shows the population distribution in Nairobi City in the 1990's.

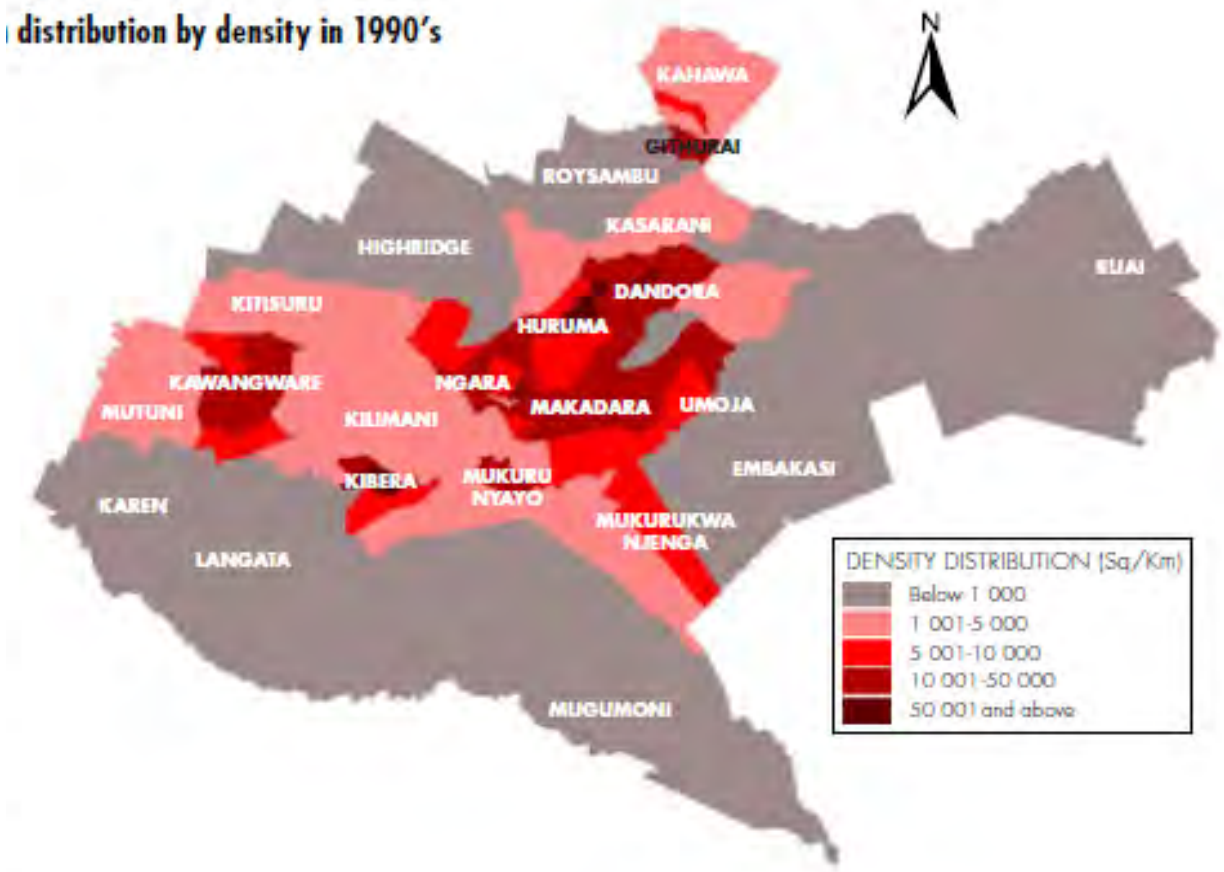


Figure 3-6: Population Distribution in Nairobi City in 1990s

The Population within Nairobi Divisions has varied characteristics and densities. Informal settlement areas like Mukuru kwa Njenga, Mukuru Nyayo and Kibera are home to most of the population that work in the Industrial Area. There is a strong correlation between work places and settlement patterns. The densities in these regions are very high due to the short distances to work places and low rent on housing, though physical infrastructure is near obsolete.

Kilimani, Kitisuru,Kasarani and Kahawa are medium density areas mostly settled by people who are in medium to high income. These areas are characterized by apartment development, maisonettes and semi detached Bungalows.

3.5.4 Population Density In Nairobi Metropolitan Region

The average population density for Nairobi City was 4509 persons per square km according to the 2009 census results, As compared to this, the population density in the Town Councils of Kikuyu, Karuri, Thika and Kangundo is around 1000-1500 persons per sq.km. The population density in the Municipal Council of Limuru, Kiambu, Ruiru and Machakos is in the range of 400-600 persons per sq.km. In County Councils of NMR, the population density ranges between a low of 18 persons per sq.km in Kajiado to about 437 persons per sq.km in Kiambu.

The Northern parts of NMR which includes the Districts of Kiambu and Thika covers about 10% of NMR area and had about 27% of NMR population and the compound annual growth of population over the past decade was 2.6%. However, the urban centres of Kikuyu, Karuri, Limuru, Kiambu, Ruiru and Thika have recorded a population growth of over 4% per annum.

District of Machakos which is in the Eastern part of NMR covers about 20% of NMR area and accommodates about 16% of NMR population. Population growth rate in this area was 1.94% per annum in the past decade. Kajiado district in the Southern part of NMR covers about 68% of NMR area and contains about 10% of NMR population. Significant population growth in Ngong, Ongata Rongai and Kiserian areas of Kajiado District has contributed to an overall compound annual growth of 5.4 percent in the Southern area of NMR. **Figure 3-8** on **Page 3-19** displays the distribution of population density in the NMR.

According to the 2009 population census figures the NRM population is pegged at 6.7 million people. Half of this figure is concentrated in Nairobi with varying densities that are defined by high concentration in the slum areas. The densities are a strong basis for determining the income distribution.

3.6 Education and Health Facilities

Social amenities in NMR are not evenly distributed over the region with Nairobi forming the Hub of both educational and health facilities and in other parts of the region. One would have to travel a distance of 5km and 30km to avail these facilities.

In Nairobi, public schools are supplemented by the private academies that help ease the congestion in public primary schools. These private schools have reduced distances covered by school going children to within a few metres. The total number of schools in the NMR area are 1,550. **Figure 3-7 below** shows the distribution of schools and 275 sub-locations in the Metropolitan Region. The concentration of schools per sub-location is higher within the Nairobi City Boundary, consistent with the high population densities, as compared with to rest of the Metropolitan Region. Kajiado has the least school distribution per sub location.

In the health sector, aside from city council run hospitals and other public hospitals, there are clinics and dispensaries that provide complimentary services. These health services facilities have tremendously improved awareness about ailments especially child mortality rates hence the steady population increase. However, the situation is very different especially in the southern parts of the metro.

Figure 3-7: Distribution of Schools and 276 Sub Locations

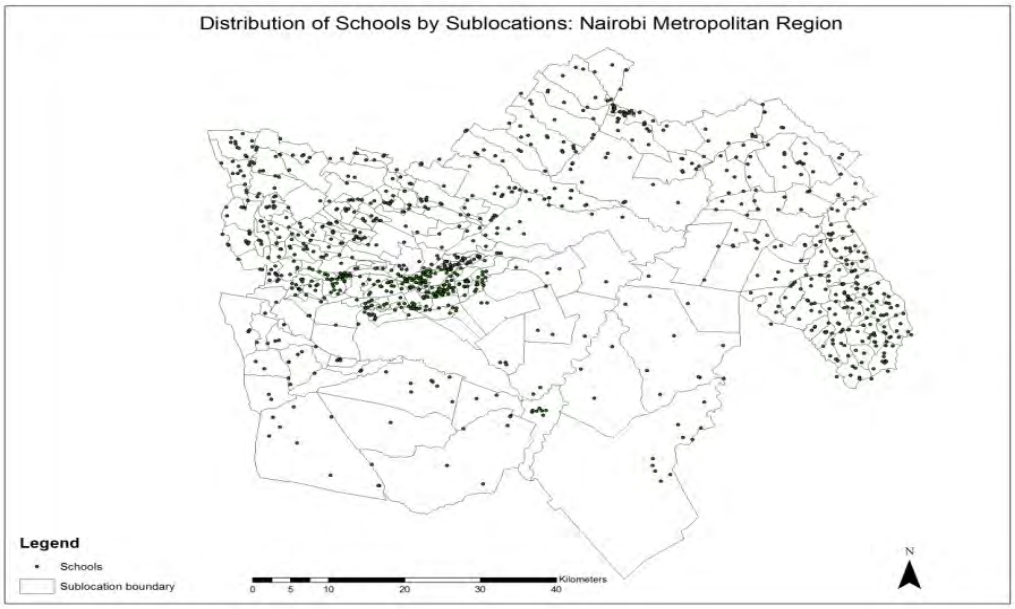
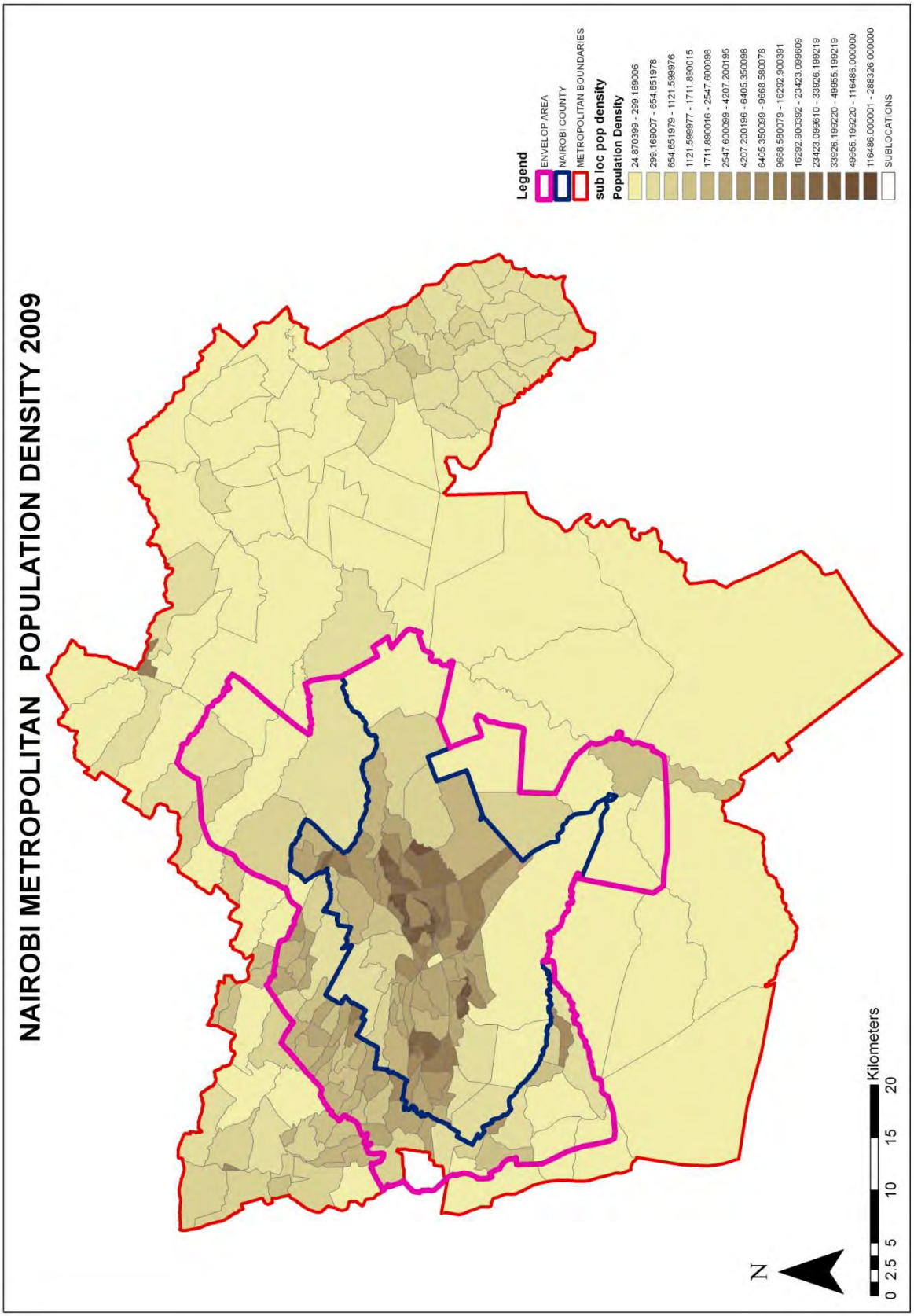


Figure 3-8: Distribution of Population Density in Nairobi Metropolitan Region 2009



3.7 Development Potential

3.7.1 Main Economic Activities –Now and Into the Future

It is known that Nairobi contributes significantly to the national GDP. Since data on the Gross Regional Domestic Product (GRDP) is not readily available for any Region, Province or District. Considering employment and earnings as a proxy, the Primary Sector (Agriculture, Forestry and Quarrying) is reported to contribute 24.5% to GRDP. The remaining 75% is contributed by the Secondary (manufacture) and Tertiary Section (services) Sector. The Secondary and Tertiary Sectors are mainly urban based activities and Nairobi, therefore is a major location for these Sectors.

However, the new opportunities available to Nairobi and the entire Metropolitan Area hinges on its central and strategic location within the African Continent. First, Nairobi and its Metropolitan Region are centrally located within the global air transport network and on the Northern Transport Corridor. This means that the NMR, properly managed can transform itself into the region's transportation and logistics hub.

Secondly, Nairobi is host to a large number of regional and international bodies which serve the region and the world. There is thus, a huge opportunity to transform Nairobi into the region and the continents diplomatic hub. Thirdly, the large number of educational institutions in and around Nairobi provides an opportunity to turn it to an international centre for education and research. In fact, this provides a basis upon which Nairobi can develop the knowledge economy in service of the country and the region.

Fourth, building on the fact that Nairobi can be transformed into a transport, commercial, education, research and diplomatic hub, it is then possible to build the requisite financial base to service this development. Fifth, is the opportunity of strengthening the role of Nairobi as the regional tourist circuit hub.

3.7.2 Employment

Kenya Vision 2030 envisages a sustained growth of GDP at 10% up to 2030. The GDP of NMR has to grow at a higher rate of 15% in the initial decades. Presently the people in the age group 15-64 are considered as the labour force. However, with socio-economic development, the labour force size will reduce. Based on revised WPR of NMR and the component spatial units, the employment size in NMR as a total, in the sub-regions and in urban centres have been forecast. The WPR of urban areas, by 2030, is proposed to be 35% and of rural areas to be 40%. The employment size in NMR, by 2030, is estimated to be 5.4million, an almost threefold increase from the present. The occupation structures of the Urban areas have been proposed based on their envisaged functions.

Presently the economy of NMR is highly informal, the ratio of formal to informal employment being 1:3:96 in NMR and 1:3:98 in Nairobi with development , it is envisaged that there will be formalization of the economy, an objective of Nairobi Metro Vision 2030, it is assumed that the ratios will normalize to 1:2 in NMR and 1:1 in Nairobi City.

To understand employment patterns in Nairobi Two spatial development patterns have been conceptualized.

- Mono Nuclei Pattern
- Multi-Nuclei Pattern

i) Mono-Nuclei Pattern

Presently Nairobi City may be termed as a Mono-Nuclei City. Most of the employment in the secondary and tertiary sectors is concentrated within or around the Central Business District (CBD) of the city. The above two sectors account for about 70% of the employment in the city. This share would increase in times to come as the share of Primary Sector within the Metropolitan City would decline. It could be as high as 95% with the Tertiary Sector (including the emerging quaternary and quinnary sectors) accounting for a share of 75%.

The concentration of employment within the CBD is a primary cause for a host of transport problems the City faces everyday like high intensity, directionally imbalanced flows concentrated along a few radial corridors, resulting in long trip lengths, high congestion, long delays, increasing accidents, high resource (energy and land) consumption and increasing environmental pollution. The pattern of development is spatially inequitable, economically inefficient and socially disruptive. Extrapolating the present structure under this concept of spatial concentration of activities (employment), a share of 80% of the potential employment is assumed to be within the CBD area and the rest 20% distributed amongst other work centers of the City.

ii) Multi-Nuclei Pattern

To alleviate the problems and disadvantages of the Mono-Nuclei Structure it is the endeavor of the city to plan and promote a Multi-Nuclei Structure This pattern may be achieved over a period of time, through efficient planning and rigorous zoning supported by an effective and extensive transport system. A number of other facilitating policies, incentives, disincentives, etc. need to be implemented to promote the desired pattern of development.

3.7.3 District Centers

A number of locations for development of District Centers, distributed over the city spatial framework, to serve a population size of up to 1.0 million, with one center for each Division (constituency), have been identified. Of the 8 Divisions, the CBD will service the 3 Divisions of Makadara, Kamukunji and Starehe. The other centres identified are

- Karen/Langata
- Dagoretti
- Westlands
- Gigiri
- Kasarani
- Githurai
- Komorock
- Industrial Area/Airport

These District Centers need to be planned, developed and managed as Centers of activities with large employment of wide type and as mixed use development, standing second, next to CBD, in the hierarchy of nuclei; and meeting the day to day needs of the Constituent Division (Constituency) population including work, business, commercial, recreation, health and other needs. Development of multi-nuclei would bring a better relationship between home and work place, an ardent objective of city planning and development. It would minimize trip lengths and thus help in reducing and managing travel demand. It would result in a dispersed pattern of trips, reduce congestion and balance directional flows. It would optimize investments on transport system development and operations and promote system productivity. Many of the traffic problems would be minimized if not eliminated altogether. In short, **the envisaged urban structure is a means of promoting sustainable development of the city transport system**.

Rationalization of Land Use Pattern in each of the Divisions, reservation of land for the proposed District Centers and formulation and implementation of zoning regulations are key requirement for the success of the Multi-Nuclei Development Structure. An extent of 100 to 150 Ha of land needs to be reserved for the District Centers at each of the 6 locations.

3.7.4 Land Use Distribution in the Nairobi Metropolitan Region (NMR)

The Nairobi City lacks a clear planning strategy which has resulted in unplanned haphazard pattern of development, leading to over concentration of employment in the CBD and industrial area, resulting in traffic congestion and environmental pollution and rapid growth of informal settlements. The main problems faced by NRM are providing shelter, basic urban services and transportation infrastructure, improving its financial and institutional structure and management, and formulating environmental policies and programmes. The main issues which need immediate attention are: the interaction between the different administrative units of the metropolis at the primary stage; the growth in urban population concentrations and dependence upon employment availability and informal settlements and high incidence of urban poverty

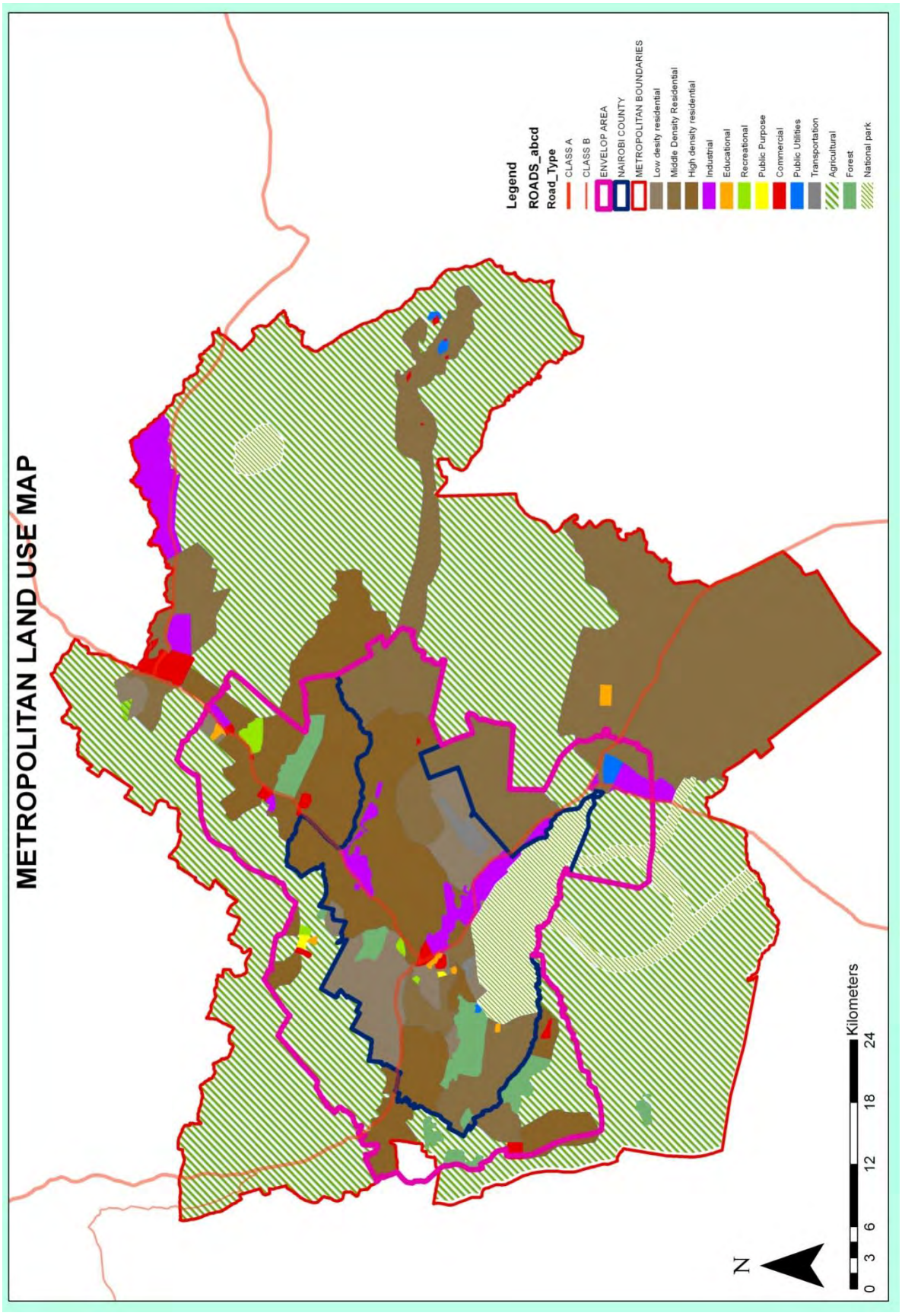
3.7.5 Land Use Analysis in the Nairobi Metropolitan Region (NMR)

Land Use is an integral component in any planning process. It helps in estimating and analysing the quantum of land put to various uses and also the quantum of land which can be utilized for future development. Land Use structures of the following Urban Centres of NMR, show that each Town has some portion of land under agricultural use which if required can be utilized for further development of Towns.

Another striking feature in Land Use distribution as shown in **Figure 3-9 on Page 3-23** is the fact that apart from Machakos, all other towns have very less recreational spaces. Green spaces are very essential for both the health of the Town and the Population.

Land use within the NMR is divided into seven (7) categories namely residential, commercial, industrial, recreational, educational, public purpose and public utility. This section examines the local authorities in the NRM based on the current economic potentials. The economic activities in an area are the benchmarks that define Land Use Distribution and trends in population growth and densities. It is important to understand the profile of each Local Authority in order to appreciate the push and pull factors that are attractive to job seekers.

Figure 3-9: The Map Showing the Land Use Distribution in the Metropolitan Region



3.8 Population Size and Growth in Metropolitan Regions

The projected population (2007) of the metropolitan region was estimated at 5,640,273 people. Table 3-4 below illustrates these projection based on the individual centres.

Table 3-4: Nairobi Metropolitan Region (NMR) - 2030: Population Forecast

No. of units	Spatial Units	2009	2030
1	Nairobi Metropolitan Region (NMR)	6,658,000	15,135,881
2	Core Nairobi	3,138,369	5,212,500
3	Total Urban within NMR	4,887,664	12,999,992
4	Outside Nairobi Metropolitan Region (ONMR)	3,519,631	9,923,381
a	Total Urban within NMR (without Nairobi)	1,749,295	7,787,492
b	Rural	1,770,336	2,,135,889
5a	NORTHERN METRO	1,786,879	4,990,641
	Urban	976,295	4,180,712
	Rural	810,584	809,929
5b	EASTERN METRO	1,045,440	2,969,576
	Urban	507,978	2,376,526
	Rural	537,462	593,050
5c	SOUTHERN METRO	687,312	1,963,164
	Urban	265,022	1,230,255
	Rural	422,290	732,910
5a	NORTHERN METRO		
I.	Ruiru	238,858	973,911
II.	Thika	139,853	570,232
III.	Limuru	104,282	425,196
IV.	Kiambu	88,869	362,351
V.	Juja	40,446	164,913
VI.	Kikuyu	234,053	954,320
VII.	Karuri	129,934	529,788
	sum	976,295	3,980,712
	Two new towns(with 100,000 in each)		200,000
	Total Urban	976,295	4,180,712
5b	Eastern Metro		
I.	Machakos	150,041	642,879
II.	Mavoko	139,380	597,199
III.	Kangundo/Tala	218,557	936,448
	Sum	507,978	2,176,526
	2 new towns(with 100,000 in each)		200,000
	Total Urban	507,978	2,376,526
5c	Southern Metro		
I.	Ngong	107,188	412,641
II.	Kitengela	58,167	223,925
III.	Ongata Rongai	40,178	154,673
IV.	Kiserian	18,096	69,664
V.	Kajiado	18,281	70,276
	Sum	241,910	931,179
	2 new towns(with 100,000 in each)		200,000
	Magadi		10,000
	Total Urban	241,910	1,141,179

Source: adopted, Ministry of Nairobi Metropolitan Development, 2008

The population is projected to grow to 7.6 million people (2012), 10.8 million (2022), and 14.3 million (2030) –Due to the rapid urbanization, it is estimated that by 2030, Kenya will be 61.5% predominantly urban population. It is also estimated that the Nairobi Metropolitan region will accommodate a bulk of this urban population. The Projected Populations in the NMR are given in Tables 3-5 and 3-6 on Page 3-25.

Table 3-5: Projected Population up to 2035

Year	1999	2009	2012	2017	2022	2027	2030	2035
Total National Population	28.7	36.3	41.5	47.2	52.9	58.7	62.1	68.4
Total Urban Population	5.4	9.0	12.3	16.9	23.1	31.7	38.2	41.2
Metropolitan Population	4.8	6.3	7.6	9.0	10.8	12.8	14.3	16.7
Urban % of National Population	18.8	24.8	29.6	35.8	43.7	54.0	61.5	63.8
NMR % of National Population	16.7	17.4	18.3	19.1	20.2	21.7	22.8	23.1
NMR % of Urban Population	88.5	70.3	61.7	53.3	46.3	40.2	37.0	35.2

Source: adopted, Ministry of Nairobi Metropolitan Development, 2008

3.8.1 Future Population Patterns-2035

The population growth within NMR will follow different growth rates. Two possibilities are considered, High Growth and Low Growth. Two assumptions are advanced to project the spatial distribution of population up to 2035. The first assumption is that population will concentrate in Nairobi City and thus development in the NMR will be Nairobi Centric. The second assumption envisages that future development in NMR will see population distributed to the areas outside Nairobi City in a Multi Centric Pattern of Growth.

3.8.2 High and Low Growth Nairobi Centric Development Scenario

Nairobi will continue to dominate as the primate city and this will see population and activities concentrate within it. A low growth rate will be witnessed in Nairobi (2.8%) due to urbanisation and uptake of modern urban culture and the average household size of 3. The outlying areas in the NMR will also witness low growth rates due to focus on Nairobi city. High growth rates might be achieved due to the anticipated vision 2030 and Nairobi Metro 2030 projects which will make Nairobi an attractive world class city. Table 3-6 below captures the growth options under this scenario within the metropolitan local authorities.

Table 3-6: Growth Options under High and Low Growth Nairobi Centric Development Scenario

Local Authority	Urban Pop. In 1999	Urban in 2009	Pop. Growth Rate	Growth Rate Low Growth Nairobi Centric	Growth Rate High Growth Nairobi Centric	Low 2020	Low 2030	Low 2035	High 2020	High 2030	High 2035
Nairobi city	2.1m	3.13m	3.93%	2.80%	5.00%	4.3m	5.6m	6.4m	5.4m	8.7m	11.2m
Kiambu	13,814	16,853	2.20%	1.20%	2.20%	19,216	21,651	22,981	21411	26616	29676
Limuru	4,141	5,100	2.30%	1.30%	2.30%	5,879	6,689	7,135	6,549	8,222	9,212
Karuri	19,746	26,574	3.40%	2.40%	3.40%	34,495	43,728	49,233	38,387	53,628	63,386
Kikuyu	4,100	6,562	6.00%	5.00%	6.00%	11,223	18,281	23,332	12,457	22,308	29,853
Thika	88,265	113,861	2.90%	1.90%	2.90%	140,053	169,057	185,739	155,935	207,538	239,428
Machakos	161,442	192,117	1.90%	1.0%.	1.90%	214,339	236,763	248,841	236,310	285,249	313,397
Kajiado	9028	13,903	5.40%	4.40%	5.40%	22,326	34,341	42,591	24,794	41,953	54,571
Ruiru	109,574	199,383	7.20%	8.20%	8.20%	428,382	858,576	1.2	474,447	1.04m	1.54m

These scenarios should be rationalised in light of:-

1. The influence of transport system changes and development within NMR – bypass, express ways, mass rapid transport system (light rail and bus rapid transit). These could see increased growth in the outlying areas and an influx of population to the NMR.

2. Effects of devolved system of government – if all counties develop their areas to meet high standards, they will retain a significant amount of local indigenous population and attract new immigrants. This would reduce pressure on NMR due to decreased rural – urban migration.

3.8.3 High and Low Growth Multi Centric Development Scenario

Under the Multi Centric Scenario, Nairobi will lose its dominance as the primate city and this will see increased growth and development of the outlying areas of the NMR. Two options for High Growth and Low Growth will take place as explained in the previous section, however the main difference is that concentration of population and activities will distributed to Multiple Centres of Development. Table 3-7 captures the growth patterns based on High and Low Growth Multi-Centric Development Scenario.

Table 3-7: Population Growth Patterns Within NMR Between 1999 - 2035

Local Authority	Urban Pop. In 1999	Urban in 2009	Pop. Growth Rate	Growth Rate Low Growth Nairobi Centric	Growth Rate High Growth Nairobi Centric	Low 2020	Low 2030	Low 2035	High 2020	High 2030	High 2035
Nairobi city	2.14m	3.13m	3.90%	2.80%	3.50%	4.25m	5.6m	6.4m	4.5m	6.4m	7.6m
Kiambu	13,814	16,853	2.20%	2.00%	3.20%	20,955	25,544	28,202	23,832	32,655	38,225
Limuru	4,141	5,100	2.30%	2.10%	3.30%	6,410	7,891	8,755	7,289	10,085	11,863
Karuri	19,746	26,574	3.40%	3.00%	4.40%	36,785	49,435	57,309	42,674	65,640	81,409
Kikuyu	4,100	6,562	6.00%	5.80%	7.00%	12,201	21,441	28,423	13,812	27,170	38,108
Thika	88,265	113,861	2.90%	2.50%	3.90%	149,395	191,239	216,369	173,439	254,274	307,878
Machakos	161,442	192,117	1.90%	1.50%	2.90%	226,304	262,635	282,933	263,109	350,178	403,985
Kajiado	9,028	13,903	5.40%	5.00%	6.40%	23,779	38,733	49,435	27,508	51,154	69,757
Ruiru	109,574	199,383	8.20%	7.80%	9.20%	455,506	965,344	1.4m	524973	1.26m	1.96m

3.9 Towns Within the Nairobi Metropolitan Region

3.9.1 Thika

The Municipal Council of Thika lies to the North of the City of Nairobi at a distance of 40 km along the Nairobi-Garissa highway. It is the second oldest Municipality within the Metropolitan Region after the City of Nairobi. Its hinterland constitutes large pineapple plantations to the North and to the East of the Town. It is an established Industrial Town with agro-processing industries and vehicle assembly. Although the Town lost the leather tannery, it is now home of food industries mainly flour milling and confectioneries. Former pasture lands to the East and South-West have been transformed into residential suburbs. The old town area of Thika Municipality remains the commercial and administrative hub. New institutions have located within the town mainly towards the East. The Town Center lies east of north of the Thika - Yatta Road and Nairobi-Garissa Road (A2). The Town has a good network of internal roads linking the central part of the residential areas. It has an established terminus for all public transport vehicles that bring traffic from the hinterland. River Chania, a tributary of the Athi River runs on the boundary of the Municipality to the North and its many water-falls is a tourist attraction. Further to the East is the Kilimanbogo Wildlife Sanctuary. The Nanyuki line of the Kenya Railways passes through the Town and the industrial area. Thika Town has both road and rail connections to Nairobi.

3.9.2 Kiambu

The Town is situated about 15kms north of Nairobi. Due to the proximity of the Town to the Nairobi Metropolitan Area, the Town has witnessed unprecedented growth during the past decade. The hinterland has many coffee plantations in and around besides a lot of educational institutions resulting in high volumes of student population. There is regular commutation between Kiambu and Nairobi as many residents of Kiambu are employed in various professions in Nairobi. The main road within Kiambu is highly congested as the shops and hawkers occupy the valuable road space. The Municipality has identified problems of congestion and unreliable public transport and is in the process of initiating remedial measures, but finances are a major constraint.

3.9.3 Machakos

Machakos is 40km to the North – East of the city of Nairobi off the Nairobi-Mombasa Highway. It serves a rich agricultural area in a hitherto marginal agro-ecological zone. The environs are home to subsistence farmers and there is little industrial activity. The only employment base is in the service sector mainly for the public institutions situated in the Town, e.g. colleges, research institutions, judiciary and little agro-processing at Mua Hills.

3.9.4 Ruiru

Ruiru is located about 20 km to the north of Nairobi City Centre on Thika Road. Ruiru Municipality was hived off from Kiambu County Council in the early 1990's to enable provision of services, for the rapidly growing population in the region between Nairobi and Thika. Ruiru borders Kiambu, Nairobi, Thika and Mavoko Municipalities. Ruiru Town is served by rail and road transport with direct linkage to Nairobi. Traffic from Ruiru is mostly to the Nairobi Metropolitan Region. Ruiru Town is home to a number of light industries that process farm produce.

3.9.5 Kikuyu

The Township is accessible from the main Nairobi-Nakuru Highway. It is approximately 20 km from Nairobi. The Township is also accessible through Kikuyu Road which is an extension of Ngong Road (C60) and also Dagoretti Road feeding also from Ngong Road. The Township Area is mainly a commercial area for the numerous industries that were set-up at the beginning of the 20th century. It has a small industrial base of steel rolling; re-cycled oil refining; cloth cutting factory etc. There is thriving horti-culture farming within the area. The catchment of many wetlands within the town council area forms the kitchen garden for the city of Nairobi. Other functions of the area are that of a dormitory town for Nairobi. The Southern bypass from Mombasa Road through Ngong Forest (when constructed) passes through the Town and joins Nakuru Road at Gitaru.

3.9.6 Limuru

Limuru is 40km to the north of the City of Nairobi. It is at the foot of the Aberdare Ranges to and the east of the Great Rift Valley. It is linked to the city of Nairobi through Limuru Road or Nakuru Road. Limuru Town Center is approximately 4kms off Nakuru Road or Kamirithu. The Municipality is in an agriculturally rich area with large tea plantations of multinational companies besides medium farms. It is also home to the shoe manufacturing factory (BATA). The area is also well endowed with dairy farming. The Township is the commercial center for the hinterland and that sustains its economic activities together with the shoe factory and dairy activities. The market is a transit point for vegetables that are grown as the hinterland as far as Githunguri and Kinale in Lari. The Limuru dairy has a milk processing plant in the Township. Apart from the

road links to the City of Nairobi through Nakuru and Limuru Roads and also from Kiambu through Nazarene Hospital, the railway line to Kisumu/Kampala traverses through the township. Railways have established major rail stop workshops in Limuru. There is regular commuting between Limuru and Nairobi, both by road and rail.

3.9.7 Karuri

Karuri is approximately 16 km from Kikuyu Township and 10 kms from Kiambu. There is no direct link between Karuri Town Center and the City of Nairobi, other than through Limuru Road and Ruaka. The main economic lifeline for Karuri area is subsistence farming as a kitchen garden for Nairobi City. To the North and West of the Township, are large tea and coffee estates. However, the latter are increasingly being replaced by housing development.

3.9.8 Kajiado

Kajiado is 80km to the South of the City of Nairobi. It is linked to Nairobi by the Nairobi-Namanga Road (A109) which branches out from Mombasa Road at Athi River. Kajiado Town is an administrative and service town for the greater Kajiado District. The administrative area together with the hospital is 3km to the south of the town centre. They are separated by a valley and Magadi rail line of the Kenya Railways. The valley is the main storm drainage for the Town flowing into Kajiado River. To the North of the centre along the Kajiado-Nairobi Road are the education institutions at a distance of 3km. The residential areas of the Municipality are to the north and north-west of the town centre. The main economic services within the Town Council area are mainly in services. There are no industries of any kind within Kajiado. The main corridor for public transport is along the Nairobi-Namanga Road.

3.9.9 Mavoko

The Municipal Council of Mavoko lies to the Southeast of the City of Nairobi. It has a common Boundary at Jomo Kenyatta International Airport. The Municipality is bordered to the East by Municipal Council of Machakos, to the North-East by Kangundo/Tala Town Council and to the South-West by Kitengela (Kajiado District).The industrial base of the Municipality located around Athi River, has continued to increase with new industries moving into the area. Other major industries include cement factories (3), meat processing (KMC) and the leather tannery.

Kitengela is a residential area for the Export Processing Zone (EPZ) and cement factories located within Mavoko Municipality.

The first EPZ was established in the Town in early 1980’s and is a beneficiary of AGOA. Population has increased tremendously due to the massive intrusion of the residential developments between the airport along Mombasa road, River Athi and in the Kitengela surroundings. The Town Center is along the Nairobi-Mombasa Highway and at the junction of Namanga-Nairobi highway. The Town Center also straddles the Nairobi-Mombasa Railway line. Recent proposals to locate the ICT centre at the Athi River (Mavoko) increases its significance as a major growth centre in NMR.

3.10 Challenges Facing Nairobi Metropolitan Region

Besides the opportunities and great development potential, Nairobi Metropolitan Region is faced with several challenges and threats. These include:

- Depressed performance in population and demographic indicators
- Inadequate Housing
- Depressed Economic and Employment Opportunities
- Inadequate Infrastructure and Utilities
- Poor Community and Social Services
- Inadequate Transportation Services
- Environmental Pollution
- Poor Safety and Insecurity Concerns
- Ineffective Legal and Governance Institutions.

3.10.1 Depressed Population & Demographic Indicators

Like other regions in Kenya, Nairobi Metropolitan Region is experiencing very rapid urban population growth. Unfortunately, the rate of population growth is not matched with the rate of economic growth. The result is decreased average per capita and house hold income. Nairobi metropolitan region is therefore faced with increased poverty (ministry of metropolitan Development, 2008). Nairobi has overall poverty index of 21% (KNBS 2007).

3.10.2 Inadequate Housing

Kenya continues to experience serious housing shortage. At the national level the housing supply is a low 35,000 units per year compared to a high demand of 150,000 units per year (ministry of National planning and vision 2030). The prolonged housing shortage has led to the proliferation of unplanned and informal settlements.

3.10.3 Depressed Economic Performance and Employment

The rapid population growth in the metropolitan region is not matched with increased economic performance. This is reflected in increased unemployment and prevalent poverty (ministry of Nairobi Metropolitan Development, 2008)

3.10.4 Inadequate Infrastructure & Utilities

The provision of infrastructure and utilities in Nairobi Metropolitan Region is poor. The household level of access to electricity, water supply and waste disposal is low. Although Nairobi has a higher level of access to services, electricity connection at 75% of households, piped water at 76% and sewer connection at 66% of households, the situation is worse in other smaller towns in the metropolitan region. The Metropolitan Region in 2010 water demand was estimated at 1,000,000 cubic metre per day compared to the low water supply of 400,000-500,000 cubic metre per day.

3.10.5 Poor Community and Social Services

Nairobi Metropolitan Region has inadequate community and social services to meet the rising demand. Schools and health centre facilities are not adequate. This is also true for open spaces, sports and recreation al facilities. It is also noted that even these facilities are available; they are ill-equipped and poorly maintained and managed. In 2003 for example, primary school net attendance ratio was 85% and secondary schools at 32%. The situation is lower and worse in other smaller Towns in the Metropolitan Region.

3.10.6 Inadequate Transportation Services

Nairobi has severely limited mobility and poor transport system. Kenya's car population is between 400-500,000 units, of which 30-40% are in Nairobi. This means that Nairobi has a high car dependence level compared to other towns. Within the City, regional commuter distances are in excessive 30-40 kilometre long. In the Metropolitan Region urban transport is expensive and poorly run. Public transport in Nairobi is mainly run by the private matatu sector. This sector is responsible for causing traffic congestion, accidents and flouting traffic rules.

3.10.7 Environmental Pollution

Nairobi City and its Metropolitan Region is experiencing increased environmental pollution. This is mainly due to inadequate disposal of wastewater and solid waste. The Metropolitan Region is also experiencing increased air pollution due to increased motor vehicle traffic and emission from processing factories in Nairobi, Thika, Mavoko, Ruiru, Kikuyu and Limuru.

3.10.8 Ineffective Legal & Government Institutions

Nairobi Metropolitan Region brings together 15 Local Authorities of different resource base and different political persuasion and is spread over four provinces: Nairobi, Central, Rift valley and Eastern.

Under the Local Government Act, all the Local Authorities report to the Ministry of Local Government. The Ministry of Nairobi Metropolitan Development has no mandate over the formation, administration and management of Local Authorities. The Local Authorities are not ready to forego their independence and report to the new Metropolitan Ministry. Other than Nairobi the other Local Authorities have extremely limited financial and technical capacity.

3.10.9 Way Forward for Metropolitan Region

In order to achieve effective development in Nairobi Metropolitan Region, the following measures have been undertaken

- Establishment of the Ministry of Nairobi Metropolitan Development
- Formulation of Policy Framework- Nairobi Metro 2030
- Preparation of Nairobi Metropolitan Spatial Plan
- Improvement of Housing
- Improvement of Economic and Investment Opportunities
- Improved Infrastructure and Utilities
- Provision of Better Community and Social Services
- Improved Transportation System
- Improved Safety and Security
- Effective Legal and Governance Institutions

Note: Metropolitan Regions are now a reality in developing countries. Nairobi Metropolitan Region presents great development potential in Kenya and the East African region. The metropolitan Region is set to be an international business and service hub.

4 Socio Economic Infrastructure, Study Area and Demographic Trends for Satellite Towns

4.1 Kikuyu Urban Centre

4.1.1 General

Kikuyu Urban Centre is located within Kikuyu District, about 20km West from Nairobi City. The Urban Centre covers an area of 136km^2.

Kikuyu is divided into 3 Locations (Civic Wards), namely Kikuyu, Kinoo and Kabete, (see Table 3.8).

Kikuyu is well served by the dual carriageway from Nairobi to Limuru with a link road from Naivasha Road.

Table 3.8: Administrative Units of Kikuyu

Name of Location	Name of Sub-Location
Kikuyu	Kikuyu Township Kari Nderi Kerwa Sigona
Kinoo	Uthiru Thogoto Kinoo Gitiba
Kabete	Lower Kabete Kibichiku Ruku Chura Muguga Nyathuna

Figure 2.4 on Page 2-13 shows Location of Kikuyu Urban Centre and its Administrative Units at Sub-Locations level.

4.1.2 Socio-Economic Infrastructure

There are reported to be 62 Primary Schools with an enrolment of 26,052 pupils and 29 Secondary Schools with an environment of 8,539 pupils in Kikuyu District.

The University of Nairobi, Kikuyu Campus is located in Kikuyu Town and has a student population of 1,200 resident students and 350 non-residents. The newly launched Thogoto PCEA Campus has a far much lesser population.

There are 2 main hospitals and 12 clinics within Kikuyu District.

There are 95 Business entities with Kikuyu ward leading in commercial activities followed by Kabete. The main Business Entities comprises of General Shops / Hardwares, Bars / Restaurant, Petrol Stations, Chemists etc.

There are 20 manufacturing / processing Industries which mainly comprise of meat processing, animal feed processing, steel fabricators, tea processing, sawmills, etc.

4.1.3 Study Area

The Terms of Reference did not explicitly identify the study area. After discussion held with the Client, it has been agreed that the Study Area for Kikuyu comprises of the Sub-locations which are in the Kikuyu District and within the agreed Envelope of Nairobi Water Demand. Sub-locations in the study area are namely, Kikuyu Township, Gitiba, Thogoto, Kinoo, Sigona, Gitaru, Uthiru, Kanyariri, Lower Kabete, Ruku, Kibichuku, Gathiga, Karura, Kirangariri, Muguga and Chura.

The Study Area for Kikuyu Urban Centre is shown on **Figure 2.4 on Page 2-13**.

4.1.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the Kikuyu District and Sub-location level to develop future population projection patterns in the Study Area. Sub-locations are classified as per Urban and Peri-Urban areas as the growth population rate is higher in Urban than Peri-urban areas.

Table 3.9 details the intercensal demographic data and intercensal growth rates, at District and Sub-location Levels.

Table 3.9: Intercensal Growth Rates in Sub-Locations Within Kikuyu Demand Area

	Census 1989			Census 1999				Census 2009			
Sub-Location	**Area (Km²)**	**Urban Pop.**	**Rural Pop.**	**Area (Km²)**	**Urban Pop.**	**Rural Pop.**	Growth Rate between 1989 & 1999	**Area (Km²)**	**Urban Pop.**	**Rural Pop.**	Growth Rate Between 1999 & 2009
Kinoo	6	7,965		8.4	14,450		6.14%	6.3	27,062		6.48%
Kikuyu Township	17	6,273		14.9	10,404		5.19%	14.2	16,302		4.59%
Uthiru	3	10,163		3.4	15,239		4.13%	3.5	24,295		4.77%
Sub-total Urban	**26**	**24,401**		**26.7**	**40,093**		**5.09%**	**24**	**67,659**		**5.37%**
Gitiba				10		3,785		10.0		5,028	
Gikambura	10		10,617	11.4		11,629	0.91%	11.9		13,612	1.59%
Thogoto	16		10,710	3.8		11,615	0.81%	6.9		16,120	3.33%
Sigona	6		5,664	6.4		7,596	2.98%	6.7		11,957	4.64%
Gitaru	4		7,407	5.3		9,599	2.63%	4.2		14,730	4.38%
Kanyariri	7		4,963	6.4		7,412	4.09%	6.6		11,027	4.05%
Lower Kabete	4		7,796	4.8		11,582	4.04%	5.0		14,531	2.29%
Ruku	3		4,127	3		5,472	2.86%	3.0		7,383	3.04%
Kibichiku	4		6,984	5.6		11,096	4.74%	5.1		16,126	3.81%
Gathiga	4		4,650	3.1		5,764	2.17%	3.3		6,826	1.71%
Karura	4		3,270	4.8		4,276	2.72%	4.5		5,598	2.73%
Kirangari	5		6,501	5.3		8,136	2.27%	4.8		9,743	1.82%
Muguga	6		6,988	6.2		9,647	3.28%	6.3		12,818	2.88%
Chura	3		1,554	2.9		2,668	5.55%	2.7		3,420	2.51%
Sub-total Rural	**76.00**		**81,231**	**79.00**		**110,277**	**3.10%**	**81.00**		**148,919**	**3.05%**
Total Study Area	102.0		**105,632**	105.7		**150,370**	**3.59%**	105.0		**216,578**	**3.72%**

The Sub-location of Kikuyu Township, Kinoo and Uthiru are fast growing Urban Centers. The growth has basically been fuelled by proximity to Nairobi and good Road Network and with many Nairobi Residents buying plots to construct own residential houses in Satellite Towns and moving away from City Estates. This trend is likely to continue in the next few years.

Demographic Trends

Between 1999 and 2009, the annual population growth was 5.3% in Urban areas and 3% in Peri-Urban areas. Growths rates will taper down to 4.4% for Urban and 1.8% for Peri-Urban by the Year 2035. These growths are comparable to previous studies[1]. The forecast population estimate for Kikuyu's Study Area is given in Table 3.10.

Table 3.10: Forecast Population Within the Kikuyu Study Area

Year	2009 Census	2010	2017	2020	2030	2035
Annual Growth Urban	**5.4%**	**5.20%**	**5.00%**	**4.80%**	**4.50%**	**4.40%**
Population - Urban	67,659	71,177	100,154	115,279	179,025	222,032
Annual Growth Peri-Urban	**3.0%**	**2.70%**	**2.50%**	**2.30%**	**2.00%**	**1.80%**
Population - Peri-Urban	148,919	152,940	181,797	194,632	237,255	259,391
Total Population	**216,578**	**224,117**	**281,951**	**309,911**	**416,280**	**481,423**
Total Pop. Growth Rate	**3.7%**	**3.5%**	**3.3%**	**3.2%**	**3.0%**	**3.0%**

Population Served

The proportion of total population within the Study Area presently served by the Water Service Provider is approximately 20% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 48% by year 2017 and 78% at the ultimate planning period, year 2035. Table 3.11 gives the population served within the planning horizon.

Table 3.11: Population Served by Water Service Provider

Year	2010	2017	2020	2030	2035
% of Urban Pop.	**40%**	**48%**	**58%**	**70%**	**78%**
Urban Population	28,471	48,074	66,862	125,317	173,185
% of Peri-urban Pop.	**10%**	**17%**	**21%**	**36%**	**40%**
Peri-urban Population	15,294	30,906	40,873	85,412	103,756
Total Population served	**43,765**	**78,979**	**107,735**	**210,729**	**276,941**
% of Pop. served	**20%**	**28%**	**35%**	**51%**	**58%**

Population Distribution

The 1999 Census gives a percentage of 33% of Low Class (Poor's) in the Kikuyu division. No data is available for the High and Medium Class. From site visits, it is estimated that the high income percentage is higher in the Kikuyu District than in Nairobi (10% in comparison to 6% for Nairobi City).

The proposed Income Group Distribution is as follows.

		Study Area	Nairobi City
• Low Income	-	33%	44%
• Medium Income	-	57%	50%
• High Income	-	10%	6%

[1]Water Supply and Sewerage Services Demand Forecast for Kikuyu Centre (2005-2030) – Uniconsult, 2007

This distribution will remain throughout the project life i.e. up to 2035.

4.2 Ruiru - Juja Urban Centres

4.2.1 General

Ruiru is a Municipality with headquarters at Ruiru Town. Ruiru Town is located about 20km from Nairobi City and covers an area of approximately 292km^2.

Ruiru is well served by the dual carriageway from Nairobi to Thika, which is currently under redevelopment to a wider highway.

Juja is a Division within Thika West District. Juja Town is located 30km from Nairobi (10km from Ruiru Town) on the Nairobi-Thika Highway.

Figure 2.5 on Page 2-16 shows Location of Juja Municipality and Juja Division and their Administrative Units at Sub-Locations level.

The Administrative Units of Ruiru Municipality and Juja Division are shown in Table 3.12:

Table 3.12: Administrative Units of Ruiru Municipality and Juja Division

	Name of Location	Name of Sub-Location
Ruiru Municipality	Gikumari	Gatongora
	Githurai	Kiuu Mwihoko Mwiki
	KahawaSukari	KahawaSukari KahawaWendani
	Theta	Theta
	Mugutha	Mugutha
	Ruiru	Gitothua Mukuyu Ruiru
Juja Division	Juja	Kiaora Milimani
	Kalimoni	Kalimoni
	Komo	Komo Weteithie

4.2.2 Socio-Economic Infrastructure

There are reported to be 67 Primary Schools with an enrolment of 30,360 pupils and 7 Secondary Schools with a population of 3,067 students in Ruiru Municipality and Juja Division.

Jomo Kenyatta University of Agriculture and Technology (JKUAT) is located in Juja. The University has a total student population of 7,931, of which 7,299 are resident students and 632 non-residents. There are 2 main hospitals and 40 clinics in Ruiru Municipality and Juja Division.

Biashara Ward of Ruiru Municipality is the main commercial hub in the study area. The main Business Entities comprise of General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists etc. There are 15 manufacturing / processing Industries. The Manufacturing / Processing Industries mainly comprise of knitwear, plastic manufacturing, pharmaceuticals and steel manufacturing.

4.2.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result of site visits made and discussions held with the Client, it has been agreed that the Study Area for Ruiru and Juja comprise of the following Sub-locations, which are within the agreed Envelope of Nairobi Water Demand Centre:

Ruiru Municipality	Juja Division
• Kiuu • Mwihoko • Mwiki • KahawaSukari • KahawaWendani • Theta • Mugutha • Gitothua • Mukuyu • Ruiru • Gatongora	• Kiaora • Milimani • Kalimoni • Komo • Weteithie

The Study Area for Ruiru Municipality and Juja Division is shown on **Figure 2.5 on Page 2-16**.

4.2.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the Sub-location level to develop future population projection patterns in the Study Area.

The following Table 3.13 details the intercensal demographic data and intercensal growth rates at Sub-Location Level.

Table 3.13: Intercensal Growth Rates in Sub-Locations within Ruiru Municipality and Juja Division

	Census 1989			Census 1999				Census 2009			
Sub-Location	Area (Km²)	Urban Pop.	Rural Pop.	Area (Km²)	Urban Pop.	Rural Pop.	Growth Rate 1989 & 1999	Area (Km²)	Urban Pop.	Rural Pop.	Growth Rate 1999 & 2009
Kiuu	150	14,887		149	56,389		14.25%	4.9	46,351		-1.94%
Mwihoko								25.8	11,934		
Mwiki								1.5	44,760		
Kahawa Sukari								4.4	8,744		
Kahawa Wendani								1.1	16,711		
Gitothua								20.7	16,186		
Mukuyu								21.4	1,897		
Ruiru	49	23,393		50.2	37,384		4.80%	8.6	41,596		1.07%
Gatongora								112.9	13,807		
Kiaora	45	11,379		46.1	19,117		5.33%	15.5	21,896		1.37%
Milimani								30.4	12,238		
Komo	40	3,532		38.9	4,256		1.88%	39.2	4,161		-0.23%
Theta	23	2,545		25.2	2,603		0.23%	31.1	23,134		24.42%
Sub-Total Urban	**307**	**55,736**		**309.4**	**119,749**		**7.95%**	**317.5**	**263,415**		**8.20%**
Mugutha	67		7,614	66.4		13,198	5.65%	59.5		15,887	1.87%
Weteithie								29.6		21,616	
Kalimoni	152		10,225	150.8		17,763	5.68%	121.3		19,861	1.12%
Sub-Total Rural	**219**		**17,839**	**217.2**		**30,961**	**5.67%**	**210.4**		**57,364**	**6.36%**
Total Study Area	**526.0**		**73,575**	**526.6**		**150,710**	**7.43%**	**527.9**		**320,779**	**7.85%**

Demographic Trends

Between 1999 and 2009, the annual population growth rate for the study area was 8.2% in urban areas and 6.36% in rural areas. In comparison, the national population growth rate between 1999 and 2009 was 3.0%.

Ruiru Municipality and Juja Division are fast growing Urban Centers in Kenya. The growth is fuelled by proximity to Nairobi and good Road Network. The current trend is that many Nairobi residents are buying plots to construct houses in Satellite Towns including Ruiru and Juja and moving away from City Estates. Many coffee plantations in the Ruiru and Juja area are being converted into residential estates. This, coupled with the on-going re-development of the Nairobi-Thika Highway traversing the area, will see the high growth rate sustained in the next decade.

The growth rate is expected to decrease after the next decade, with time to levels near the national average of 3% as the area approaches its land carrying capacity and gets saturated with development.

It is proposed that the following population growth rates be adopted for Ruiru and Juja for the Study Period, 2009 to 2035:

Table 3.14: Population Growth Rates Adopted for Ruiru Municipality and Juja Division

Type of Area	Proposed Population Growth Rate		
	2009 – 2020	2021 - 2030	2030 - 2035
Urban Areas	7.0%	5.5%	3.0%
Rural Areas	5.0%	3.5%	2.0%

Based on the above population growth rates, the Population Projection for the study area is given in Table 3.15.

Table 3.15: Forecast Population for Ruiru Municipality and Juja Division

Year	2009 Census	2010	2017	2020	2030	2035
Annual Growth Urban	**8.20%**	**7.00%**	**7.00%**	**6.30%**	**5.50%**	**4.20%**
Population - Urban	263,415	281,854	452,596	543,639	928,614	1,140,706
Annual Growth Rural	**6.36%**	**5.00%**	**4.50%**	**4.50%**	**3.50%**	**2.50%**
Population - Rural	57,364	60,232	81,968	93,539	131,946	149,284
Total Population	**320,779**	**342,086**	**534,564**	**637,178**	**1,060,559**	**1,289,990**
Pop. Growth Rate	7.8%	6.6%	6.6%	6.0%	5.2%	4.0%

Population Served

The proportion of total population within the Ruiru and Juja Study Area presently served by the Water Service Provider is approximately 20% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 28% by year 2017 and 60% at the ultimate planning period, year 2035.

Table 3.16 gives the population served within the planning horizon.

Table 3.16: Projected population served by Water Service Provider

Year	2010	2017	2020	2030	2035
% of Urban Pop. served	**20%**	**28%**	**35%**	**55%**	**60%**
Urban Population served	56,371	126,727	190,274	510,738	684,424
% of Rural Pop. served	**0%**	**10%**	**20%**	**40%**	**48%**
Rural Population served	0	8,197	18,708	52,778	71,657
Total Population served	**56,371**	**134,924**	**208,981**	**563,516**	**756,080**
% of Pop. served	**16%**	**25%**	**33%**	**53%**	**59%**

Population Distribution

The 1999 Census gives the percentage of Low Income Group in the Study Area as 28% of the population. No data are available for the High Income and Medium Income Groups. From site visits, it was estimated that the proportion of the High Income Group in the Study Area is comparable to Nairobi.

The proposed Population Distribution by Income Group for the Study Area in comparison to Nairobi City is as follows:

		Study Area	**Nairobi City**[2]
• Low Income	-	28%	44%
• Medium Income	-	68%	50%
• High Income	-	4%	6%

It is assumed that this distribution will remain constant throughout the project life i.e. up to 2035.

4.3 Kiambu Municipality

4.3.1 General

Kiambu Municipality is located within Kiambu East District. The Municipality covers an area of approximately 59km^2.KiambuTown is the headquarters of the Municipality. The Town is located about 20km north of Nairobi. Kiambu is well served by road link from Nairobi.

Figure 2.6 on Page 2-18 shows the Location of Kiambu Municipality its Administrative Units at Sub-Locations level.

The Administrative Units of Kiambu Municipality are shown in Table 3.17:

Table 3.17: Administrative Units of Kiambu East District

Name of Location	Name of Sub-Location
Wanguthu	Kanunga Ngegu
Kiambaa S/A	Kiambu Town Kiamumbi Thindigua
Ndumberi	Karunga Ndumberi
Riabai	Kihingo Riabai

[2]Water Supply and Sewerage Services Demand Forecast for Ruiru Municipality (2005-2030) – Uniconsult, 2007

4.3.2 Socio-Economic Infrastructure

It is reported that there is a total enrolment of 18,449 pupils in Primary Schools and 4,360 students in Secondary Schools and Tertiary Institutions within the Municipality, including the Kiambu Institute of Science and Technology.

There are 4 hospitals and about 45 health centres / dispensaries / nursing homes in the Municipality.

Commercial activities in the Municipality are concentrated in Kiambu Town. The main Business Entities comprises of General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists, etc. There are no major industries in the Municipality.

4.3.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result of site visits made and discussions held with the Client, it has been agreed that the Study Area is the whole of Kiambu Municipality which comprises of the following Sub-locations.

Table 3.18: Administrative Units Within the Study Area

Name of Location	Name of Sub-Location
Wanguthu	Kanunga Ngegu
Kiambaa S/A	Kiambu Town Kiamumbi Thindigua
Ndumberi	Karunga Ndumberi
Riabai	Kihingo Riabai

The Study Area for Kiambu Municipality is shown on **Figure 2.6 on Page 2-18.**

4.3.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the Sub-location level to develop future population projection patterns in the Study Area.

Table 3.19 details the intercensal demographic data and intercensal growth rates at Sub-Location Level.

Table 3.19: Intercensal Growth Rates in Sub-Locations within Kiambu Municipality

	Census 1989			Census 1999				Census 2009			
Sub-Location	**Area (Km²)**	**Urban Pop.**	**Peri-Urban Pop.**	**Area (Km²)**	**Urban Pop.**	**Peri-Urban Pop.**	**Growth Rate between 1989 & 1999**	**Area (Km²)**	**Urban Pop.**	**Peri-Urban Pop.**	**Growth Rate Between 1999 & 2009**
Kiambu Town	2	4,453		2.3	5,498			1.4	7,893		
Karunga				3.2	6,187			3.3	8,243		
Sub-Total Urban	**2**	**4,453**		**5.5**	**11,685**			**4.7**	**16,136**		**3.28%**
Ndumberi	8		13,417	4.9		11,794		4.9		13,715	
Riabai	8		12,605	3.3		10,330		4.1		14,359	
Ngegu				2.5		5,967		3.0		8,011	
Kanunga	7		8,994	5.2		5,824		5.0		5,854	
Kiamumbi				10.9		3,593		11.2		8,443	
Thindigua	31		7,575	21.0		7,075		20.5		10,903	
Kihingo				5.1		8,244		5.1		11,550	
Sub-Total Peri-Urban	**54**		**42,591**	**52.9**		**52,827**		**53.8**		**72,835**	**3.26%**
Total Study Area	**56**		**47,044**	**58.4**		**64,512**	**3.21%**	**58.5**		**88,971**	**3.27%**

Demographic Trends

Between 1999 and 2009, Urban and Peri-Urban areas experienced similar population growth i.e. 3.28% p.a. in Urban Areas and 3.26% p.a. in the Peri-Urban Areas. Overall growth rate for the whole area was 3.27%.

The annual population growth rate for Kiambu Municipality between 1999 and 2009 was comparable to the national population growth rate which was 3.0%.

The population growth rate in Kiambu Municipality is expected to decrease in the next decades due to a limited growth potential as the area is approaching its ultimate land carrying capacity.

It is proposed that the following population growth rates be adopted for Kiambu Municipality for the Study Period, 2009 to 2035:

Table 3.20: Population Growth Rates Adopted for Kiambu Municipality

Period	2009 – 2020	2021 - 2030	2031 - 2035
Population Growth Rate	3.3%	3.3%	2.8%

Based on the above population growth rates, the Population Projection for the study area is given in Table 3.21.

Table 3.21: Forecast Population for Kiambu Municipality

Year	2009 Census	2010	2017	2020	2030	2035
Annual Growth Urban	**3.28%**	**3.80%**	**3.80%**	**3.70%**	**3.60%**	**3.50%**
Population - Urban	16,136	16,749	21,746	24,250	34,539	41,021
Annual Growth Peri-Urban	**3.26%**	**3.00%**	**3.00%**	**3.00%**	**2.50%**	**2.50%**
Population - Peri-Urban	72,835	75,020	92,265	100,821	129,059	146,018
Total Population	**88,971**	**91,769**	**114,011**	**125,071**	**163,598**	**187,040**
Pop. Growth Rate	3.27%	3.1%	3.1%	3.1%	2.7%	2.7%

Population Served

The proportion of total population within the Kiambu Study Area presently served by the Water Service Provider is approximately 20% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 72% by year 2017 and 85% at the ultimate planning period, year 2035. Table 3.22 below gives the population served within the planning horizon.

Table 3.22: Projected Population Served by Water Service Provider

Year	2010	2017	2020	2030	2035
% of Urban Pop. served	**65%**	**72%**	**75%**	**80%**	**85%**
Urban Population served	10,887	15,657	18,187	27,631	34,868
% of Rural Pop. served	**25%**	**32%**	**38%**	**48%**	**53%**
Rural Population served	18,755	29,525	38,312	61,948	77,390
Total Population served	**29,642**	**45,182**	**56,499**	**89,579**	**112,258**
% of Pop. served	**32%**	**40%**	**45%**	**55%**	**60%**

Population Distribution

The District Development Plan (2008) gives the percentage of Low Income Group in Kiambu East District as 25% of the population. No data is available for the High Income and Medium Income Groups. From site visits, it was estimated that the proportion of the High Income Group in the Study Area is higher than that in Nairobi.

The proposed Population Distribution by Income Group for the Study Area is as follows:

		Study Area	**Nairobi City**
• Low Income	-	25%	44%
• Medium Income	-	65%	50%
• High Income	-	10%	6%

It is assumed that this distribution will remain constant throughout the project life i.e. up to 2035.

4.4 Karuri Town

4.4.1 General

Karuri Town is located in Karuri Sub-location, Kiambaa Location of Kiambu East District. The Town is located about 20km from Nairobi.

Figure 2.7 on Page 2-20 shows the Location of Karuri Town and its Administrative Units at Sub-Locations level.

The Administrative Units of Kiambu East District are shown in Table 3.23.

Table 3.23: Administrative Units of Kiambu East District

Name of Location	Name of Sub-Location
Cianda	Cianda Kawaida
Kihara	Gachie Karura Kihara Mahindi Wangunyu
Kiambaa	Karuri Kiambaa Muchatha Njiku Njoro
Ruaka	Ndenderu Ruaka
Wanguthu	Gathanga Kanunga Ngegu
Kamiti	Anmer Kamiti
Kiambaa S/A	Kiambu Town Kiamumbi Thindigua
Ndumberi	Karunga Ndumberi
Riabai	Kihingo Riabai
Tinganga	Kagongo Tinganga

4.4.2 Socio-Economic Infrastructure

There is 1 hospital and a number of health centres / clinics in Karuri Town.

Commercial activities in Karuri Town are dominated by small scale enterprises including General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists etc. There are no major industries in the Town.

4.4.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result of site visits made and discussions held with the Client, it has been agreed that the Study Area for Karuri comprises of the following Sub-locations, which are within the agreed Envelop of Nairobi Water Demand Centre:

Table 3.24: Sub-Locations within Agreed Envelop of Nairobi Water Demand Centre

Name of Location	Name of Sub-Location
Kihara	Gachie Karura Kihara Mahindi Wangunyu
Kiambaa	Karuri Kiambaa Muchatha Njiku Njoro Gathanga
Ruaka	Ndenderu Ruaka

The Study Area for Karuri Town is shown on **Figure 2.7 on Page 2-20.**

4.4.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the Sub-location level to develop future population projection patterns in the Study Area. A trend of 20 year growth has been considered as reasonable.

Table 3.25 details the intercensal demographic data and intercensal growth rates at Sub-Location Level.

Table 3.25: Intercensal Growth Rates in Sub-Locations within Karuri Demand Area

	Census 1989			Census 1999				Census 2009			
Sub-Location	**Area (Km²)**	**Urban Pop.**	**Rural Pop.**	**Area (Km²)**	**Urban Pop.**	**Rural Pop.**	**Growth Rate between 1989 & 1999**	**Area (Km²)**	**Urban Pop.**	**Rural Pop.**	**Growth Rate Between 1999 & 2009**
Gachie				2.6	12,069			2.7	22,443		
Kihara				2.8	10,535			2.7	14,434		
Karuri	9	14,962		3.9	9,886			4.0	11,436		
Muchatha	7	8,908		3.2	9,602			3.2	13,104		
Ndenderu				3.3	7,356			3.3	10,175		
Ruaka	7	9,419		4.2	6,175			4.1	13,488		
Sub-Total Urban	**23**	**33,289**		**20**	**55,623**		**5.27%**	**20**	**85,080**		**4.34%**
Kihara	8		12,839								
Karura	5		5,160	2.7		3,718		2.5		4,718	
Mahindi				2.6		2,970		2.5		3,896	
Wangunyu				2.4		3,072		2.6		3,576	
Kiambaa	5		6,457	4.2		7,873		4.3		7,907	
Njiku				5.9		9,269		6.2		11,317	
Njoro				3.0		2,918		3.0		4,910	
Gathanga	5		6,069	5.6		7,043		5.6		8,530	
Sub-Total Rural	**23**		**30,525**	**26.4**		**36,863**	**1.90%**	**26.7**		**44,854**	**1.98%**
Total Study Area	**46**		**63,814**	**46.4**		**92,486**	**3.78%**	**46.7**		**129,934**	**3.46%**

Demographic Trends

Between 1999 and 2009, the population in Urban areas grew at a rate of 4.34% while the population in the Rural areas grew at a rate of 1.98%. Overall growth rate for the whole area was 3.46%.

The population growth rate in the study area is expected to decrease in the next decades due to a limited growth potential as the area is approaching its ultimate land carrying capacity.

It is proposed that the following population growth rates be adopted for the study area:

Table 3.26: Population Growth Rates Adopted for Karuri Area

Type of Area	Proposed Population Growth Rate		
	2009 – 2020	2021 - 2030	2031 - 2035
Urban Areas	4.0% - 3.5%	3.5% - 3.2%	3.2%
Rural Areas	2.0%	1.8%	1.5%

Based on the above population growth rates, the Population Projection for the study area is given in Table 3.27.

Table 3.27: Forecast Population for Karuri Area

Year	2009 Census	2010	2017	2020	2030	2035
Annual Growth Urban	**4.34%**	**4.00%**	**3.80%**	**3.50%**	**3.20%**	**3.20%**
Population - Urban	85,080	88,483	114,879	127,369	174,526	204,296
Annual Growth Rural	**1.98%**	**2.00%**	**2.00%**	**2.00%**	**1.80%**	**1.50%**
Population - Rural	44,854	45,751	52,554	55,770	66,662	71,814
Total Population	**129,934**	**134,234**	**167,433**	**183,139**	**241,188**	**276,110**
Pop. Growth Rate	3.46%	3.3%	3.2%	3.0%	2.8%	2.7%

Population Served

The proportion of total population within the Karuri Study Area presently served by the Water Service Provider is approximately 20% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 37% by year 2017 and 65% at the ultimate planning period, year 2035. Table 3.28 gives the population served within the planning horizon.

Table 3.28: Projected population served by Water Service Provider

Year	2010	2017	2020	2030	2035
% of Urban Pop. served	**30%**	**37%**	**41%**	**55%**	**65%**
Urban Population served	26,545	42,505	52,221	95,989	132,792
% of Rural Pop. served	**0%**	**8%**	**13%**	**30%**	**40%**
Rural Population served	0	4,204	7,250	19,999	28,726
Total Population served	**26,545**	**46,710**	**59,471**	**115,988**	**161,518**
% of Pop. served	**20%**	**28%**	**32%**	**48%**	**58%**

Population Distribution

The District Development Plan (2008) gives the percentage of Low Income Group in Kiambu East District as 25% of the population. No data is available for the High Income and Medium Income Groups. From site visits, it was estimated that the proportion of the High Income Group in the Study Area is higher than that in Nairobi.

The proposed Population Distribution by Income Group for the Study Area is as follows:

		Study Area	Nairobi City[3]
• Low Income	-	25%	44%
• Medium Income	-	65%	50%
• High Income	-	10%	6%

It is assumed that this distribution will remain constant throughout the project life i.e. up to 2035.

4.5 Githunguri Town

4.5.1 General

Githunguri Town is located in Githunguri District. The District covers an area of approximately 174km^2.

Githunguri Town is the main Urban Centre in the District. The Town is located in Githunguri Sub-Location, which covers an area of approximately 15km^2.

The area of focus under this study is Githunguri Sub-Location, which incorporates Githunguri Town and makes up the main urbanised area in Githunguri District.

Figure 2.8 on Page 2-23 shows the Location of Githunguri Town and its Administrative Units at Sub-Locations level.

4.5.2 Socio-Economic Infrastructure

At present (2010), it is reported that Githunguri Sub-Location has a total of 5,545 students and 139 staff in Nursery, Primary and Secondary Schools.

There is 1 Hospital and about 10 Health Centres and Clinics in Githunguri Town.

Commercial activities in Githunguri Town are dominated by small scale enterprises comprising of General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists etc. The main industry is a milk dairy.

4.5.3 Study Area

The Terms of Reference did not explicitly identify the study area. Following discussions with the Client, it has been agreed that the Study Area to be considered under this Study is Githunguri Sub-Location (which incorporates Githunguri Town and makes up the main urbanised area in Githunguri District.

The Study Area for Githunguri Town is shown on **Figure 2.8 on Page 2-23**.

[3]Water Supply and Sewerage Services Demand Forecast for Nairobi Municipality (2005-2030) – Uniconsult, 2007

4.5.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the Sub-location level to develop future population projection patterns in the Study Area. A trend of 20 year growth has been considered as reasonable.

Table 3.29 details the intercensal demographic data and intercensal growth rates at Sub-Location Level.

Table 3.29: Population and Intercensal Growth Rates for Githunguri Sub-Location

Year	Population	Intercensal Growth Rate
1989	10,359	1989 - 1999 - 3.0%
1999	13,915	
2009	17,722	1999 - 2009 - 2.45%

Demographic Trends

Analysis of census data for Githunguri Sub-Location shows that the intercensal growth rates for the Sub-location have progressively declined in the last two census periods from 3.0% in 1989-1999 to 2.45% in 1999-2009.

The trend of declining growth rate is expected to continue over the next decades due to limited growth potential in the area and as the Town gets saturated with development.

It is proposed that the following population growth rates be adopted for Githunguri Sub-location for the Study Period, 2009 to 2035.

Table 3.30: Proposed Population Growth Rates to be adopted for Githunguri Sub-Location

Period	2009 – 2020	2021 - 2030	2031 - 2035
Population Growth Rate	2.4%	2.2%	2.0%

Based on the above population growth rates, the Population Projection for the study area is given in Table 3.31.

Table 3.31: Forecast Population for Githunguri Sub-Location

	2009 Census	2010	2017	2020	2030	2035
Annual Growth Urban	**2.45%**	**2.40%**	**2.30%**	**2.20%**	**2.00%**	**2.00%**
Total Population	**17,722**	18,147	21,279	22,714	27,688	30,570

Population Served

The proportion of total population within the Githunguri Demand Area presently served by the Water Service Provider is approximated at full coverage according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will remain at full coverage within the planning horizon.

Population Distribution

The 2008 District Development Plan for the larger Kiambu District which at the time included Githunguri indicates that 25% of the population is living below the poverty line (Low Class). No data are available for the High Income and Medium Income Groups. From site visits, it was

estimated that the proportion of the High Income Group in the Study Area is comparable to that in Nairobi.

The proposed Population Distribution by Income Group for the Study Area is as follows:

		Study Area	Nairobi City
• Low Income	-	25%	44%
• Medium Income	-	73%	50%
• High Income	-	2%	6%

It is assumed that this distribution will remain constant throughout the project life i.e. up to 2035.

4.6 Mavoko Municipality

4.6.1 General

The Mavoko Municipality Water Supply Centre covers Mavoko Municipality in the recently created Athi River District and Kitengela town in Kajiado North District. The Mavoko Municipality hosts Athi River and Mlolongo towns which are the main urban centres and neighbours Kitengela under Kajiado County Council. The trio has been put together due to their proximity to one another and to Nairobi, except Makutano (Kyumvi) which is supplied from Nol Turesh pipeline and has independent water supply system.

The area falls within the jurisdiction of Mavoko Water and Sanitation Company within Tanathi Water Services Board and borders Nairobi Province to the North, Kajiado District to the East and South and Machakos District to the West. Nairobi National Park and Kitengela Conservancy Area forms the Eastern boundary of the Study Area.

Figure 2.9 on Page 2-26 shows the Location of Mavoko Municipality and its Administrative Units at Sub-Locations level.

There are 7nr administrative units (sub-locations) in Machakos and Kajiado North Districts under which the Study Area for the three urban areas falls. These administrative units are as listed in Table 3.32.

Table 3.32: Administrative Units in the Study Area

Area	Sub-Location
Mlolongo	Syokimau Katani
Athi River	Athi River North Ngelani Athi River Township
Kitengela	Kitenkela

4.6.2 Socio-Economic Infrastructure

The study area consists of the fastest growing urban centres in the country as a consequence of 'burst' overflows of industrialization and human settlement in Nairobi city. The busy Nairobi-Mombasa highway and Namanga road cross the study area while the Nairobi National Park defines the western boundary of the study area. Approximately the study coverage area is 240 km^2 and falls within the Arid and Semi-Arid Lands (ASALS) of Kenya.

The study area education institutions comprise of public primary and secondary schools, training colleges and institutes. According to Machakos District Development Plan, the number of Primary School going population stands at 22% while Secondary School going population is 10% of the total population. The Kajiado District Development Plan gives 22% as Primary School going while 9% of the total population as Secondary School.

The study area does not have a major national, regional or district hospital. It has been reported that the existing health facilities comprise of 15 health centres, dispensaries and clinics which are both public and privately operated.

The commercial activities within the study area include shops, offices, banks, hotels and restaurants. At present most of the commercial activities are located along the major highways and within Athi River Town Centre. It is however envisaged that the commercial centres will be mixed with residential areas in future

The study area has the highest industrialization potential in the country courtesy to vast land currently under ranches which is gradually changing use from ranching to industrial and commercial areas. Currently there are approximately 150 light and heavy industries in the area which include 4nr. Cement factories, the Export Processing Zone Complex Factories, Kenya Meat Commission, Mabati Rolling Mills among others.

4.6.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result site visits have been made, discussions held with the Client and agreed that the Study Area for Mavoko Municipality comprise of the towns of Mlolongo, Athi River and Kitengela which are within the Envelope of Nairobi Water Demand and in the following sub-locations in Machakos and Kajiado North Districts:

- Syokimau
- Katani
- Athi River North
- Ngelani
- Athi River Township
- Kitenkela

The Study Area for Mavoko Municipality is shown on **Figure 2.9 on Page 2-26**.

4.6.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the study area Sub-location level to develop future population projection patterns.

Table 3-3 details the intercensal demographic data and intercensal growth rates, at Sub-location Level:

Table 3.33: Intercensal Growth Rates within Mavoko Municipality Area

Area	Sub-location Name	1989 Census		1999 Census			2009 Census			Population within Study Area	
		Area (Km²)	Total Population	Area (Km²)	Total Population	Growth Rate Between 1999 & 2009	Area (Km²)	Total Population	Growth Rate Between 1999 & 2009	Urban	Peri-Urban
Mlolongo	Syokimau			38.5	5,984		37.3	42,154	21.56%	35,831	6,323
	Katani			41.7	1,401		40.8	9,983	21.70%	6,489	3,494
	Sub-total			**80.2**	**7,385**		**78.1**	**52,137**	**21.58%**	**42,320**	**9,817**
Athi River	Athi River North			37.8	1,362		38.3	1,572	1.44%	-	1,572
	Ngelani			94.7	4,110		95.0	3,397	-1.89%	1,783	764
	Athi River Township			38.1	21,696		39.5	49,721	8.65%	47,235	2,486
	Sub-total			**170.6**	**27,168**		**172.8**	**54,690**	**7.25%**	**49,018**	**4,822**
Kitengela	Kitenkela	386	6,548	192	12,648	6.80%	89.2	27,545	8.09%	17,353	7,437
	Sub-total	**386**	**6,548**	**192**	**12,648**	**6.80%**	**89.2**	**27,545**	**8.09%**	**17,353**	**7,437**
TOTAL		**386**	**6,548**	**442.8**	**47,201**	**21.84%**	**340.1**	**134,372**	**11.03%**	**108,692**	**22,077**

Part of the sub-location areas within the study area do not fully fall within the study area, the population within the study area has been estimated by using the population data up to Enumeration Area level. This has also been used to estimate the population within urban areas which has been done by overlaying the sub-location boundaries on projected raster images before using the EA boundaries to estimate the urban and peri-urban populations.

The urbanization trend within the study area has been influenced by its proximity to Nairobi and the high industrialization potential of the area providing huge employment opportunities. It is also suitable as a residential area for the working class in Nairobi with people purchasing plots in the area to construct own residential / rental houses and moving away from City Estates. This trend is likely to continue in the next 25 of years.

Demographic Trends

The intercensal growth rate between 1989/1999 and 1999/2009 indicates an average annual growth rate of 6.8% and 10.82% respectively for the whole area. The District Development Plan indicates a demographic growth rate of 2.56%, between year 2008 and year 2012. The average growth rate for each of the areas studied for 1999/2009 is 21.6% for Mlolongo, 7.2% for Athi River and 8.1% for Kitengela area.

For the purposes of this Study, the adopted population growth rate for the Study Area has been taken differently for the three urban centres for urban and peri-urban areas. It is anticipated that the present growth rates are at their peak and will start declining towards year 2035.

The forecasted population estimates and the growth rates for the Mlolongo, Athi River and Kitengela areas are given in **Table 3.34**.

Table 3.34: Forecast Population

Area	Year	2009 Census	2010	2017	2020	2030	2035
Mlolongo	Annual Urban Growth		**18.0%**	**14.0%**	**10.0%**	**7.0%**	**4.8%**
	Urban Population	42,320	49,937	124,957	166,318	327,172	413,602
	Annual Peri-urban Growth		**5.00%**	**4.00%**	**3.00%**	**2.70%**	**2.70%**
	Peri-urban Population	9,817	10,308	13,565	14,822	19,347	22,104
	Sub-Total Population	**52,137**	**60,245**	**138,521**	**181,140**	**346,519**	**435,706**
	Pop. Growth Rate	21.6%	15.6%	12.6%	9.4%	6.7%	4.7%
Athi River	Annual Urban Growth		**6.0%**	**5.0%**	**4.0%**	**3.0%**	**3.0%**
	Urban Population	49,018	51,959	73,112	82,241	110,525	128,129
	Annual Peri-urban Growth		**2.00%**	**1.80%**	**1.50%**	**1.50%**	**1.30%**
	Peri-urban Population	4,822	4,919	5,573	5,828	6,763	7,214
	Sub-Total Population	**53,841**	**56,878**	**78,685**	**88,069**	**117,289**	**135,344**
	Pop. Growth Rate	7.2%	5.6%	4.7%	3.8%	2.9%	2.9%
Kitengela	Annual Urban Growth		**7.0%**	**6.0%**	**5.0%**	**4.0%**	**3.0%**
	Urban Population	17,353	18,568	27,920	32,320	47,842	55,462
	Annual Peri-urban Growth		**2.00%**	**2.00%**	**1.80%**	**1.50%**	**1.50%**
	Peri-urban Population	7,437	7,586	8,714	9,193	10,669	11,493
	Sub-Total Population	**24,791**	**26,154**	**36,633**	**41,513**	**58,511**	**66,955**
	Pop. Growth Rate	8.1%	5.5%	4.9%	4.3%	3.5%	2.7%
Total Population		**130,768**	**143,278**	**253,840**	**310,722**	**522,319**	**638,005**
Total Pop. Growth Rate		**11.0%**	**9.6%**	**8.5%**	**7.0%**	**5.3%**	**4.1%**

Population Served

The proportion of total population within the Study Area presently served by the Water Service Provider is approximately 23% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 28% by year 2017 and 60% at the ultimate planning period, year 2035. Table 3.35 gives the population served within the planning horizon.

Table 3.35: Projected population Served by Water Service Provider

Area	Year	2010	2017	2020	2030	2035
Mlolongo	% of Urban Pop.	**15%**	**25%**	**31%**	**55%**	**60%**
	Urban Population	7,491	31,239	51,558	179,945	248,161
	% of Peri-urban Pop.	**5%**	**10%**	**20%**	**40%**	**45%**
	Peri-urban Population	515	1,356	2,964	7,739	9,947
	Sub-Total Pop. Served	**8,006**	**32,596**	**54,523**	**187,684**	**258,108**
	% of Pop. served	**13%**	**24%**	**30%**	**54%**	**59%**
Athi River	% of Urban Pop.	**35%**	**40%**	**45%**	**58%**	**65%**
	Urban Population	18,186	29,245	37,009	64,105	83,284
	% of Peri-urban Pop.	**5%**	**15%**	**20%**	**40%**	**50%**
	Peri-urban Population	246	836	1,166	2,705	3,607
	Sub-Total Pop. Served	**18,432**	**30,081**	**38,174**	**66,810**	**86,891**
	% of Pop. served	**32%**	**38%**	**43%**	**57%**	**64%**
Kitengela	% of Urban Pop.	**25%**	**30%**	**40%**	**50%**	**55%**
	Urban Population	4,642	8,376	12,928	23,921	30,504
	% of Peri-urban Pop.	**5%**	**10%**	**20%**	**35%**	**40%**
	Peri-urban Population	379	871	1,839	3,734	4,597
	Sub-Total Pop. Served	**5,021**	**9,247**	**14,767**	**27,655**	**35,101**
	% of Pop. served	**19%**	**25%**	**36%**	**47%**	**52%**
Total population Served		**31,459**	**71,924**	**107,464**	**282,149**	**380,101**
% of Population served		**22%**	**28%**	**35%**	**54%**	**60%**

Population Distribution

The 2008 to 2012 Physical Development Plan for the larger Machakos and Kajiado District indicates that 43% and 33% respectively of the urban population is living below the poverty line (Low Class). No data is available for the High Class and Middle Income Groups.

From site visits made to the area, it is estimated that the Income Group Distribution for Mlolongo, Athi River and Kitengela areas is the same as in Nairobi as shown in previous studies.

Table 3.36 shows the proposed population distribution for Mavoko Municipality Water Supply Demand Centre.

Table 3.36: Income Group Distribution for the Study Area

Type of Housing		
Low Class	**Middle Class**	**High Class**
39.2%	56.5%	4.3%

The above population distribution is anticipated to remain the same throughout the Project design life i.e. up to year 2035.

4.7 Ongata Rongai / Ngong / Kiserian Urban Centres

4.7.1 General

The towns of Ngong, Ongata Rongai and Kiserian fall under Kajiado North District in Kajiado County, Rift Valley Province under Tanathi Water Services Board area of jurisdiction. The towns are located to the South of Nairobi City.

There are 21 administrative units (sub-locations) all in Kajiado North District and Ngong Division under which the study areas for the three towns fall. The administrative units are listed in Table 3.37.

Table 3.37: Administrative Units in the Study Area

Area	Sub-Location
Ngong	- Ngong Township
	- Kerarapon
	- Bulbul
	- Olepolos
	- Oloolua
	- Upper Matasia
	- Olkeri
Ongata Rongai	- Ongata Rongai
	- Olekasasi
	- Lower Matasia
	- Embakasi
	- Lower Nkoroi
	- Upper Nkoroi
	- Kandisi
	- Kware
	- Mosoi Range
Kiserian	- Naserian
	- Olchoro-onyore
	- Olteyani
	- Kahuho
	- Oloosurutia

4.7.2 Socio-Economic Infrastructure

There are reported to be 8 Primary and 19 Secondary Schools with an enrolment of 5,948 and 1,478 students respectively in Ngong area while in Ongata Rongai area there are 5 Primary and 5 Secondary Schools with a total enrolment of 4,085 and 691 students respectively. In Kiserian area there are 6 Primary and 1 Secondary Schools with an enrolment of 4,096 and 166 students respectively.

In Ngong, Ongata Rongai and Kiserian areas, there are 16, 10 and 5 Health Centres respectively. There are no major national, regional or district hospital in the area.

The main Business Entities in the study area comprise of General Shops / Hardware, Bars / Restaurants, Petrol Stations, Chemists etc. There are no Manufacturing / Processing Industries within the study area.

4.7.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result site visits have been made, discussions held with the Client and agreed that the Study Area for Ngong and Ongata Rongai towns comprise of Ngong Division, limited to the mandated area of supply by the water service provider and the developed area between Nairobi City boundary and Ngong Hills.

Figure 2.10 on Page 2-30 shows the Study area Boundary.

4.7.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the study area Sub-location level, to develop future population projection patterns. A trend of 20 year growth has been considered.

Table 3.38 details the intercensal demographic data and intercensal growth rates, at Sub-location Level:

Table 3.38: Intercensal Growth Rates in Study Area Sub

Area	Sub-location Name	1989 Census		1999 Census			2009 Census			Urban Satus	
		Area (Km²)	Total Pop.	Area (Km²)	Total Pop.	Growth Rate 1989-1999	Area (Km²)	Total Pop.	Growth Rate 1999-2009	Urban	Peri-Urban
Ngong	Ngong Township	37.0	8,775	10.9	12,110	3.27%	8.5	18,091	4.10%	18,091	-
	Kerarapon						3.9	3,004		1,051	1,953
	Bulbul	25.0	8,260	2.3	8,591	0.39%	2.5	13,637	4.73%	13,637	-
	Olepolos						3.2	8,564		5,138	3,426
	Oloolua			13.1	7,174		9.7	8,549	1.77%	4,275	4,275
	Upper Matasia	39.0	8,231	21	6,873	-1.79%	17.4	7,817	1.30%	704	6,332
	Olkeri	24.0	6,417	23.3	11,131	5.66%	7.9	4,104	-9.50%	410	3,694
	Sub-total	**125.0**	**31,683**	**70.6**	**45,879**	**3.77%**	**53.1**	**63,766**	**3.35%**	**43,306**	**19,678**
Ongata Rongai	Ongata Rongai	39.0	24,058	5.5	16,264	-3.84%	5.8	40,178	9.47%	40,178	-
	Olekasasi						10.8	4,500		2,250	2,250
	Lower Matasia						6.4	4,419		442	3,977
	Embakasi			4.9	3,771		3.7	7,021	6.41%	702	6,319
	Lower Nkoroi						6.8	6,272		2,509	3,763
	Upper Nkoroi						5.2	4,408		1,322	3,086
	Kandisi			5.2	21,749		2.6	4,881	-13.88%	4,637	244
	Kware						1.3	22,193		22,193	-
	Mosoi Range						2.3	21,311		19,180	2,131
	Sub-total	**39.0**	**24,058**	**15.6**	**41,784**	**5.68%**	**44.9**	**115,183**	**10.67%**	**93,413**	**21,770**
Kiserian	Naserian						11.3	14,045		11,236	2,809
	Olchoro-onyore						37.4	4,885		244	2,198
	Olteyani						17.2	4,899		-	1,470
	Kahuho						6.1	6,325		4,744	1,581
	Oloosurutia						3.7	8,296		6,222	2,074
	Sub-total						**75.7**	**38,450**		**22,446**	**10,132**
Total Population		**164.0**	**55,741**	**86.2**	**87,663**	**4.63%**	**173.7**	**217,399**	**9.51%**	**159,165**	**51,580**

Part of the sub-location areas within the study area do not fully fall within the study area, the population within the study area has been estimated using the population data up to Enumeration Area (EA) level. This has also been used to estimate the population within urban areas which has been done by overlaying the sub-location boundaries on projected raster images before using the EA boundaries to estimate the urban and peri-urban populations. Table 3.38 shows the population at sub-location level within the study area and the urban and peri-urban population based on 2009 census.

The urbanization trend within Ngong, Ongata Rongai and Kiserian areas has been fuelled by their proximity to Nairobi, making these areas to be suitable residential areas for the working class in Nairobi with people purchasing plots in the area to construct own residential / rental houses and moving away from City Estates. This trend is likely to continue in the next 25 years though expected to slow down after 10 years.

Demographic Trends

The intercensal growth rate between 1989/1999 and 1999/2009 indicates an average annual growth rate of 5.3% and 6.2% respectively for all the areas. The District Development Plan for Ngong Division indicates a demographic growth rate of 5.1%, between year 2009 and 2010 which is considered too low for the three towns.

For the purposes of this Study, the adopted population growth rate for the Study Area has been taken differently for the three urban centres for urban and peri-urban areas. It is anticipated that the present growth rates are at their peak and will start declining towards year 2035.

The forecasted population estimates and the growth rates for the Ngong, Ongata Rongai and Kiserian areas are given in Table 3.39:

Table 3.39: Forecast Population

Area	Year	2009 Census	2010	2017	2020	2030	2035
Ngong	Annual Urban Growth		**4.80%**	**4.50%**	**4.00%**	**3.20%**	**3.20%**
	Urban Population	43,306	45,385	61,763	69,475	95,197	111,435
	Annual Peri-urban Growth		**2.70%**	**2.50%**	**2.50%**	**2.00%**	**2.00%**
	Peri-urban Population	19,678	20,209	24,023	25,870	31,535	34,817
	Sub-Total Population	**62,984**	**65,594**	**85,785**	**95,344**	**126,732**	**146,252**
	Pop. Growth Rate	3.3%	4.1%	3.9%	3.6%	2.9%	2.9%
Ongata Rongai	Annual Urban Growth		**8.50%**	**6.50%**	**5.50%**	**4.20%**	**3.80%**
	Urban Population	93,413	101,353	157,501	184,945	279,074	336,284
	Annual Peri-urban Growth		**2.70%**	**2.50%**	**2.50%**	**2.00%**	**2.00%**
	Peri-urban Population	21,770	22,358	26,576	28,620	34,887	38,518
	Sub-Total Population	**115,183**	**123,711**	**184,078**	**213,565**	**313,961**	**374,802**
	Pop. Growth Rate	10.7%	7.4%	5.8%	5.1%	3.9%	3.6%
Kiserian	Annual Urban Growth		**5.20%**	**4.80%**	**4.50%**	**3.50%**	**3.50%**
	Urban Population	22,446	23,613	32,786	37,414	52,776	62,681
	Annual Peri-urban Growth		**2.70%**	**2.50%**	**2.50%**	**2.00%**	**2.00%**
	Peri-urban Population	10,132	10,406	12,369	13,320	16,237	17,927
	Sub-Total Population	**32,578**	**34,019**	**45,155**	**50,734**	**69,013**	**80,609**
	Pop. Growth Rate	5.2%	4.4%	4.1%	4.0%	3.1%	3.2%
Total Population		**210,746**	**223,324**	**315,018**	**359,643**	**509,706**	**601,663**
Total Pop. Growth Rate			**6.0%**	**5.0%**	**4.5%**	**3.5%**	**3.4%**

Population Served

The proportion of total population within Ngong, Ongata Rongai and Kiserian Study Area presently served by the Water Service Provider is approximately 7% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 15% by year 2017 and 50% at the ultimate planning period, year 2035. Table 3.40 gives the population served within the planning horizon.

Table 3.40: Projected population served by Water Service Provider

Area	Year	2010	2017	2020	2030	2035
Ngong	% of Urban Pop.	**10%**	**20%**	**30%**	**50%**	**55%**
	Urban Population	4,538	12,353	20,842	47,598	61,289
	% of Peri-urban Pop.	**5%**	**10%**	**20%**	**40%**	**50%**
	Peri-urban Population	1,010	2,402	5,174	12,614	17,409
	Sub-Total Pop. served	**5,549**	**14,755**	**26,016**	**60,212**	**78,698**
	% of Pop. served	**8%**	**17%**	**27%**	**48%**	**54%**
Ongata Rongai	% of Urban Pop.	**8%**	**13%**	**18%**	**43%**	**48%**
	Urban Population	8,108	20,475	33,290	120,002	161,416
	% of Peri-urban Pop.	**0%**	**10%**	**20%**	**40%**	**45%**
	Peri-urban Population	0	2,658	5,724	13,955	17,333
	Sub-Total Pop. served	**8,108**	**23,133**	**39,014**	**133,957**	**178,750**
	% of Pop. served	**7%**	**13%**	**18%**	**43%**	**48%**
Kiserian	% of Urban Pop.	**10%**	**20%**	**30%**	**55%**	**60%**
	Urban Population	2,361	6,557	11,224	29,027	37,609
	% of Peri-urban Pop.	**0%**	**10%**	**20%**	**40%**	**45%**
	Peri-urban Population	0	1,237	2,664	6,495	8,067
	Sub-Total Pop. served	**2,361**	**7,794**	**13,888**	**35,522**	**45,676**
	% of Pop. served	**7%**	**17%**	**27%**	**51%**	**57%**
Total population Served		**16,019**	**45,682**	**78,919**	**229,691**	**303,123**
% of Population served		**7%**	**15%**	**22%**	**45%**	**50%**

Population Distribution

The 2008 to 2012 Physical Development Plan for the larger Kajiado District indicates that a percentage of 33% of the urban population is living below the poverty line (Low Class). No data is available for the High Class and Middle Income groups.

From site visits, it is estimated that the Income Group Distribution for Ngong, Ongata Rongai and Kiserian areas is the same as in Nairobi as shown in previous studies.

Table 3.41 shows the adopted Income Group Distribution for Ngong, Ongata Rongai and Kiserian Water Supply Demand Centre.

Table 3.41: Income Group Distribution for the Study Area

Type of Housing		
Low Class	**Middle Class**	**High Class**
39.2%	56.5%	4.3%

The above population distribution is anticipated to remain the same throughout the Project life i.e. up to year 2035.

4.8 Thika Municipality

4.8.1 General

Thika is a Municipality with headquarters at Thika Town. The Municipality is located in Thika West Division of Thika West District, with an area of approximately 92km$^{2.}$

Thika is located about 40km from Nairobi City and served by the dual carriageway from Nairobi, which is currently under redevelopment to a wider highway.

Figure 2.11 on Page 2-32 shows the location of Thika Municipality and the Administrative Units in the Study Area at Sub-Location level. The Administrative Units of Thika Municipality are shown in Table 3.42:

Table 3.42: Administrative Units of Thika Municipality

Name of Location	Name of Sub-Location
Biashara	Karimenu Majengo Township Umoja
Makongeni	Kamenu Kianjau Komu

4.8.2 Socio-Economic Infrastructure

According to the District Education Office, the 2010 population in the Education Sector, including students and teachers, is 29,112 in Primary Schools and 7,278 in Secondary Schools respectively.

The main Tertiary Education Institutions are two Universities, Mt. Kenya University and Grets a University, with a combined enrolment of approximately 6,000 students.

Thika Municipality has 2 main Hospitals and approximately 43 Health Centres / Clinics.

Thika Town is the main commercial hub in the study area. The main Business Entities comprise of General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists etc.

There are about 30 manufacturing / processing Industries established in the Town. The Manufacturing / Processing Industries mainly comprise of car assembly, edible oil refining, food processing, tobacco processing, leather products, textiles, etc.

4.8.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result of site visits made and discussions held with the Client, it has been agreed that the Study Area for Thika is Thika Municipality, comprising of the Sub-locations listed in Table 3.43 below.

Table 3.43: Sub-Locations within the Study Area

Name of Location	Name of Sub-Location
Biashara	Karimenu Majengo Township Umoja
Makongeni	Kamenu Kianjau Komu

Figure 2.11 on Page 2-32 shows the Administrative Units of Study Area at Sub – Location level.

4.8.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the Sub-location level to develop future population projection patterns in the Study Area.

Table 3.44 details the intercensal demographic data and intercensal growth rates at Sub-Location Level.

Table 3.44: Intercensal Growth Rates in Sub-Locations within Thika Municipality

	Census 1989		Census 1999			Census 2009		
Sub-Location Name	**Area (Km²)**	**Pop.**	**Area (Km²)**	**Pop.**	**Growth Rate 1989 - 1999**	**Area (Km²)**	**Pop.**	**Growth Rate 1999 - 2009**
Karimenu (half rural)	29	3,619	28.1	4,578	2.38%	26.4	9,414	7.48%
Majengo	38	13,692	33.1	17,663	2.58%	2.9	17,194	-0.27%
Township	4	9,865	3.2	10,846	0.95%	4.0	11,699	0.76%
Umoja						9.8	8,329	
Kamenu (Rural)						33.3	37,477	
Kianjau						7.8	17,987	
Komu	25	34,299	29.1	56,145	5.05%	6.7	36,672	-4.17%
Total	**96**	**61,475**	**93.5**	**89,232**	**3.80%**	**90.9**	**138,772**	**4.51%**

Demographic Trends

Between 1999 and 2009, the annual population growth rate for Thika Municipality was 4.51%. In comparison, the national population growth rate between 1999 and 2009 was 3.0%.

The high growth rate has been fuelled by proximity to Nairobi and good Road Network. The current trend is that many Nairobi residents are buying plots to construct houses in the Satellite Towns, including Thika, and moving away from City Estates.

The high growth rate of Thika Municipality is expected to be sustained in the next two decades by the on-going redevelopment of the Thika-Nairobi dual carriageway into an eight-lane highway. However, the growth rate will decrease with time as land values increase and the area gets saturated with development.

It is proposed that the following population growth rates be adopted for Thika Municipality for the Study Period, 2009 to 2035:

Population Growth Rates Adopted for Thika Municipality

Period	2009 – 2020	2021 - 2030	2031 - 2035
Population Growth Rate	4.5%	4.0%	3.0%

Based on the above population growth rates, the Population Projection for the study area is given in Table 3.45.

Table 3.45: Forecast Population for Thika Municipality

Year	2009 Census	2010	2017	2020	2030	2035
Annual Growth Urban		**5.80%**	**5.60%**	**4.80%**	**4.00%**	**3.40%**
Population - Urban	**96,588**	102,190	149,643	172,242	254,961	301,353
Annual Growth Rural		**1.80%**	**1.60%**	**1.50%**	**1.20%**	**1.00%**
Population - Peri Urban	**42,184**	42,943	47,990	50,182	56,540	59,424
Total Population	**138,772**	**145,133**	**197,633**	**222,425**	**311,501**	**360,777**
Pop. Growth Rate	**4.5%**	**4.6%**	**4.5%**	**4.0%**	**3.4%**	**3.0%**

In the study area, the whole of Kamenu Sub-location and half of Karimenu Sub-location have been considered as Rural Areas. Township, Umoja, Majengo, Komu, Kianjau and the half of Karimenu adjacent to the Thika-Nairobi Highway have been considered as Urban.

Population Served

The proportion of total population within the Thika Town Study Area presently served by the Water Service Provider is approximately 68% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 85% by year 2017 and 95% at the ultimate planning period, year 2035. Table 3.46 gives the population served within the planning horizon.

Table 3.46: Projected population served by Water Service Provider

Population Served	2010	2017	2020	2030	2035
% of Urban Pop.	**80%**	**85%**	**89%**	**94%**	**95%**
Urban Population	81,752	127,197	153,296	239,663	286,286
% of Rural Pop.	**40%**	**45%**	**49%**	**59%**	**64%**
Rural Population	17,177	21,596	24,589	33,359	38,031
Total Population	**98,929**	**148,792**	**177,885**	**273,022**	**324,317**
% of Pop. served	**68%**	**75%**	**80%**	**88%**	**90%**

Population Distribution

The 2008-2012 District Development Plan for the larger Thika District gives the percentage of Low Income Group in the Study Area as 36% of the population. However no data is available for the High Class and Medium Income Groups.

From site visits, it was estimated that the proportion of the High Income Group in Thika Municipality is comparable to Nairobi.

The proposed Population Distribution by Income Group for the Study Area is as follows:

		Study Area	**Nairobi City**
• Low Income	-	36%	44%
• Medium Income	-	59%	50%
• High Income	-	5%	6%

It is assumed that this distribution will remain constant throughout the project life i.e. up to 2035.

4.9 Limuru Town

4.9.1 General

Limuru Town is located within Kiambu West District and is about 40km from Nairobi City. The main part of the Town is situated at the western side of a valley which slopes in the North – South direction.

Figure 2.12 on Page 2-35 shows the locations of Limuru Town and its administrative units to Sub-location level.

Limuru is well served by the High Way from Nairobi to Nakuru, Nairobi / Banana / Limuru Road and Nairobi / Kiambu / Limuru Road. Table 3.47 shows the Sub - Locations within Kiambu West District

Table 3.47: Administrative units of Kiambu West District

Name of Sub-Location
Limuru Township
Kamirithu
Mabrouke
Bibirioni
Kiawaroga
Rironi
Ithanji
Karambaini
Gatimu
Kabuku
Ngecha
Redhill

4.9.2 Socio-Economic Infrastructure

The present reported number of Primary Schools is 23 with an enrolment of 13,818 pupils and 574 teachers, the Secondary Schools are 18 with an environment population of 7,800 pupils and 425 teachers in the Study Area.

There are 3 Main Hospitals and 23 Clinics at present within the Study Area.

The main Business Entities comprises of General Shops / Hardware, Bars / Restaurants, Petrol Stations, Chemists etc.

The Manufacturing / Processing Industries mainly comprise of meat processing, animal feed processing, uPVC pipes manufacturing, tea processing, milk processing, sawmills etc. The following are considered as the main Industries within the Study Area.

- Bata Shoe Factory which has a present population of 287 person
- Limuru Fresh Milk Processing Factory
- Polypipes for manufacturing of uPVC Pipes
- Limuru Dairy Farmers – Milk Processing

4.9.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result, site visits have been made, discussions held with the Client and it has been agreed that the Study Area for Limuru to comprise of the Sub-locations, of Limuru Township, Kamirithu and Mabrouke

A Layout Plan showing the Study Area Boundary is given in **Figure 2.12 on Page 2-35.**

4.9.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and Intercensal growth rates at the Limuru West District and Sub-location level to develop future population projection patterns in the Study Area. A trend of 20 year growth has been considered as reasonable. Table 3.48 details the Intercensal demographic data and Intercensal growth rates, at the three Sub-location Levels

Table 3.48: Intercensal Growth Rates in Sub-locations within Limuru Demand Area

	Census 1989			Census 1999				Census 2009			
Sub-Location	**Area (Km²)**	**Urban Pop.**	**Peri-urban Pop.**	**Area (Km²)**	**Urban Pop.**	**Peri-urban Pop.**	**Growth Rate 89-99**	**Area (Km²)**	**Urban Pop.**	**Peri-urban Pop.**	**Growth Rate 99-09**
Limuru Township	1	1,742		0.6	3,160		6.14%	1.5	4,355		3.26%
Kamirithu	16	12,341		17.1	16,048		2.66%	16.3	17,321		0.77%
Total Urban	**17**	**14,083**		**17.7**	**19,208**		**3.15%**	**17.8**	**21,676**		**1.22%**
Marbrouke				15.9		11,260		16.4		15,935	
Total Peri-Urban				**15.9**		**11,260**		**16.40**		**15,935**	**3.53%**
Total Study Area	**17.0**		**14,083**	**33.6**		**30,468**		**34.2**		**37,611**	**2.13%**

The Sub-location of Limuru Township and Kamirithu are medium growing Urban Centres. The growth has basically been fuelled by proximity to Nairobi and good Road Network, with the main Nairobi Nakuru Highway and proposed Southern By Pass traversing through the area. Also majority of Nairobian residents are buying plots along the Nairobi- Nakuru High Way Corridor to construct own residential / rental houses and moving away from City Estates. This trend is likely to continue in the next few years.

Demographic Trends

The Intercensal growth rate between 1999 and 2009 within the Study Area indicates an average annual growth rate of 1.22% for Urban area and 3.53% for Peri-Urban area. The current District Development Plan indicates a demographic growth rate of 2.56%, between years 2008 to year 2012 for Kiambu West District.

The adopted population growth rate for both Urban and Peri-Urban Area is taken as 3%, however this is expected to decline to 2% by the year 2020 as the area reaches its ultimate land carrying capacity and become saturated. The forecast population is given in Table 3.49.

Table 3.49: Forecast Population

Year	2009 Census	2010	2017	2020	2030	2035
Annual Growth Urban	**3.2%**	**3.00%**	**3.00%**	**3.00%**	**2.00%**	**2.00%**
Population - Urban	21,676	22,326	27,459	30,005	36,576	40,382
Annual Growth Rural	**2.8%**	**3.00%**	**2.80%**	**2.50%**	**2.20%**	**2.00%**
Population - Rural	15,935	16,413	19,913	21,444	26,658	29,432
Total Population	**37,611**	**38,739**	**47,372**	**51,449**	**63,233**	**69,814**
Total Population Growth Rate	**3.0%**	**3.0%**	**2.9%**	**2.8%**	**2.1%**	**2.0%**

Population Served

The proportion of total population within the Limuru Study Area presently served by the Water Service Provider is approximately 27% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 46% by year 2017 and 68% at the ultimate planning period, year 2035. Table 3.50 gives the population served within the planning horizon.

Table 3.50: Projected Population Served by Water Service Provider

Year	2010	2017	2020	2030	2035
% of Urban Pop.	**40%**	**46%**	**53%**	**63%**	**68%**
Urban Population	8,931	12,631	15,902	23,043	27,460
% of Rural Pop.	**10%**	**20%**	**30%**	**45%**	**50%**
Rural Population	1,641	3,983	6,433	11,996	14,716
Total Population served	**10,572**	**16,614**	**22,336**	**35,039**	**42,176**
% of Pop. served	**27%**	**35%**	**43%**	**55%**	**60%**

Population Distribution

The 2008 to 2012 Physical Development Plan for the larger Kiambu West District indicates that a percentage of 25% of the population is living below the poverty line (Low Class). However no data is available for the High Class and Medium Income Groups.

From site visits, it was estimated that the high income percentage is low in Kiambu West District than in Nairobi which stands at 6%. The proposed Income Group Distribution for the Study Area is as follows.

		Study Area	**Nairobi City**
• Low Income	-	25%	44%
• Medium Income	-	73%	50%
• High Income	-	2%	6%

The above population distribution is anticipated to remain the same throughout the Project life i.e. up to year 2035.

4.10 Gatundu Town

4.10.1 General

Gatundu Town falls under the newly formed Gatundu South District in Kiambu County, Central Province. The town is located approximately 40km to the North of Nairobi city and hosts the District administration offices.

The town is on the eastern slopes of the Kikuyu Escarpment at coordinates 1^0 00' 43''S and 36^0 54' 13''E and at an elevation between 1680m amsl to the West and 1600m amsl to the East. Gituru River forms the town's Northern boundary while the Southern boundary is Thiririka River.

Figure 2.13 on Page 2-37 shows the locations of Gatundu Urban Centre and its administrative units to Sub-location level.

There are 4nr administrative units (sub-locations) in Gatundu District which fall within the town's study area. These administrative units are listed in Table 3.51:

Table 3.51 : Administrative units in Gatundu Study Area

Location	Sub-location
Ngenda	Ituru
	Kirangari
	Githunguchu
	Kimunyu

4.10.2 Socio-Economic Infrastructures

There are reported to be 6nr Primary Schools with an enrolment of 2,829 pupils and 2nr Secondary Schools with a population of 1,462 students in the study area.

Gatundu town hosts the Gatundu District hospital, the main health facility within the town and 1nr private Health Centre.

In the Physical Development Plan for Gatundu town, the area set for industrial development amounts to 3.3ha while 10.1ha have been zoned for commercial development.

The main Commercial Centres/areas in Gatundu Town include the Central Business District, Jua Kali Site, open air market, Council stalls etc. Only 1nr coffee factory in the study area has been classified as industrial.

4.10.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result site visits have been made, discussions held with the Client and agreed that the Study Area for Gatundu town comprise of the urban and peri-urban areas surrounding the town and other potential areas around the town.

Figure 2.13 on Page 2-37 shows the Study area Boundary.

4.10.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at Sub-location level to develop future population projection patterns. A trend of 20 year growth has been considered reasonable to make projections for the next 25 years.

Table 3.52 details the intercensal demographic data and intercensal growth rates, at Sub-location Level:

Table 3.52: Intercensal Growth Rates for the Study Area

Sub-location Name	1989		1999			2009		
	Area (Km²)	Total Pop.	Area (Km²)	Total Population	Growth Rate 1999-2009	Area (Km²)	Total Pop.	Growth Rate 1999-2009
Ituru	7	4,312	6.9	4,474	0.37%	6.5	4,526	0.12%
Kirangari			2.7	4,304		2.6	5,199	1.91%
Githunguchu	10	9,562	7.3	7,424	-2.50%	7.4	7,908	0.63%
Kimunyu	10	7,323	10.7	8,254	1.20%	10.4	8,699	0.53%
TOTAL	**27**	**21,197**	**27.6**	**24,456**	**1.44%**	**26.9**	**26,332**	**0.74%**

Part of the sub-location areas within the study area do not fully fall within the study area, the population within the study area has been estimated using the population data up to Enumeration Area (EA) level. This has also been used to estimate the population within urban areas which has been done by overlaying the sub-location boundaries on projected raster images before using the EA boundaries to estimate the urban, peri-urban and rural populations.

The intercensal growth rates show a reducing population growth rate for the study area. This trend is expected to change within the next 10 years as the areas surrounding Nairobi city get filled up, people are expected to move further outside Nairobi towards areas like Gatundu town.

Population Growth Trends

The intercensal growth rate between 1989/1999 and 1999/2009 indicates an average annual growth rate of 1.4% and 0.7% respectively for the whole area. The District Development Plan for Gatundu District indicates a demographic growth rate of 0.8%, between year 2008 and year 2010.

For the purposes of this study, the adopted population growth rate for the Study Area has been taken as 1.0% presently but it is expected to increase to 1.5% by year 2017 before starting to reduce up to 1.2% by year 2035. A lower growth rate has been used for the rural population. The forecasted population for Gatundu town up to year 2035 is given in Table 3.53.

Table 3.53: Forecast Population

Population & Growth Rates	2009 Census	2010	2017	2020	2030	2035
Annual Urban Growth		**1.00%**	**1.50%**	**1.40%**	**1.20%**	**1.20%**
Urban Population	8,247	8,330	9,245	9,638	10,859	11,527
Annual Rural Growth		**0.80%**	**0.80%**	**0.70%**	**0.50%**	**0.40%**
Rural Population	7,088	7,144	7,554	7,714	8,108	8,272
Total Population	**15,335**	**15,474**	**16,799**	**17,352**	**18,968**	**19,799**
Total Pop. Growth Rate	**0.74%**	**0.9%**	**1.2%**	**1.1%**	**0.9%**	**0.9%**

Population Served

The proportion of total population within the Gatundu Town Demand Area presently served by the Water Service Provider is approximated at full coverage according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will remain at full coverage within the planning horizon.

Population Distribution

The 2008 to 2012 Physical Development Plan for the larger Gatundu District indicates that a 35.5% of the total population is living below the poverty line (Low Class). No data is available for the High Class and Middle Income groups.

From site visits made, it is estimated that the high income population is higher in Gatundu District than in Nairobi which stands at 4.3% as indicated by previous studies.

The adopted Income Group Distribution for the Gatundu study area is as follows:

		Study Area	Nairobi City
• Low Income	-	30%	44%
• Medium Income	-	60%	50%
• High Income	-	10%	6%

The above population distribution is anticipated to remain the same throughout the Project design life i.e. up to year 2035.

4.11 Tala & Kangundo Towns

4.11.1 General

The Towns of Tala and Kangundo fall under Kangundo District in Machakos County Eastern Province of the Republic of Kenya. The Towns are under the jurisdiction area of Tanathi Water Services Board. The study area for the towns is defined by the urban and peri-urban areas of these towns and the anticipated future urban growth areas.

The study area is located approximately 60km to the East of Nairobi city and is the furthest study area from the capital city compared to other satellite towns studied under this Project.

The main urban areas within the study area are Tala and Kangundo Towns in addition to Nguluni centre which is approximately 4km from Tala Town along the Tala-Nairobi Road. It is anticipated that in future, Tala Town which is the fastest growing town will develop towards Nguluni centre.

There are 8nr administrative units (sub-locations) in Kangundo District which fall within the study area. Table 3.54 shows the administrative units of this Study Area at Sub – location level.

Table 3.54: Administrative Units within the Study Area

Urban Area	Sub-Location
Tala	- Sengani
	- Kyaume
	- Katine
	Nguluni
	Kithimani
Kangundo	- Ndunduni
	- Isinga
	- Muisuni

4.11.2 Socio-Economic Infrastructure

The study area education institutions comprise of public and private primary and secondary schools, training colleges and institutes. According to Kangundo District Development Plan, the number of Primary School going population stands at 22% while Secondary School going population is 10% of the total population.

In Tala and Kangundo areas there are 2nr and 1nr Health Centres respectively. There is one major District hospital in Kangundo Town.

The main Business Entities in the study area comprises of General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists etc. There are no Manufacturing / Processing Industries within the study area.

4.11.3 Study Area

The Terms of Reference did not explicitly identify the study area. As a result site visits have been made, discussions held with the Client and it was agreed that the Study Area for Tala-Kangundo Towns comprise of the urban and peri-urban areas surrounding the towns and the future anticipated growing areas. The Sub-locations which fall within the study area include Sengani, Kyaume, Katine, Ndunduni, Isinga, Muisuni, Nguluni and Kithimani.

Figure 2.14 on Page 2-39 shows the boundary of the Study Area.

4.11.4 Demographic Trends

Intercensal Growth Rate

Demographic trends from Central Bureau of Statistics (CBS) for 1989, 1999 and 2009 have been analysed to establish trends in terms of population size and intercensal growth rates at the study area Sub-location level to develop future population projection patterns. A trend of 20 year growth has been considered reasonable to make projections for the next 25 years.

Table 3-55 details the intercensal demographic data and intercensal growth rates, at Sub-location Level:

Table 3.55: Intercensal Growth Rates within Tala-Kangundo Towns

Area	Sub-location Name	1989		1999			2009		
		Area (Km²)	Total Population	Area (Km²)	Total Population	Growth Rate Between 1999 & 2009	Area (Km²)	Total Population	Growth Rate Between 1999 & 2009
Tala	Sengani	15	6,975				14	9,610	
	Kyaume	161	1,299				6	8,755	
	Katine	15	6,217				14.4	7,932	
	Nguluni	58	9,196	10.9	3,458	-9.32%	10.6	4,431	2.51%
	Kithimani						10.9	2,868	
	Sub-total	**249**	**14,491**	**10.9**	**3,458**	**-13.35%**	**55.7**	**33,596**	**25.53%**
Kangundo	Ndunduni						6.2	3,913	
	Isinga	13	8,794	8.7	6,535	-2.93%	8.6	6,686	0.23%
	Muisuni	9	9,549	5.9	6,148	-4.31%	6.1	6,204	0.09%
	Sub-total	**22**	**18,343**		**12,683**	**-3.62%**	**20.9**	**16,803**	
Total population		**271.0**	**32,834**	**10.90**	**16,141**	**-6.85%**	**76.6**	**50,399**	**12.06%**

Part of the sub-location areas within the study area do not fully fall within the study area, the population within the study area has been estimated by using the population data up to Enumeration Area level. This has also been used to estimate the population within urban areas which has been done by overlaying the sub-location boundaries on projected raster images before using the EA boundaries to estimate the urban and peri-urban populations.

The intercensal growth rates show a reducing population growth rate for the study area. This trend is expected to change within the next 10 years since as the areas surrounding Nairobi city get filled up, people are expected to move further outside Nairobi towards areas like Tala-Kangundo.

Population Growth Trends

The intercensal growth rate between 1989/1999 and 1999/2009 indicates an average annual growth rate of -6.85% and 12.06% respectively for all the areas. The sharp contrast between the intercensal growth rates is due to the changes in administrative boundaries. The District Development Plan for Kangundo District indicates a demographic growth rate of 4.7%, between year 2008 and year 2010 which is considered too high for these towns.

For the purpose of this Study, the adopted population growth rate for the Study Area has been taken differently for the two urban centres for urban and rural areas. The growth rates are expected to increase up to a peak in year 2020 before starting to decline up to year 2035. Lower growth rates have been adopted for Kangundo town with the highest being for Tala Town. The forecasted population estimates and the growth rates for the Tala and Kangundo Towns are given in Table 3.56.

Table 3.56: Forecast Population

Area	Year	2009 Census	2010	2017	2020	2030	2035
Tala	Annual Urban Growth		**3.20%**	**3.30%**	**3.00%**	**2.60%**	**2.50%**
	Urban Population	6,186	6,384	8,013	8,756	11,319	12,806
	Annual Rural Growth		**1.50%**	**1.50%**	**1.20%**	**1.20%**	**1.00%**
	Rural Population	4,047	4,108	4,559	4,725	5,324	5,595
	Sub-Total Population	**10,234**	**10,492**	**12,572**	**13,482**	**16,643**	**18,402**
	Pop. Growth Rate	2.5%	2.5%	2.6%	2.4%	2.1%	2.0%
Kangundo	Annual Urban Growth		**0.60%**	**0.50%**	**0.50%**	**0.40%**	**0.40%**
	Urban Population	4,780	4,809	4,980	5,055	5,261	5,367
	Annual Rural Growth		**0.35%**	**0.35%**	**0.35%**	**0.32%**	**0.30%**
	Rural Population	4,071	4,085	4,186	4,230	4,368	4,433
	Sub-Total Population	**8,851**	**8,894**	**9,166**	**9,285**	**9,628**	**9,800**
	Pop. Growth Rate	0.3%	0.5%	0.4%	0.4%	0.4%	0.4%
Total Population		**19,084**	**19,386**	**21,738**	**22,767**	**26,271**	**28,202**
Population Growth Rate		**1.6%**	**1.6%**	**1.6%**	**1.6%**	**1.4%**	**1.4%**

Population Served

The proportion of total population within the Study Area presently served by the Water Service Provider is approximately 34% according to the data obtained from the water company. For planning purposes, it has been assumed that the proportion of the total population served will rise to 42% by year 2017 and 87% at the ultimate planning period, year 2035. Table 3.57 gives the population served within the planning horizon.

Table 3.57: Population Served by Water Service Provider

Area	Year	2010	2017	2020	2030	2035
Tala	% of Urban Pop.	**40%**	**45%**	**55%**	**80%**	**93%**
	Urban Population	2,554	3,606	4,816	9,055	11,910
	% of Rural Pop.	**15%**	**25%**	**30%**	**55%**	**70%**
	Rural Population	616	1,140	1,418	2,928	3,917
	Sub-Total Pop. Served	**3,170**	**4,746**	**6,234**	**11,983**	**15,827**
	% of Pop. served	**30%**	**38%**	**46%**	**72%**	**86%**
Kangundo	% of Urban Pop.	**55%**	**65%**	**70%**	**90%**	**95%**
	Urban Population	2,645	3,237	3,538	4,735	5,098
	% of Rural Pop.	**20%**	**30%**	**40%**	**70%**	**80%**
	Rural Population	817	1,256	1,692	3,057	3,547
	Sub-Total Pop. Served	**3,462**	**4,493**	**5,230**	**7,792**	**8,645**
	% of Pop. served	**39%**	**49%**	**56%**	**81%**	**88%**
Total population Served		**6,632**	**9,238**	**11,464**	**19,775**	**24,472**
% of Population served		**34%**	**42%**	**50%**	**75%**	**87%**

Population Distribution

The 2008 to 2012 Physical Development Plan for the larger Kangundo District indicates that a 41% of the urban population is living below the poverty line (Low Class). No data is available for the High Class and Middle Income groups.

From site visits made to the study area, it is estimated that the high income population is lower in Kangundo District than in Nairobi which stands at 6%.

The adopted Income Group Distribution for Tala-Kangundo study area is as follows:

		Study Area	Nairobi City[4]
• Low Income	-	41%	44%
• Medium Income	-	57%	50%
• High Income	-	2%	6%

- 41% of Low Income
- 57% of Medium Income
- 2% of High Income

The above population distribution is anticipated to remain the same throughout the Project design life i.e. up to year 2035.

[4]Water Supply and Sewerage Services Demand Forecast for Nairobi Municipality (2005-2030) – Uniconsult, 2007

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Appendix 4.1 - Forecast Water Demands for Nairobi City by Pressure Zones and by main Service Reservoirs

Chapter 4 - Water Demand Forecast

1 Review of Existing Reports

1.1 Demographic Trends Adopted in Previous Studies to Calculate Water Demand

The Howard Humphreys ''Long Term Development Plan'' Regional Studies (1986) was based on Intercensal Data from 1969 to 1979 and projections were presented upto the year 2010.

Subsequent Studies by other Consultants – Sogrea / Cape Consult (2005), Uniconsult (March 2007) and Seureca / Cas (August 2007) have based their analysis for Water Demand on Intercensal Data 1969 – 1979, 1979 – 1989 and 1989 – 1999 respectively.

The present Study has the benefit of recently published population data by Central Bureau of Statistics for the Year 2009. A comparison of growth rates adopted under the previous studies with actual intercensal growth rates is given in Table 4-1.

Table 4-1: Comparison of Population Growth Rates Used In Previous Studies / Intercensal Growth Rates

Source		Period	Population Growth Rate
i	Central Bureau of Statistics (Intercensal Results)	1969 - 1979	4.9%
		1979 – 1989	4.7%
		1989 - 1999	4.8%
		1999 – 2009	3.9%
ii	Howard Humphreys – Long Term Development Plan (Regional Studies) 1986	1985 - 1995	5.3%
		1995 – 2000	5.0%
		2000 - 2010	4.5%
iii	Nairobi Water and Sewerage Emergency Physical Investments Project, Diagnostic of the Current Situation – Sogreah / Cape Consult January 2005.	1999 – 2006	3.4%
		2006 – 2008	3.3%
		2008 – 2010	3.2%
		2010 – 2012	3.1%
		2012 – 2014	3.0%
		2014 – 2016	2.9%
		2016 – 2018	2.8%
		2018 – 2020	2.7%
iv	Water Supply and Sewerage Services Demand Forecast for Nairobi City – Uniconsult Kenya (March 2007) & Nairobi Water and Sewerage Institutional Restructuring Project, Hydraulic Network Modelling – Seureca / Cas Consulting Engineers (August 2007)	1999 – 2005	4.3%
		2005 – 2010	4.3%
		2010 – 2020	3.7%
		2020 - 2030	3.0%

The population growth rates adopted by the Howard Humphreys and Uniconsult and Seureca / Cas Studies are relatively higher than the actual intercensal growth rates published by the Central Bureau of Statistics. The population growth rates adopted by the Sogreah / Cape Studies are marginally lower than the actual intercensal growth rates (see Table 4-1 above).

1.2 Per Capita Water Consumption Rates Used in Previous Studies

Table 4-2 shows a comparison of Per Capita Water Consumption Rates between those recommended in the Ministry of Water and Irrigation "Practice Manual 2005" and those used under previous studies for water demand forecasting.

Table 4-2: Per Capita Consumption Rates Adopted in Previous Studies

		Per Capita Consumption Rates l/cap/day					
		Urban Areas			Rural Areas		
		High Class Housing	Medium Class Housing	Low Class Housing	High Potential	Medium Potential	Low Potential
i)	Ministry of Water & Irrigation "Practice Manual 2005"	250	150	75	60	50	40
ii)	Long Term Development Plan – Howard Humphrey (1986)	250	150	IC 75 Kiosk 20	60	50	40
iii)	Water Demand Forecast for Nairobi City, Uniconsult (March 2007)	275	170	IC 75 Kiosk 20	-	-	-
iv)	Hydraullic Nework Modeling Seureca / Cas (August 2007)	275	170	IC 75 Kiosk 20	-	-	-

IC – Individual Connection

1.3 Water Demand Forecast in Previous Studies

The water demand forecast for Nairobi City have been updated at different times under a number of previous studies as detailed below;

1.3.1 Third Nairobi Water Supply Project – Long Term Development Plan – Howard Humphreys (1986)

The Howard Humphreys Study forecast the water demand for Nairobi and other regional areas upto Year 2010. Table 4-3 summarizes the population and water demand forecast for 1985, 1995 and 2010.

Table 4-3 : Projections of Water Demand for Nairobi – Howard Humphreys (June 1985)

Year	1985	1995	2010
Population Nairobi	1,162,000	1,950,000	3,860,000
Population Served	1,035,000	1,853,000	3,667,000
Domestic Demand (m^3/d)	81,100	167,500	377,300
Commercial-Industrial-Public Water Demand	51,000	93,900	219,800
Total Demand	132,100	261,400	596,700
Add UfW (20%)	71,100	65,400	149,200
Total Water Demand m^3/day	203,200	326,700	745,800

In 2010 the average per capita is 193 l/d (the rate includes others demands and UfW). The water demand forecast for Nairobi and other Regional Areas is given in Table 4-4.

Table 4-4 : Summary of Water Demand Projections within the Study Area in m^3/d

(Howard Humphreys, 1985)

Area	Water Demand m^3/day		
	1985	1995	2010
Nairobi - Urban	203,200	326,700	745,900
Other Urban Centers	27,300	51,200	104,600
Rural Areas	38,300	61,100	113,900
Total Water Demand m^3/day	268,800	439,000	964,400

1.3.2 Nairobi Water and Sewerage Emergency Physical Investments Project, Diagnostic of the Current Situation – Sogreah / Cape Consult January 2005.

The Sogreah / Cape Consult Study (2005) carried out a simplified forecast of water demand in Nairobi based on the hypothesis that the gross demand will follow the increase in population as forecasted in official forecasts. No detailed demand study was carried out by Sogreah / cape Consult. The forecast demand is detailed in Table 4-5.

Table 4-5 : Projections of Water Demand for Nairobi – Sogreah/Cape (2005)

Year	2005	2010	2015	2020
Nairobi Population	2,751,860	3,240,155	3,772,503	4,335,279
Annual Growth Rate	3.4%	3.2%	2.9%	2.7%
Gross Water Demand (m^3/day)	498,737	587,233	683,714	785,709

1.3.3 Water Supply and Sewerage Services Demand Forecast for Nairobi City – Uniconsult Kenya (March 2007) & Nairobi Water and Sewerage Institutional Restructuring Project, Hydraulic Network Modelling – Seureca / Cas Consulting Engineers (August 2007)

A detailed Water Demand Study Report for Nairobi City was carried out by Uniconsult (March 2007). In August 2007 Seureca / Cas Consulting Engineers under the Consultancy Services for Hydraulic Network Modelling carried out a comprehensive review of the water demand forecast by Uniconsult. The review concluded that the water demand study by Uniconsult had omitted some sub-locations during the analysis of population and water demand forecasting. The Seureca / Cas Study corrected this anomaly and presented the revised population and water demand forecast which is detailed in Table 4-6.

Table 4-6 : Projections of Water Demand for Nairobi – Seureca /CAS (2007)

	2005	2010	2015	2020	2025	2030
Population (Million)	2.62	3.25	3.92	4.72	5.47	6.34
Annual Growth		4.4%	3.8%	3.7%	3%	3%
Water Demand (m^3/d)	387,419	480,861	583,141	701,086	819,777	957,496
+ water losses *	154,797	192,133	233,000	280,126	327,550	382,577
Gross Water Demand	**542,216**	**672,994**	**816,141**	**981,212**	**1,147,327**	**1,340,073**

*Water losses estimated at 28% during the treatment, the transmission and in the distribution system.

2 Methodology For Forecasting Water Demand Within The Study Area

2.1 General

This section presents the methodology adopted by EBI/MBIP in forecasting the water demand within the Study Area.

The study area includes the following Districts:

- Within Central Province: Muranga North, Muranga South, Kiambu East, Kikuyu, Kiambu West, Lari, Thika East, Thika West, Ruiru, Gatanga and Gatundu Districts
- Within Rift Valley Province: Kajiado North District
- Within Eastern Province : Machakos and Kagundo Districts

Water demand is defined as the volume of water different categories of consumers can afford to consume in a context of unrestricted supply. The water demand of a Municipality is dependent on the climate, economic considerations, sanitation facilities and industrial / institutional requirements.

The future water demand involves estimating the overall demand of the supply area for the present year (2010) and the long term requirements up to the year 2035.

This section outlines the water demand evaluation for different categories of consumers based on recommended water consumption criteria given in the MWI Practice Manual for Water Supply Services in Kenya, 2005.

The water demand in the supply area has been classified into four categories as follows:

- Domestic
- Institutional (Health, Education, Administration)
- Commercial
- Industrial

The spatial distribution of the water demand within the Municipality / City is largely dependent on the land use, density and spread of the population.

The domestic water consumption can be categorized into the following three main user groups based in incomes, housing density and mode of supply (see table 4-7)

Table 4-7 : Categorisation of Domestic Consumers

Income Group	Type of Housing	Mode of Supply
High income	Low density	Always connected / metered water supply
Medium income	Medium density	Always connected / metered water supply
Low income	High density	With or without individual connections

In most cases, it has been determined that the current and historical billing records were not representative of the current water demand for different reasons:

- The water production is not enough to supply all the consumers (water shortage)
- The served areas don't cover all the potential consumers
- Some water meters are faulty or consumers are not metered
- The billing system is not adequate

As a result of the above, the Economic Methods using demand functions on the basis of registered consumption cannot be used to estimate the future demand. Instead, an analytical approach has been used involving estimation of water by different categories of customers with specific consumption demand behaviours and requirements.

Total demand = Domestic + Institutional + Commercial + Industrial demand+ UfW

The per capita water demand for each category of consumer has been based on the parameters set out in the MWI Practice Manual.

2.2 Domestic Water Demand

Consumption Rates

The per capita demand for domestic consumers is dependent on the income levels, density of housing, sanitary equipment and water consuming facilities – garden, carwash, fire fighting, etc.

The Practice Manual indicates demand per capita for different income levels for Urban and Rural areas (Table 4-8).

Table 4-8 : Consumption Rates for Urban Areas and Rural (Practice Manual, 2005)

Consumer	Unit	Urban Areas			Rural Areas		
		High Class	Medium Class	Low Class Housing	High Potential	Medium Potential	Low Potential
People with individual connections	l/capita/day	250	150	75	60	50	40
People without individual connections	l/capita/day	_	_	20	20	15	10

According to the Practice Manual, the water consumption figures include 20% allowance for losses through leakage and wastage (UfW). No additional peak-factors shall be applied to calculate the design demand.

As seen above, the total water demand is calculated including UfW. UfW varies from Town to Town but Water Service Providers should strive to meet at most 25% for UfW which is considered to be practical. As a result, the demands per capita adopted to calculate the total water demand are the ones proposed in the Practice Manual less 20% for UfW for Urban Areas (see Table 4-9 on Page 4-6). The rates have been kept the same for Rural Areas and the demand per capita for people without individual connections in Urban Areas has been taken as 30 l/capita/day. UfW has however been added later in the Net Water Demand based on the present situation but decreasing within the planning period. This is based on the assumption that interventions to reduce UfW will be effected with time.

Table 4-9 : Adopted Consumption Rates Without UfW

Consumer	Unit	Urban Areas			Rural Areas		
		High Class	Medium Class	Low Class Housing	High Potential	Medium Potential	Low Potential
People with individual connections	l/capita/day	200	120	60	60	50	40
People without individual connections	l/capita/day	_	_	30	20	15	10

2.3 Institutional Water Demand

A guidance for Institutional Water Demand is given in the MWI Practice Manual for Water Supply Services in Kenya, 2005 as follows:

Table 4-10 : Consumption Rates for Schools, Health Sector and Administrations

(MWI Practice Manual, 2005)

Consumer	Unit	Rural & Urban area
Boarding schools	l/capita/day	50
Day schools with WC	l/capita/day	25
Without WC	l/capita/day	5
Hospitals Regional District	l/bed/ day	400 200 100 } + 20 l per outpatient and day (minimum of 5,000 l/day)
Dispensary and Health Centre	l/day	5,000
Administrative offices	l/capita/day	25

Education (schools) Water Demand

When possible, the number of schools must be determined and the above demand per capita above applied.

When there is no data available, a demand per capita of 5.5 l/d can be applied for Education. Table 4-11 on page 4-7 shows the calculation.

For Nairobi, the ratio between the total enrolment for primary and secondary schools (453 000 pupils) and the total population (2.7 M) in 2006 was 17% (source: Provincial Director of Education, Nairobi, 2006). A ratio of 20 % has been adopted. This is lower than the 30% proposed in the MWI Practice Manual.

Table 4-11 : Demand per Capita for Education

Education	Number	Water Demand l/day	Total Water Demand (l/d)
Population	1,000		
Number of pupils (20% of population)	200		
Day schools (90%)	180	25	4,500
Boarding schools (10%)	20	50	1,000
		Total	**5,500**
		Water Demand per Capita (l/capita/d)	**5.5**

Health Sector Water Demand

The MWI Practice Manual specifies that the development of health facilities should be based on the existing situation, the plans by Ministry of Health and the anticipated growth of the population. In the long term, one health centre and two to four dispensaries will be planned to serve about 35,000 to 40,000 people. The number of hospital beds can be assumed to 0.8 beds per 1000 people.

When there is no data available on the number of health facilities and their water consumption, a demand of 0.8 l/capita/day can be applied (see calculation in Table 4-12).

Table 4-12 : Demand per Capita for Health Sector

Health Sector	Number	Water Demand l/day	Total Water Demand(l/d)
Population	40,000		
Health centre	1	5,000	5,000
Dispensary	4	5,000	20,000
Hospital bed	32	200	6,400
		Total	**31,400**
		Water Demand per Capita (l/capita/d)	**0.8**

Administration Water Demand

The public services include the local government operational services for social amenities such as the fire fighting, parks, markets, etc. Also included are Technical institutes, Training centres, Police and Prisons institutions, etc.

When the number of employees in Administration services is known, a demand per capita of 25 l/day is applied. Otherwise, an average of 5 l/capita/day can be adopted to cover for the public services sector (it is assumed that 1 person in every 5 is working in a public administration).

Total Institutional Water Demand

The Institutional water demand includes Education, Health and Public Administration. Where no data exists, an overall demand for Institutional of 11.3 l/capita/day can be adopted (sum of Education, Health and Administration).

2.4 Commercial Water Demand

“Commercial” includes small shops, workshops, restaurants, bars, etc. Commercial water demand should be based on the existing situation where data is available. It is anticipated that the future increase in commercial activity will be directly related to growth of population (MWI Practice Manual, 2005).

2.5 Industrial Water Demand

"Industrial" comprises large enterprises, tourist hotels, military camps, etc. Industrial Water demand should be based on the existing data where possible. The development of large establishments should be indicated in Urban plans.

3 Water Demand Forecast

The Total Water Demand forecast takes into consideration Population growth, Income distribution and the per capita water demand which is considered constant over the planning period. The Water network coverage has been taken as increasing over the planning period as more resources are mobilised to cater for the population not covered. Unaccounted for Water (UfW) has been taken as constant within the planning period.

3.1 Access for Water

The 2009 Kenya Population and Housing Census (Volume II) presents data at District Level on the number of households served by main Source of Water: Pond/Dam, Lake, Stream, Spring /Well/ Boreholes, Piped into dwelling, Piped, Jabia / Rain harvested, Water Vendor and others.

When households fall in categories "piped into dwelling" and "piped", that means that they are supplied from water systems which are managed by a Public Water Operator, a Water Community Scheme or a Private Operator. The supply of water is from a planned water scheme or a private borehole linked to a small reservoir and includes a small piped network. The category "Spring/Well/Boreholes" includes boreholes that are not connected to a piped system.

In terms of water demand, three categories can be considered:

- **Households Piped into Dwelling** - In general, these households are located in Urban centres and have a high water demand per capita.
- **Households Piped** - this includes consumers who have a tap connection into their yard or they are sharing a tap in a building. Their water demand is lower as they have no individual facilities in their house/flat (shower, flush toilets, etc.)but have communal facilities.
- **All the others** – these comprises the population which does not get water from a water supply system but depend on alternative sources e.g. debes, water tankers, etc.

The 2009 Census also gives the percentage of population living in Urban Areas. Table 4-13 on page 4-9 gives the percentage of population per each category for piped into dwelling, piped and for others who are not piped. The percentage of people living in Urban Centres has also been provided. In average, within the study area, 17,8% of the population is supplied by a pipe into dwelling, 36.6% by a pipe into the yard and 45.6% by other sources. In average 68% of the total population lives in urban areas. This percentage drops to 39.8% in the Study Area without Nairobi City.

Table 4-13 : Population per Source (PD, P and others) and Population Living in Urban Area

Province / District		Area (km^2)	Pop. 2009 Census	Water Sources			Pop. In Urban
				PD	P	Others	
Nairobi City		**696**	**3,138,366**	**23.4%**	**52.3%**	**24.2%**	**100%**
Central	**Study Area**	**5,102**	**2,565,863**				
	Muranga North	935	346,283	6.2%	23.2%	70.6%	7.6%
	Muranga South	1,025	432,701	2.8%	11.4%	85.8%	3.7%
	Kiambu East	189	253,751	10.4%	21.1%	68.6%	69.3%
	Kikuyu	236	265,829	14.0%	29.7%	56.3%	0.0%
	Kiambu West	282	131,132	9.8%	32.9%	57.3%	46.8%
	Lari	439	123,895	2.8%	14.8%	82.3%	0.0%
	Githunguri	174	147,763	2.9%	12.7%	84.3%	6.8%
	Gatanga	312	113,094	60.1%	29.8%	10.1%	0.0%
	Thika East	413	77,073	5.7%	26.5%	67.8%	0.0%
	Thika West	327	218,544	21.2%	52.7%	26.1%	81.0%
	Ruiru	292	241,007	19.2%	41.2%	39.6%	98.3%
	Gatundu	478	214,791	7.4%	36.2%	56.4%	2.6%
Rift Valley	Kajiado North (Ngong Division)	717	237,805	15.4%	36.1%	48.5%	96.0%
Eastern	Machakos	1,976	442,930	6.6%	16.1%	77.2%	96.0%
	Kangundo	755	219,103	1.1%	4.1%	94.8%	7.6%
Sub-Total without Nairobi		**8,549**	**3,465,701**	**12.8%**	**22.4%**	**64.9%**	**39.8%**
TOTAL STUDY AREA		**9,245**	**6,604,067**	**17.8%**	**36.6%**	**45.6%**	**68.0%**

PD = Piped into Dwelling, P = Piped.

3.2 Population Projections and Distribution Based on Income Levels

Projections using growth rates for the 1999 - 2009 Intercensal Periods as the base reference population have been projected upto year 2035 at high, medium and low growth rate scenarios.

For Nairobi City the growth rates have been analysed on the basis that Nairobi's growth in future will be Multi – Centric i.e., the area around Nairobi City Boundary will be urbanised and become a contiguous part of Nairobi. This trend is already evident from the on-going development in the metro areas of Ruiru / Juja, Kiambu, Kikuyu, Ongata Rongai, Ngong, Mavoko, etc.

The Multi – Centric Growth Strategy will further be compounded on completion of the ongoing Nairobi – Thika Highway, Eastern, Northern and Southern Bypasses which will not only ease the current traffic congestion but will open up underdeveloped areas leading to rapid urbanisation. Other factors favouring the Multi – Centric Growth Strategy are the high price of land and property in Nairobi City, traffic congestion, lack of adequate public transportation facilities, general degradation of infrastructure, availability of enough schools and other amenities within convenient range of residents, etc.

Population distribution based on income levels has been based on data obtained from the Urban Poverty Estimates for Kenya's Provinces, Districts and Divisions published by Central Bureau of Statistics following the 1999 Census. This data gives the percentage of poor (Low income) population in each division. The determination of number of poor people is based on a monetary poverty line which represents the cost of basic basket of food (allowing 2250 calories/adult). This cost is revised every year. Urban poverty estimates for 2009 census have not been released to date, therefore figures for 1999 have been used in estimating the distribution of population based on income levels.

Using wage earners brackets by major towns from statistical abstracts, 2005, CBS, Table 4-14 on page 4-10 gives the type of housing expected in the project area.

Table 4-14 : Housing Type Distribution for Three Towns (Statistical Abstracts, 2005, CBS)

	Type of Housing		
	Low Class	**Middle Class**	**High Class**
Income per Month	<KShs 10,000	Between 10,000 and 50,000 KShs	>KShs 50,000
Nairobi City	39.2%	56.5%	4.3%
Thika Town	35.8%	64.2%	2.6%
Athi River Town	23.2%	75.7%	1.2%

3.3 Coverage Area / Individual Connections

Approximately 92% of Nairobi Population receive water from NCWSC piped network either through direct connections, water kiosks or water vendors as described in Table 4-15.

Table 4-15 : Number of Households by Water Sources in Nairobi City

Water Sources:	**Pond / Dam**	**Lake**	**Stream**	**Spring / Well / Borehole**	**NCWSC Network**	**Jabia / Rain Harvesting**	**Other**	**Total**
Households	2,761	99	1,345	70,729	907,704	1,691	687	**985,016**
Percentage	0.28%	0.01%	0.14%	7.18%	92.15%	0.17%	0.07%	**100%**

Source: 2009 Population and Housing Census

The existing NCWSC network can be considered largely as the most important source of water for Nairobi. A 92% coverage of Nairobi population means that approximately 2.9 million inhabitants of Nairobi City rely on NCWSC water supply at present.

However, the per capita water coverage in Nairobi's informal settlements is very low with the demand being far above the supply (Sogreah / Cape, 2005). Access to water in these areas is a major problem due to the high cost of water purchased from water vendors (about Kshs. 1,000 /m^3) as a result of inadequacy and unreliability of the existing water supply system. Water kiosks are known to sell water at three times more than that charged by NCWSC.

According to NCC (1996), 12% of the plots in the informal settlements have direct access to water in the plot while the majority (86% of the plots) obtain water from kiosks and water vendors.

In the water demand calculation, it has been estimated that the high and medium income population have 100% water supply coverage by the public (NCWSC) network and are served by individual water connections. This is estimated to remain constant within the planning period upto year 2035.

For the low income earners, it has been estimated that all the households in the informal settlement get water from NCWSC with only 9% getting water through individual connections while the rest obtain through other means e.g. water kiosks, water vendors etc. A low per capita rate of 30l/c/d has been adopted for low income earners with no individual connections. The connection ratio in the low income areas is however expected to increase within the planning period from the present 9% to 24% by year 2035 as shown Table 4-16 on page 4-11.

Table 4-16 : Water Supply Coverage by Income Level

Year	2010	2017	2020	2030	2035
Population	3,257,615	4,107,466	4,517,800	6,086,401	7,063,903
High Income (IC)	6%	6%	6%	6%	6%
Medium Income (IC)	50%	50%	50%	50%	50%
Low Income (IC)	9%	12%	16%	22%	24%
Low Income (NIC)	35%	32%	28%	22%	20%
% of Pop. supplied by IC	**65%**	**68%**	**72%**	**78%**	**80%**

IC - Individual Connection

NIC - No Individual Connection

Overall, the population served by the public network (NCWSC) through individual connections presently stands at 65% and is expected to increase to 80% at the ultimate planning period, year 2035 as new interventions to meet forecasted water demand are developed.

It is expected that the increase in population within the planning period coupled with increase in water supply coverage through increased number of households served by individual connections will result to huge investment needs to facilitate the implementation of new water connections. It is estimated that approximately 25,000 new connections will be required annually due to increased population and water supply coverage. It is therefore recommended that future financing to increase Nairobi City Water Supply situation should incorporate the need to incorporate the new water connections to ensure equitable water supply to the residents especially in the low income areas.

3.4 "Other Demand" – Commercial, Industrial, etc.

The Average Billed volume by category of consumption from July to December 2010 is given in Table 4-17.

Table 4-17 : Average Billed Volumes per Category from July to December 2010 (Source: NCWSC)

Category of Consumers	Billed Volumes (m^3/d)
Metered Residential	177,077
Water Kiosks	6,482
EPZ (water transfer towards Athi)	8,916
Metereed Social Services	28
Commercial	66,057
Industrial	6,310
Community Project	2
Government	6,446
Total	**271,318**

The average billed consumption for commercial, industrial, government, community project, social services is 78,843m^3/d. This is categorized as "Other Water Demand" in the water demand calculation. This water demand is expected to grow at a higher growth rate than the population based on the industrial growth aspirations of the Country which are entrenched in Vision 2030.

3.5 Water Demand Forecast – Nairobi City

Table 4-18 summarizes the comparison of water demand forecasts from various studies including the current Egis/MIBP JV Study.

Table 4-18 : Summary of Water Demand Forecast from Various Studies

	2010	2020	2030	2035
Howard Humphrey (1985)*				
Population	3,860,000			
Water Demand (m^3/d)	745,800			
Sogreah/Cape (2005)				
Population	3,240,155	4,335,279		
Water Demand (m^3/d)	587,233	785,709		
Uniconsult (March 2007)				
Population	3,251,219	4,720,845	6,352,396	
Water Demand (m^3/d)	417,307	690,765	1,052,780	
Seureca/Cas (August 2007)				
Population	3,250,000	4,720,000	6,340,000	
Water Demand (m^3/d)	672,994	981,212	1,340,073	
EBI/MIBP (2010)				
Population Based on Medium Growth Scenario	**3,250,338**	**4,403,791**	**5,693,457**	**6,444,969**
Water Demand (m^3/d)	**578,643**	**728,309**	**1,018,528**	**1,205,322**

** Uniconsult Water Demand Figures are lower as some sub-locations were missed out. These were reviewed and updated by the Seureca / Cas Study.*

The EBI/MIBP water demand forecasts carried out under the on-going study are based on per capita consumption rates (excluding 20% UfW) outlined in the Ministry of Water and Irrigation Practice Manual (2005). A UfW component of 53% of the Net Water Demand has been adopted in the initial planning period. This includes 40% distribution losses, 4% Transmission losses and 5% Treatment losses. The Distribution losses are however expected to reduce within the planning period to 25% which has been considered as practical. Table 4-19 summarises the adopted water demand based on medium scenario of population growth for Nairobi City and the adopted water losses.

Table 4-19 – Nairobi City Water Demand – Medium Population Growth Rate

Year	**2010**	**2017**	**2020**	**2030**	**2035**
Population Forecast	**3,250,338**	**4,040,325**	**4,403,791**	**5,693,457**	**6,444,969**
Population Growth Rate	**3.6%**	**3.2%**	**2.9%**	**2.6%**	**2.5%**
Net Water Demand	**378,495**	**480,067**	**533,560**	**746,174**	**883,020**
Distribution Losses	40%	28%	25%	25%	25%
Transmission Losses	4%	4%	4%	4%	4%
Treatment Losses	5%	5%	5%	5%	5%
Total Water Losses	**53%**	**40%**	**37%**	**37%**	**37%**
Gross Water Demand	**578,643**	**671,018**	**728,309**	**1,018,528**	**1,205,322**

The gross water demand forecast is based on population not served by individual connections consuming 30l/cap/day (35% in 2010, 28% in 2020, 22% in 2030 and 20% in 2035). Details of the Nairobi City Water Demand Calculations based on the medium population growth scenario are given in Table 4-20 on page 4-14. The Seureca / Cas and Uniconsult Studies were based on 100% of the population being on the network and consumption rates related to income groups. These forecasts for water demand are therefore higher than those estimated under the current study.

The Nairobi Water Demand together with the urbanised areas around the Nairobi City boundary which include Kikuyu, Kiambu, Karuri, Ruiru-Juja, Mavoko Municipality area, Ngong, Ongata Rongai and Kiserian has also been estimated. This water demand is referred to as the Nairobi Envelop Area Water Demand. Nairobi City Water demand forecast for low, medium and high population growth scenarios is given in Table 4-21 and **Figure 4-1** on page 4-15. Table 4-22 and **Figure 4-2** on page 4-16 gives the Nairobi City Plus Envelop Areas water demand.

Forecast water demands for Nairobi City by Pressure Zones and by main Service Reservoirs are shown in **Appendix 4.1**.

Table 4-20: Nairobi Water Demand Calculation – Medium Population Growth Scenario

1. Population Forecasts by Nairobi Divisions

Dictricts	Divisions	Population by Census			Growth Rate		Growth Rate Forecast					Population Forecast				
		1989	1999	2009	1989-1999	1999-2009	2010	2017	2020	2030	2035	2010	2017	2020	2030	2035
NAIROBI PROVINCE		**1,324,570**	**2,143,254**	**3,138,366**	**4.9%**	**3.9%**	**3.6%**	**3.2%**	**2.9%**	**2.6%**	**2.5%**	**3,250,338**	**4,040,325**	**4,403,791**	**5,693,457**	**6,444,969**
NAIROBI WEST		360,582	527,248	684,762	3.9%	2.6%	2.5%	2.2%	2.0%	1.9%	1.9%	701,753	819,538	871,010	1,052,159	1,156,782
	Dagoretti	144,779	240,509	329,577	5.2%	3.2%	3.0%	2.7%	2.5%	2.2%	2.2%	339,464	409,060	440,513	547,605	610,551
	Kibera	215,803	286,739	355,185	2.9%	2.2%	2.0%	1.8%	1.6%	1.6%	1.6%	362,289	410,477	430,497	504,554	546,231
NAIROBI EAST		310,289	632,318	1,144,416	7.4%	6.1%	5.2%	4.6%	4.1%	3.6%	3.3%	1,204,000	1,657,496	1,879,233	2,737,054	3,256,656
	Embakasi	154,006	434,884	925,775	10.9%	7.8%	6.2%	5.4%	4.8%	4.2%	3.8%	983,173	1,420,739	1,635,302	2,467,603	2,973,460
	Makadara	156,283	197,434	218,641	2.4%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	220,827	236,757	243,931	269,451	283,196
NAIROBI NORTH		515,406	776,078	1,062,086	4.2%	3.2%	3.0%	2.6%	2.2%	1.9%	1.7%	1,093,776	1,310,283	1,402,187	1,709,360	1,868,734
	Central	178,069	234,942	274,607	2.8%	1.6%	1.5%	1.3%	1.2%	1.0%	1.0%	278,726	305,101	316,217	349,300	367,118
	Kasarani	191,429	338,925	525,624	5.9%	4.5%	4.0%	3.3%	2.8%	2.4%	2.0%	546,649	686,137	745,401	944,908	1,043,255
	Pumwani	145,908	202,211	261,855	3.3%	2.6%	2.5%	2.5%	2.2%	2.0%	2.0%	268,401	319,045	340,569	415,151	458,360
NAIROBI WESTLANDS		138,293	207,610	247,102	4.1%	1.8%	1.5%	1.5%	1.5%	1.2%	1.2%	250,809	278,359	291,074	327,950	348,105

2. Net / Gross Water Demand

Year		2010	2017	2020	2030	2035
Population Growth		3.6%	3.2%	2.9%	2.6%	2.5%
Population		3,250,338	4,040,325	4,403,791	5,693,457	6,444,969
% Pop. supplied by IC		65%	68%	72%	78%	80%
Income levels						
High (IC)		6%	6%	6%	6%	6%
Medium (IC)		50%	50%	50%	50%	50%
Low (IC)		9%	12%	16%	22%	24%
Low (NIC)		35%	32%	28%	22%	20%
Domestic Water Demand (m^3/d)						
High (IC)	200	39,004	48,484	52,845	68,321	77,340
Medium (IC)	120	195,020	242,420	264,227	341,607	386,698
Low (IC)	60	17,552	29,090	42,276	75,154	92,808
Low (NIC)	30	34,129	38,787	36,992	37,577	38,670
Total Domestic WD		**285,705**	**358,781**	**396,341**	**522,659**	**595,515**
Other Water Demand - GR		3.1%	3.9%	4.2%	5.0%	5.2%
Other Water Demand		92,790	121,286	137,219	223,515	287,505
Net Water Demand		**378,495**	**480,067**	**533,560**	**746,174**	**883,020**
UfW		53%	40%	37%	37%	37%
Gross Water Demand (m^3/d)		**578,643**	**671,018**	**728,309**	**1,018,528**	**1,205,322**

IC - Individual Connections
NIC - No Individual Connections

Higher Coverage Area (Individual Connections) Scenario

Year		2010	2017	2020	2030	2035
Population Growth		3.6%	3.2%	2.9%	2.6%	2.5%
Population		3,250,338	4,040,325	4,403,791	5,693,457	6,444,969
% Pop. supplied by IC		65%	72%	75%	85%	90%
Income levels						
High (IC)		6%	6%	6%	6%	6%
Medium (IC)		50%	50%	50%	50%	50%
Low (IC)		9%	16%	19%	29%	34%
Low (NIC)		35%	28%	25%	15%	10%
Domestic Water Demand (m^3/d)						
High (IC)	200	39,004	48,484	52,845	68,321	77,340
Medium (IC)	120	195,020	242,420	264,227	341,607	386,698
Low (IC)	60	17,552	38,787	50,203	99,066	131,477
Low (NIC)	30	34,129	33,939	33,028	25,621	19,335
Total Domestic WD		**285,705**	**363,629**	**400,305**	**534,616**	**614,850**
Other Water Demand - GR		3.1%	3.9%	4.2%	5.0%	5.2%
Other Water Demand		92,790	121,286	137,219	223,515	287,505
Net Water Demand		**378,495**	**484,915**	**537,523**	**758,130**	**902,355**
UfW		53%	40%	37%	37%	37%
Gross Water Demand (m^3/d)		**578,643**	**677,795**	**733,719**	**1,034,848**	**1,231,714**

Table 4-21: Water Demand Forecast – Nairobi City

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	3,250,338	4,035,762	4,398,910	5,687,515	6,438,453
	Growth Rate	3.6%	3.1%	2.9%	2.6%	2.5%
Medium scenario	Population	3,257,615	4,107,466	4,517,800	6,086,401	7,063,903
	Growth Rate	3.8%	3.4%	3.2%	3.0%	3.0%
High scenario	Population	3,260,647	4,193,984	4,666,816	6,555,578	7,783,445
	Growth Rate	3.9%	3.7%	3.6%	3.5%	3.5%
Income Distribution						
Low Income - 44%			Medium Income - 50%		High Income - 6%	
Population Served by Public Water Service Provider (Individual Connections)						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage as I.Cs		65%	68%	72%	78%	80%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		581,912	728,293	802,206	1,053,452	1,198,674
Medium scenario		582,928	740,870	823,488	1,126,797	1,314,493
High scenario		583,351	756,322	850,479	1,213,417	1,448,104

Year 2009 Nairobi City Census Population - 3,138,369

Figure 4-1: Water Demand for High, Medium and Low Population Projections Scenarios – Nairobi City

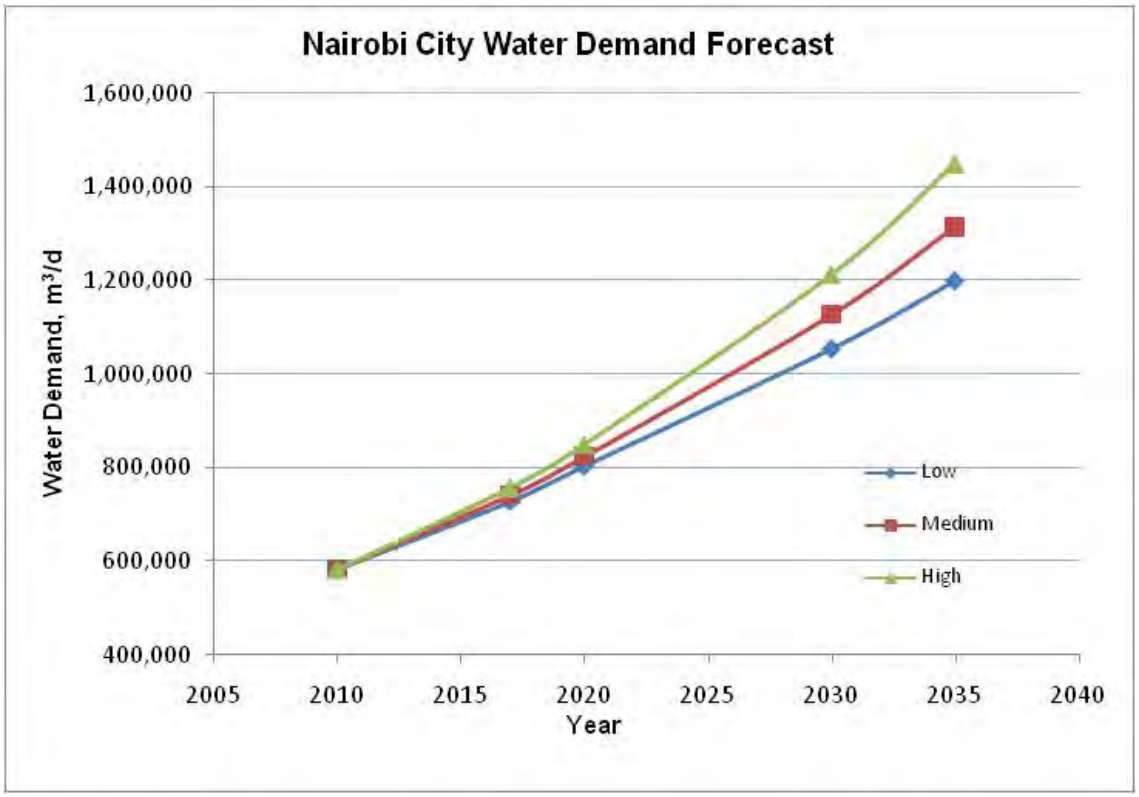
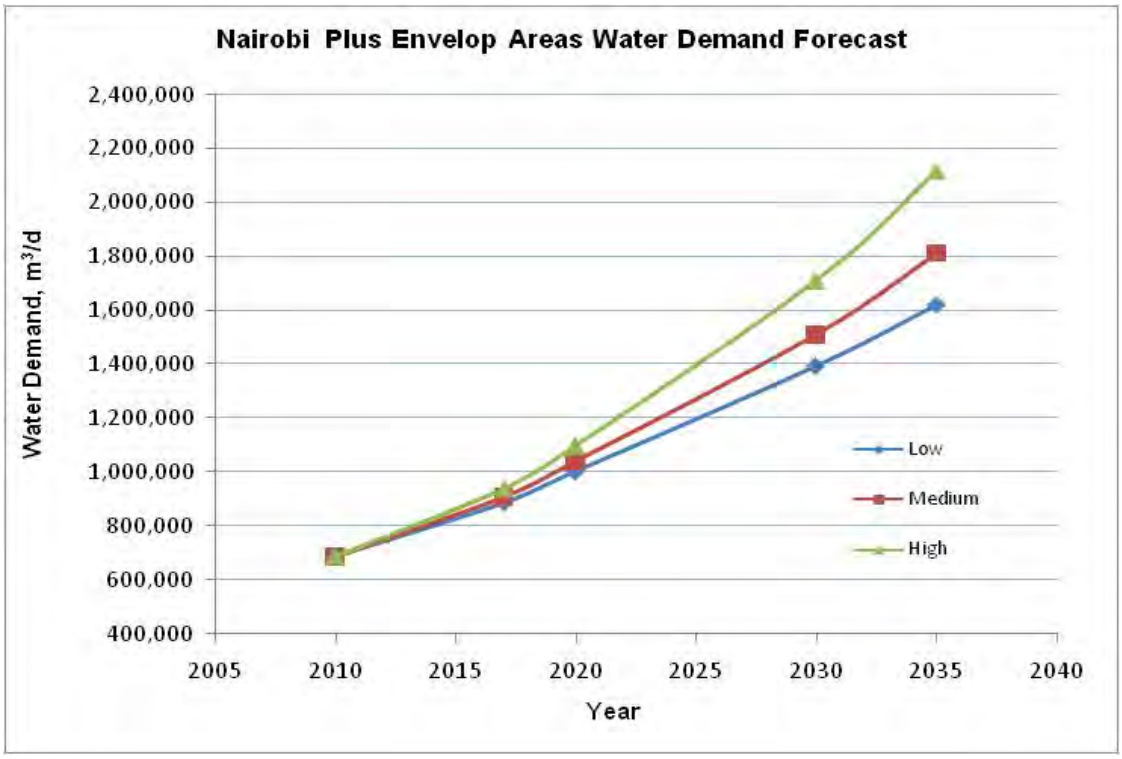


Table 4-22: Water Demand Forecast - Nairobi City Plus Envelop Areas

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	4,401,675	5,603,356	6,182,053	8,235,299	9,366,921
	Growth Rate	3.9%	3.5%	3.3%	2.9%	2.6%
Medium scenario	Population	4,416,424	5,774,282	6,443,464	9,000,052	10,538,134
	Growth Rate	4.3%	4.0%	3.7%	3.4%	3.2%
High scenario	Population	4,435,598	6,057,637	6,923,163	10,404,949	12,591,534
	Growth Rate	4.7%	4.7%	4.6%	4.3%	3.9%
Income Distribution						
Low Income - 42%			Medium Income - 52%		High Income - 6%	
Population Served by Public Water Service Provider (*Individual Connections*)						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage as I.Cs		53%	56%	62%	72%	76%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		685,522	886,230	1,001,015	1,391,262	1,621,312
Medium scenario		687,217	908,415	1,037,721	1,510,188	1,811,127
High scenario		689,037	942,125	1,098,823	1,707,882	2,117,194

Year 2009 Nairobi City plus Envelop Areas Census Population - 4,236145

Figure 4-2: Water Demand for High, Medium and Low Population Projections Scenarios – Nairobi & Envelop Areas



4 Water Demand Forecast - Satellite Towns

The Water Demands for the Region where the bulk water sources for Nairobi and the Satellite Towns emanate have been calculated.

The population design capacity of existing schemes and the location of the Intakes of the existing water supply schemes in the Region and demographic trends are detailed in **Chapter 2, Section 4.**

4.1 Methodology For Water Demand Forecast - Towns

The water demand forecast for individual Satellite Towns have been made based on low, medium and high projections to year 2035. The three levels of projection are influenced by the population growth rate and the rate of growth of the institutional, commercial and industrial sectors in the individual Satellite Towns.

The percentage of population supplied by individual connections through the licensed Water Service Provider varies from one Satellite town to another. Supply through individual connections has however been assumed to increase within the planning period based on increased water supply interventions.

The consumption rates as recommended in the Working Paper for Development of Water Sources for Satellite Towns – Version 1 (October 2011) have been used. The rates were based on Variant 4 which was recommended in Working Paper after comparisons with percapita rates in other cities in the developing and developed countries.

The four variants developed are as described below:

Variant 1 - Consumption Rates as per MWI Practice Manual, Coverage Area growing at higher rate from 18% in Year 2010 to 69% in Year 2035.

Variant 2 - Consumption Rates as per MWI Practice Manual (as in Variant 1), Coverage Area growing at lower rate from 18% in Year 2010 to 57% in Year 2035.

Variant 3 - Consumption Rates **Adjusted Below** MWI Practice Manual High Income Population – 150l/c/d, Middle Income – 100l/c/d, Low Income – 50l/c/d, Population not on network 30l/c/d, Coverage Area growing from 18% in Year 2010 to 69% in Year 2035 (Similar to Variant 1).

Variant 4 - Consumption Rates **Adjusted Below** MWI Practice Manual High Income Population – 150l/c/d, Middle Income – 100l/c/d, Low Income – 50l/c/d, Population not on network 30l/c/d (as in Variant 3), Coverage Area growing at lower rate from 18% in Year 2010 to 57% in Year 2035 (Similar to Variant 2)

The average per capita rates for Nairobi City vary from 179l/c/d to 186l/c/d for different design horizons and coverage areas. These figures are comparable with the per capita consumptions in other Cities of similar economic structure and type of development.

1996 – ADB Study of 27 Asian Cities over 1 Million Population[1]

[1] Water Supply – Alan C. Twort, Dan A Ratnayaka & Marcolm J. Brandt

Hong King 112 l/c/d, Jakarta 135/l/c/d, Shangai 143l/c/d, Colombo 165l/c/d, Singapore 183l/c/d, Kuala Lumpar 200l/c/d, Bangkok 265l/c/d

1995 – European Countries[1]

33% Cities – 150 – 160l/c/d (Range 113 – 260l/c/d)

Switzerland, Italy, Norway – over 200l/c/d

The most plausible and likely per capita consumptions for the Satellite Towns (Nairobi Envelop and Others) was found to be in the range of 100 – 130l/c/d. Similar per capita rates are reflected in Variant 3 and 4.

It was recommended that future water demand forecast for the Satellite Towns be based on average per capital consumption rate of 117l/c/d as per Variant 4 (Satellite Towns in Nairobi Envelop).

The Water Supply Development Strategy for Satellite Towns was therefore developed on the basis of meeting the water demand forecast as per Variant 4. The adopted percapita rates excluding the Unaccounted for Water component are given in Table 4-23.

Table 4-23: Adopted Domestic Consumption Rates for Satellite Towns

Consumer	Unit	Urban Areas		
		High Class	Medium Class	Low Class
People with individual connections	l/capita/day	150	100	50
People without individual connections	l/capita/day	_	_	30

A per capita consumption rate of 30l/c/d has been adopted for low income earners with no individual connections and for population out of the public water supply coverage area.

The percapita rates recommended in the Ministry of Water and Irrigation Guidelines (2005) excluding the Unaccounted for Water component are given in the Table 4-24.

Table 4-24: Consumption Rates for Urban Areas and Rural (MWI Practice Manual, 2005)

Consumer	Unit	Urban Areas			Rural Areas		
		High Class	Medium Class	Low Class Housing	High Potential	Medium Potential	Low Potential
People with individual connections	l/capita/day	250	150	75	60	50	40
People without individual connections	l/capita/day	_	_	20	20	15	10

The water demand for commercial, education, institutional, health, industrial and administration sectors has been estimated based on the present socio-economic infrastructure obtained for each of the Satellite Towns. The consumption rates as recommended in the MWI Practice Manual (2005) have been used in the water demand calculation.

At present, the UfW in some of the Satellite Towns is very high and unacceptable. An average UfW component of 53% of the Net Water Demand has been applied in the water demand calculation at the start of the planning period for the Satellite Towns. This includes 40% distribution losses, 4% Transmission losses and 5% Treatment losses. The Distribution losses

are however expected to reduce within the planning period to 25% in year 2035 which has been considered as practical. This is based on the assumption that interventions to reduce the high UfW will be effected.

4.2 Water Demand Forecast - Kikuyu Urban Centre

4.2.1 Domestic Water Demand

In Kikuyu, another category is added, namely Peri-Urban where Rural areas are developing into Urban areas. The demand per capita for Peri-Urban is the mean between Medium and Low income.

Table 4-25 below gives the projected domestic water demand in Kikuyu Study Area.

Table 4-25: Projected Domestic Water Demand

Year	l/c/day	2010	2017	2020	2030	2035
Total Population		224,117	281,951	309,911	416,280	481,423
Urban Areas						
High Income	150	427	721	1,003	1,880	2,598
Medium Income	100	1,623	2,740	3,811	7,143	9,872
Low income	50	470	793	1,103	2,068	2,858
Peri-Urban Areas	90	1,376	2,781	3,679	7,687	9,338
Urban NOT served	30	1,281	1,562	1,453	1,611	1,465
Peri-Urban NOT served	20	2,753	3,018	3,075	3,037	3,113
Total Water Demand, m^3/d		**7,930**	**11,616**	**14,124**	**23,426**	**29,243**

4.2.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities was compiled in previous studies. The number of Schools is expected to grow at urban population growth rate. Table 4-26 gives the forecast water demand for Schools.

Table 4-26: Projected Water Demand for the Schools

Year	l/c/d	2010	2017	2020	2030	2035
Annual growth rate		5.2%	4.8%	4.8%	4.5%	4.2%
Total Enrolment		**33,568**	**46,607**	**53,646**	**83,311**	**102,339**
Enrolment Day School (75%)		25,176	34,956	40,235	62,483	76,754
Enrolment Boarding School (25%)		8,392	11,652	13,412	20,828	25,585
Water demand Day school	25	629	874	1,006	1,562	1,919
Water demand Boarding school	50	420	583	671	1,041	1,279
Kikuyu Campus		223	310	356	553	680
Thogoto PECA School		223	310	356	553	680
Total Water Demand, m^3/d		**1,495**	**2,076**	**2,389**	**3,710**	**4,558**

Health Sector

An inventory of existing facilities was compiled in previous studies and was projected to develop at the urban population growth rate. To calculate the water consumption per hospital, a bed

capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-27 gives the Health Sector water demand forecast.

Table 4-27: Projected Water Demand for Health Sector

Year	m^3/d	2010	2017	2020	2030	2035
Growth Rate		5.2%	4.8%	4.8%	4.5%	4.2%
No. Hospital		3	4	5	7	9
No. Clinic		15	21	24	37	46
Water Demand - Hospital	30	90	125	144	223	274
Water Demand - Clinics	5	75	104	120	186	229
Total Water Demand, m^3/d		**165**	**229**	**264**	**410**	**503**

Administration

A consumption rate of 1 litre/capita per day for Administrative Sector has been applied, based on the MWI Practice Manual since there were no available data. The demand for the Administrative Sector is projected to grow at the same rate as for the general population. Table 4-28 gives the water demand forecast for Public Administration.

Table 4-28: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Population		224,117	281,951	309,911	416,280	481,423
Total Water Demand, m^3/d	**1**	**224**	**282**	**310**	**416**	**481**

4.2.3 Commercial & Industrial Water Demand

The commercial activity in Kikuyu is dominated by small scale enterprises engaged in trade and services. These enterprises mainly consist of general shops offering a variety of goods and services for the general needs of the Town and the peri-urban inhabitants. It is assumed that the future increase in commercial activity is likely to be associated with the growth in the population of the town. An inventory of existing Commercial / Institutions / Industries was prepared in a previous report[1] and projected a water demand of 1,933m^3/day by the year 2010 (see Table 4-29).

Table 4-29: Water Demand for Commercial and Industrial (m^3/d)

Year	2010	2017	2020	2030	2035
Annual Growth Rate	5.2%	4.8%	4.8%	4.5%	4.2%
Commercial Water Demand	1,335	1,854	2,134	3,313	4,070
Industrial Water Demand	598	830	956	1,484	1,823
Total Water Demand, m^3/d	**1,933**	**2,684**	**3,089**	**4,797**	**5,893**

4.2.4 Overall Water Demand

The overall water demand of the Study Area has been estimated for the present (year 2010) Short Term (Year 2017) and the Ultimate (Year 2035) based on the adopted population growth rates. Unaccounted for Water (UfW) is currently estimated at 53%. The UfW has however been

assumed to progressively decrease to 37% by Year 2035. The water demands are given in Table 4-30.

Table 4-30: Water Demand for Kikuyu Study Area

Year	Projected Water Demand (m^3/day)				
	2010	**2017**	**2020**	**2030**	**2035**
Population	**224,117**	**281,951**	**309,911**	**416,280**	**481,423**
Domestic water demand	7,930	11,616	14,124	23,426	29,243
Education water demand	1,495	2,076	2,389	3,710	4,558
Health water demand	165	229	264	410	503
Administration water demand	224	282	310	416	481
Commercial water demand	1,335	1,854	2,134	3,313	4,070
Industrial water demand	598	830	956	1,484	1,823
Total Water demand, m^3/d	**11,747**	**16,887**	**20,176**	**32,759**	**40,678**
UfW	53%	40%	37%	37%	37%
Total Production Required, m^3/d	**17,959**	**23,604**	**27,540**	**44,716**	**55,526**

The current production capacity is 4,202m^3/day, which is far too low to cover the present water demand of 19,121 m^3/d. It meets only 22% of this Demand.

4.2.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

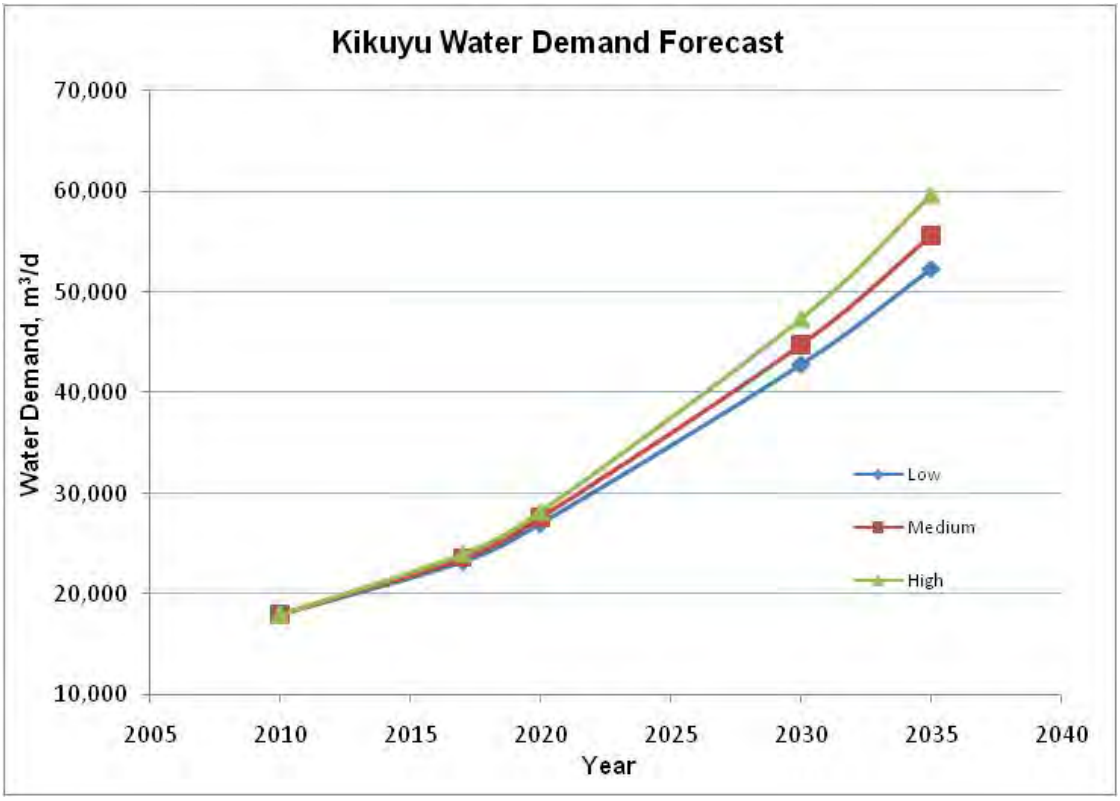
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-31 on page 4-22 and presented in graphical form as shown in **Figure 4-3 on** page 4-22.

Table 4-31: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	223,670	275,198	300,268	390,030	441,639
	Growth Rate	3.3%	3.0%	2.9%	2.6%	2.5%
Medium scenario	Population	224,117	281,951	309,911	416,280	481,423
	Growth Rate	3.5%	3.3%	3.2%	3.0%	3.0%
High scenario	Population	224,834	290,529	322,882	453,398	535,738
	Growth Rate	3.8%	3.7%	3.6%	3.5%	3.4%
Income Distribution						
Low Income - 33%		Medium Income - 57%		High Income - 10%		
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		20%	28%	35%	51%	58%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		17,940	23,245	26,983	42,767	52,322
Medium scenario		17,959	23,604	27,540	44,716	55,526
High scenario		18,001	24,062	28,278	47,390	59,686

Year 2009 Kikuyu Area Census Population - 216,578

Figure 4-3: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.3 Water Demand Forecast – Ruiru-Juja Urban Centres

4.3.1 Domestic Water Demand

Table 4-32 gives the projected Domestic Water Demand for Ruiru and Juja.

Table 4-32: Projected Domestic Water Demand

Year	l/c/day	2010	2017	2020	2030	2035
Population served		**56,371**	**134,924**	**208,981**	**563,516**	**756,080**
Urban Areas						
High Income	150	338	760	1,142	3,064	4,107
Medium Income	100	3,833	8,617	12,939	34,730	46,541
Low income	50	789	1,774	2,664	7,150	9,582
Rural Areas	60	0	492	1,122	3,167	4,299
Urban NOT served	30	6,764	9,776	10,601	12,536	13,688
Rural NOT served	20	1,205	1,475	1,497	1,583	1,553
Total Water Demand, m^3/d		**12,930**	**22,895**	**29,964**	**62,231**	**79,770**

4.3.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities was compiled in previous studies[1]. The population in the Education Sector is expected to grow at the general population growth rate.

The Water Demand Projection for the Education Sector is given in Table 4-33.

Table 4-33: Projected Water Demand for Education Sector

Year	l/c/d	2010	2017	2020	2030	2035
Annual growth rate		7.0%	7.0%	6.3%	5.5%	4.2%
Total Enrolment		**32,781**	**52,639**	**63,228**	**108,002**	**132,670**
Enrolment Day School (75%)		24,586	39,479	47,421	81,002	99,502
Enrolment Boarding School (25%)		8,195	13,160	15,807	27,001	33,167
Water demand Day school	25	615	987	1,186	2,025	2,488
Water demand Boarding school	50	410	658	790	1,350	1,658
Jomo Kenyatta University		380	610	733	1,252	1,538
Total Water Demand, m^3/d		**1,404**	**2,255**	**2,709**	**4,627**	**5,684**

Health Sector

An inventory of existing facilities was compiled in previous studies[1] and was projected to grow at the general population growth rate. To calculate the water consumption per hospital, a bed capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-34 on page 4-24 gives the water demand forecast for the Health Sector.

Table 4-34: Projected Water Demand for Health Sector

Year	m³/d	2010	2017	2020	2030	2035
Growth Rate		7.0%	7.0%	6.3%	5.5%	4.2%
No. of Hospitals		2	3	4	7	8
No. of Clinics		40	64	77	132	162
Water Demand - Hospitals	30	60	96	116	198	243
Water Demand - Clinics	5	200	321	386	659	809
Total Demand - Health Sector		**260**	**418**	**501**	**857**	**1,052**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector. The demand for Administrative Sector has been projected to grow at the general population growth rate. Table 4-35 gives the water demand forecast for the Administrative Sector.

Table 4-35: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Total Population		342,086	534,564	637,178	1,060,559	1,289,990
Water Demand Administration, m³/d	**1**	**342**	**535**	**637**	**1,061**	**1,290**

4.3.3 Commercial & Industrial Water Demand

Commercial activity in Ruiru and Juja is dominated by small scale enterprises engaged in trade and services. The main Business Entities comprises of General Shops / Hardware, Bars / Restaurants, Petrol Stations, Chemists etc. The main manufacturing / processing Industries include knitwear, plastic manufacturing, pharmaceuticals and steel manufacturing.

It is assumed that the future increase in commercial and industrial activity is likely to be associated with the growth in the population of towns.

An inventory of existing Commercial / Institutions / Industries was prepared in a previous report[1] and projected a water demand of 2,197m³/day by the year 2010. Table 4-36 gives the water demand forecast for the Commercial and Industrial Sector.

Table 4-36: Projected Water Demand for Commercial and Industrial Sector

Year	2010	2017	2020	2030	2035
Growth	7.0%	7.0%	6.3%	5.5%	4.2%
Commercial Water Demand	630	1,012	1,215	2,076	2,550
Industrial Water Demand	1567	2,516	3,022	5,163	6,342
Total Commercial /Industrial, m³/d	**2,197**	**3,528**	**4,238**	**7,238**	**8,892**

4.3.4 Water Demand in Proposed New Town Developments

There are some New Town Developments planned within Ruiru Municipality. These Developments are areas planned as new Towns / Cities in which people will live and work. Known examples of such Developments include the proposed Tatu City and the proposed Northlands Development.

It is expected that these New Town Developments will trigger the migration of people from other areas, into Ruiru Municipality. However, majority of these immigrants are expected to be from Nairobi and other areas in close vicinity of Ruiru. The Water Demand associated with the people expected to migrate into these New Town Developments is already accounted for in the Water Demand for Nairobi and other Satellite Towns near Ruiru. The Water Demand in the New Town Developments will therefore not be taken into account under the Ruiru and Juja Demand.

4.3.5 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which has been estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035.

The Overall Water Demand is shown in Table 4-37.

Table 4-37: Overall Water Demand for Ruiru Municipality and Juja Division

Year	**2010**	**2017**	**2020**	**2030**	**2035**
Population	**342,086**	**534,564**	**637,178**	**1,060,559**	**1,289,990**
Domestic water demand	12,930	22,895	29,964	62,231	79,770
Education water demand	1,404	2,255	2,709	4,627	5,684
Health water demand	260	418	501	857	1,052
Administration water demand	342	535	637	1,061	1,290
Commercial water demand	630	1,012	1,215	2,076	2,550
Industrial water demand	1,567	2,516	3,022	5,163	6,342
Total Water demand, m^3/d	**17,133**	**29,630**	**38,049**	**76,014**	**96,687**
UfW	53%	40%	37%	37%	37%
Required Water Production, m^3/d	**26,193**	**41,416**	**51,937**	**103,759**	**131,978**

The current production capacity is **3,980m^3/day**, which is only 13.80% of the current (year 2010) water demand of 28,842m^3/d.

4.3.6 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

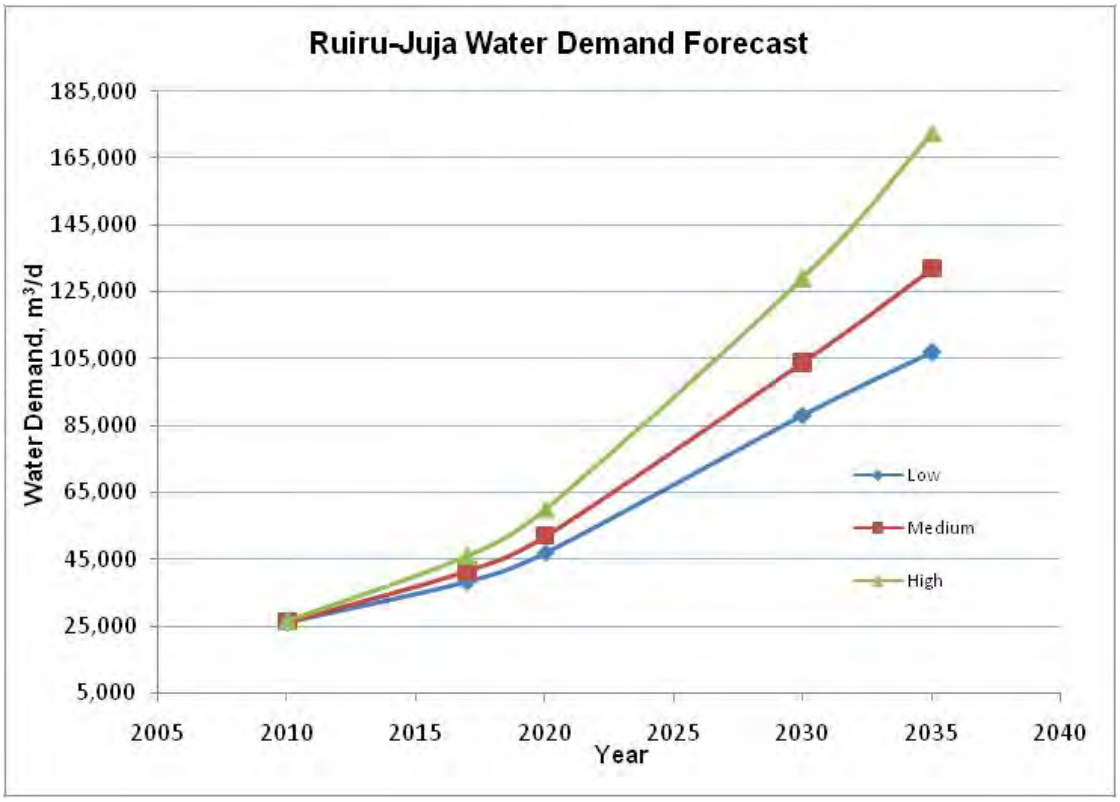
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-38 on Page 4-26 and presented in graphical form as shown in **Figure 4-4** on page 4-26.

Table 4-38: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	339,956	495,454	579,224	905,181	1,050,058
	Growth Rate	6.0%	5.5%	5.3%	4.6%	3.0%
Medium scenario	Population	342,086	534,564	637,178	1,060,559	1,289,990
	Growth Rate	6.6%	6.6%	6.0%	5.2%	4.0%
High scenario	Population	346,841	595,655	740,454	1,329,561	1,698,895
	Growth Rate	8.1%	8.0%	7.5%	6.0%	5.0%
Income Distribution						
Low Income - 4%			Medium Income - 68%		High Income - 28%	
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		16%	25%	33%	53%	59%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		26,064	38,239	47,032	88,080	106,835
Medium scenario		26,193	41,416	51,937	103,759	131,978
High scenario		26,476	45,933	60,091	128,969	172,646

Year 2009 Ruiru-Juja Area Census Population - 320,779

Figure 4-4: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.3.7 Conclusions and Summary

The Population and Water Demand Projections calculated in the previous Study[1] for the 2030 horizon is much lower than that calculated in this Study (EBI/MIBP). The comparison is given in Tables 4-39 and 4-40.

Table 4-39: Comparison of Population Projections for Ruiru and Juja Between Previous Study and EBI / MIBP Study

Study	Projected Population		
	2010	2017	2030
Previous Study [Uniconsult (2007) [1]]	174,877	237,413	580,432
EBI / MIBP JV	342,086	534,564	1,060,559

Table 4-40: Comparison of Water Demand Projections for Ruiru and Juja Between Previous Study and EBI / MIBP Study

Study	Projected Overall Water Demand (m^3/day)		
	2010	2017	2030
Previous Study [Uniconsult (2007) [1]]	32,796	50,222	107,512
EBI / MIBP JV	28,842	51,831	141,204

The previous Study, Uniconsult (2007)[1], had a horizon of up to year 2030. For year 2030, the projected Population from the Uniconsult Study is only 55% of the projected Population worked out in this Study (EBI/MIBP). The projected Water Demand from the Uniconsult Study for year 2030 is only 76% of the projected Water Demand worked out in this Study (EBI / MIBP).

The main reason for the big variance between the Uniconsult (2007) Study and this Study (EBI/MIBP) is an error in the year 1999 population used by Uniconsult.

The Study Area covered by the Uniconsult Study and this Study is the present day Ruiru District and Juja Division of Thika West District. For this area, Uniconsult used a year 1999 population figure of 86,064 whereas the actual year 1999 population of the Study Area as obtained from the 1999 Census Report was 150,710.

In this Study, the 1999 population of the Study Area as obtained from the 1999 Census Report, i.e. 150,710 has been adopted. The Population and Water Demand Projections worked out in this Study should be adopted.

4.4 Water Demand Forecast – Kiambu Municipality

4.4.1 Domestic Water Demand

Table 4-41 gives the projected Domestic Water Demand for Kiambu Municipality.

Table 4-41: Projected Domestic Water Demand

Year	l/c/day	2010	2017	2020	2030	2035
Population served		29,642	45,182	56,499	89,579	112,258
Urban Areas						
High Income	150	163	235	273	414	523
Medium Income	100	708	1,018	1,182	1,796	2,266
Low income	50	136	196	227	345	436
Peri-Urban Areas	90	1,688	2,657	3,448	5,575	6,965
Urban NOT served	30	176	183	182	207	185
Rural NOT served	20	1,125	1,255	1,250	1,342	1,373
Total Water Demand, m^3/d		**3,996**	**5,543**	**6,562**	**9,681**	**11,748**

4.4.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities was compiled in a previous Study[2]. The population in the Education Sector is expected to grow at the general population growth rate. The Water Demand Projection for the Education Sector is given in Table 4-42.

Table 4-42: Projected Water Demand for Education Sector

Year	l/c/d	2010	2017	2020	2030	2035
Annual growth rate		3.8%	3.8%	3.7%	3.6%	3.5%
Total Enrolment		**22,809**	**29,613**	**33,024**	**47,035**	**55,863**
Enrolment Day Schools (75%)		17,107	22,210	24,768	35,276	41,897
Enrolment Boarding Schools (25%)		5,702	7,403	8,256	11,759	13,966
Water demand Day Schools	25	428	555	619	882	1,047
Water demand Boarding Schools	50	285	370	413	588	698
Total Water Demand, m^3/d		**713**	**925**	**1,032**	**1,470**	**1,746**

Health Sector

An inventory of existing facilities was compiled in previous studies [2]and was projected to grow at the general population growth rate. To calculate the water consumption per hospital, a bed capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-43 gives the water demand forecast for the Health Sector.

[2]Feasibility Study for Water Supply and Sanitation in Seven Towns in Kenya – Kiambu Town – Wanjohi Consulting Engineers / Al-Olbaid Engineering Consultants - January 2009

Table 4-43: Projected Water Demand for Health Sector

Year	m^3/d	2010	2017	2020	2030	2035
Growth Rate		3.8%	3.8%	3.7%	3.6%	3.5%
No. of Hospitals		4	5	6	8	10
No. of Clinics		45	58	65	93	110
Water Demand - Hospitals	30	120	156	174	247	294
Water Demand - Clinics	5	225	292	326	464	551
Total Demand - Health Sector		**345**	**448**	**500**	**711**	**845**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector. The demand for Administrative Sector has been projected to grow at the general population growth rate. Table 4-44 gives the water demand forecast for the Administrative Sector.

Table 4-44: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Population		91,769	114,011	125,071	163,598	187,040
Water Demand Administration	**1**	**92**	**114**	**125**	**164**	**187**

4.4.3 Commercial & Industrial Water Demand

Commercial activity in Kiambu Municipality is dominated by small scale enterprises engaged in trade and services. The main Business Entities comprises of General Shops / Hardware, Bars / Restaurants, Petrol Stations, Chemists etc. There are no major industries in the Municipality.

It is assumed that the future increase in commercial and industrial activity is likely to be associated with the growth in the population of towns.

An inventory of existing Commercial / Institutions / Industries was prepared in a previous Study[2] and projected a water demand of $270m^3$/day by the year 2010. Table 4-45 gives the water demand forecast for the Commercial and Industrial Sector.

Table 4-45: Projected Water Demand for Commercial and Industrial Sector

Year	2010	2017	2020	2030	2035
Growth	3.8%	3.8%	3.7%	3.6%	3.5%
Commercial Water Demand	270	351	391	557	661
Total Water Demand	**270**	**351**	**391**	**557**	**661**

4.4.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which is currently estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035. The Overall Water Demand is shown in Table 4-46.

Table 4-46: Overall Water Demand for Kiambu Municipality

Year	2010	2017	2020	2030	2035
Total Population	**91,769**	**114,011**	**125,071**	**163,598**	**187,040**
Domestic water demand	3,996	5,543	6,562	9,681	11,748
Education water demand	713	925	1,032	1,470	1,746
Health water demand	345	448	500	711	845
Administration water demand	92	114	125	164	187
Comm. & Indu. water demand	270	351	391	557	661
Total Water demand, m^3/d	**5,416**	**7,381**	**8,610**	**12,582**	**15,187**
UfW	53%	40%	37%	37%	37%
Total Production Required, m^3/d	**8,280**	**10,317**	**11,753**	**17,175**	**20,730**

The current water supply to Kiambu Municipality from 11 Nr Boreholes and bulk water supply from Ngethu Pipeline is about **3,300 m^3/day**, which is only 37% of the current (year 2010) water demand of 8,951m^3/d.

4.4.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

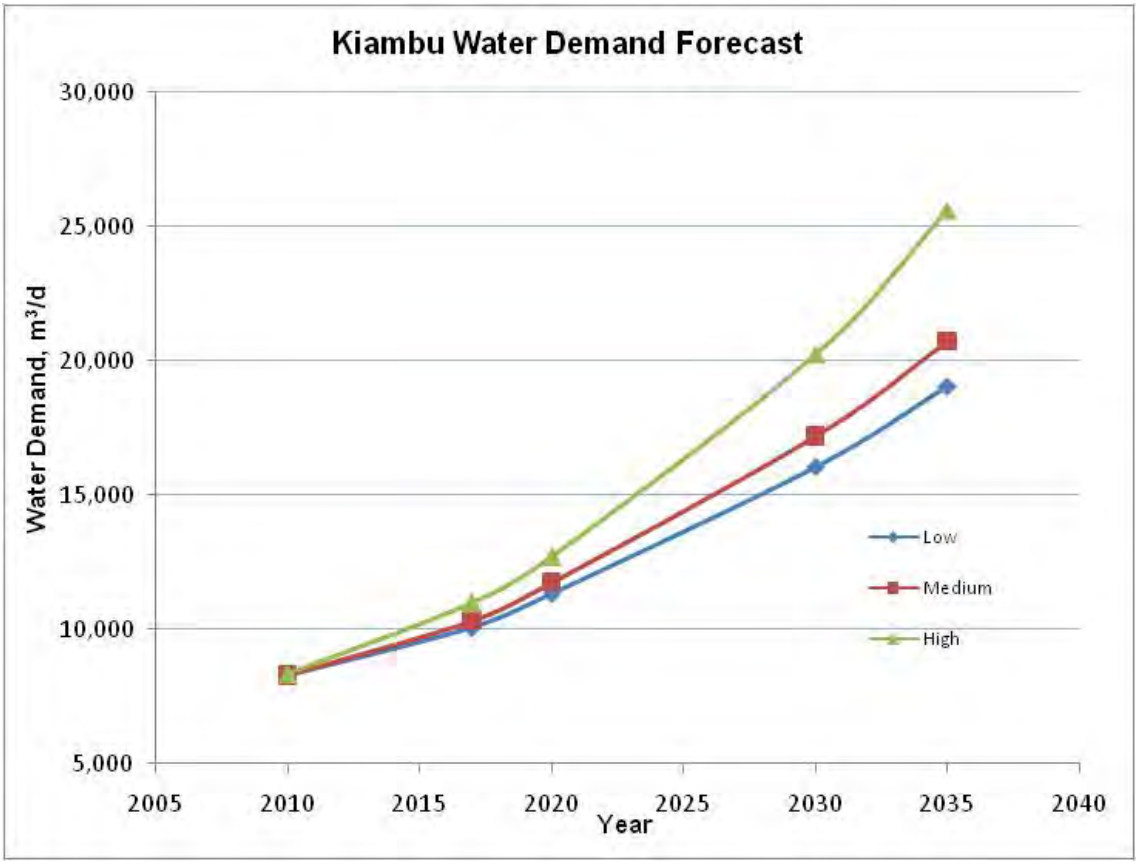
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-47 on page 4-31 and presented in graphical form as shown in **Figure 4-5** on page 4-31.

Table 4-47: **Water Demand Forecast at High, Medium and Low Population Growth Rates**

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	91,834	112,944	122,765	158,972	180,024
	Growth Rate	3.2%	3.0%	2.8%	2.6%	2.5%
Medium scenario	Population	91,769	114,011	125,071	163,598	187,040
	Growth Rate	3.1%	3.1%	3.1%	2.7%	2.7%
High scenario	Population	92,400	119,843	133,415	190,640	228,049
	Growth Rate	3.9%	3.8%	3.6%	3.6%	3.6%
Income Distribution						
Low Income - 25%		Medium Income - 65%		High Income - 10%		
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		32%	40%	45%	55%	60%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		8,279	10,068	11,328	16,069	19,059
Medium scenario		8,280	10,317	11,753	17,175	20,730
High scenario		8,326	10,968	12,715	20,268	25,610

Year 2009 Kiambu Area Census Population - 88,971

Figure 4-5: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.4.6 Conclusions and Summary

The Population and Water Demand Projections calculated in the previous Study [2]is much lower than that calculated in this Study (EBI/MIBP). The comparison is given in Tables 4-48 and 4-49.

Table 4-48: Comparison of Population Projections for Kiambu Municipality

Study	Projected Population		
	2010	2020	2030
Previous Study [Wanjohi (2009) [2]]	82,887	106,725	137,418
EBI / MIBP JV	91,769	114,011	163,598

Table 4-49: Comparison of Water Demand Projections for Kiambu Municipality

Study	Projected Overall Water Demand (m^3/day)		
	2010	2020	2030
Previous Study [Wanjohi (2009) [2]]	7,649	9,332	11,525
EBI / MIBP JV	8,951	15,202	23,764

The previous Study, Wanjohi (2009) [2], had a horizon of up to year 2030. For year 2030, the projected Population from the Wanjohi Study is only **84%** of the projected Population worked out in this Study (Egis/ MIBP). The 2030 projected Water Demand from Wanjohi Study is only 48% of the projected Water Demand worked out in this Study (Egis/MIBP).

The main reasons for the big variance between the Wanjohi (2009) Study and this Study (Egis/ MIBP) are the following:

i) The Wanjohi Study was undertaken in year 2008, one year before the 2009 census. This explains the low year 2010 projected population in the Study. In this Study (EBI / MIBP) the projected population for year 2010 is based on the 2009 population census data and is therefore more accurate.

ii) The Wanjohi Study adopted a per capita consumption rate of 50 litres / person / day for all domestic consumers, irrespective of income class distribution of the population, type of areas (rural / peri-urban / urban), etc. This resulted in the Domestic Water Demand Projections being unrealistically low.

In this Study (Egis / MIBP), the Ministry of Water & Irrigation Practice Manual (2005) guidelines have been used in allocating per capita consumption rates to different income classes – low, middle and high income classes. A realistic distribution of the population into the 3 classes has been made and the following per capita consumption rates applied, which are much higher than that used in the Wanjohi Study:

Type of Area	Income Group	Per Capita Demand (Litres / Capita / Day)
Urban	High Income	150
	Medium Income	100
	Low Income	50
Peri-Urban		90

4.5 Water Demand Forecast – Karuri Town

4.5.1 Domestic Water Demand

Table 4-50 below gives the projected Domestic Water Demand for Karuri.

Table 4-50: Projected Domestic Water Demand

Year	l/c/day	2010	2017	2020	2030	2035
Total Population		134,234	167,433	183,139	241,188	276,110
% of Population Served		20%	28%	32%	48%	58%
Urban Areas						
High Income	150	398	638	783	1,440	1,992
Medium Income	100	1,725	2,763	3,394	6,239	8,631
Low income	50	332	531	653	1,200	1,660
Rural Areas	60	0	252	435	1,200	1,724
Urban NOT served	30	1,858	2,171	2,254	2,356	2,145
Rural NOT served	20	915	967	970	933	862
Total Water Demand, m^3/d		**5,229**	**7,322**	**8,490**	**13,368**	**17,014**

4.5.2 Institutional Water Demand

Education Sector

Enrolment Numbers for schools are only available for the entire Kiambu East District, but not for individual sub-locations. The water demand in the education sector has therefore been estimated using a per capita demand rate of 8 litres/capita/day, as determined for the neighbouring Kiambu Municipality.

The Water Demand Projection for the Education Sector is given in Table 4-51.

Table 4-51: Projected Water Demand for Education Sector

Year	l/c/d	2010	2017	2020	2030	2035
Population		134,234	167,433	183,139	241,188	276,110
Total Water Demand, m^3/d	8	1074	1339	1465	1930	2209

Health Sector

The water demand in the health sector has been estimated using a per capita demand rate of 4 litres/capita/day, as determined for the neighbouring Kiambu Municipality. Table 4-52 on page 4-34 gives the water demand forecast for the Health Sector.

Table 4-52: Projected Water Demand for Health Sector

Year	m^3/d	2010	2017	2020	2030	2035
Growth Rate		4.0%	3.8%	3.5%	3.2%	3.2%
No. of Hospitals		2	3	3	4	5
No. of Clinics		40	52	58	79	92
Water Demand - Hospitals	30	60	78	86	118	139
Water Demand - Clinics	5	200	260	288	394	462
Total Demand - Health Sector		**260**	**338**	**374**	**513**	**600**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector. The demand for Administrative Sector has been projected to grow at the general population growth rate. Table 4-53 gives the water demand forecast for the Administrative Sector.

Table 4-53: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Population		134,234	167,433	183,139	241,188	276,110
Water Demand Administration	**1**	**134**	**167**	**183**	**241**	**276**

4.5.3 Commercial & Industrial Water Demand

Commercial activity in Karuri is dominated by small scale enterprises engaged in trade and services. The main Business Entities comprises of General Shops / Hardware, Bars / Restaurants, Petrol Stations, Chemists etc. There are no major industries in the Town.

It is assumed that the future increase in commercial and industrial activity is likely to be associated with the growth in the population of towns.

The water demand in the commercial & industrial sector has been estimated using a per capita demand rate of 3 litres/capita/day, as determined for the neighbouring Kiambu Municipality. Table 4-54 gives the water demand forecast for the Commercial and Industrial Sector.

Table 4-54: Projected Water Demand for Commercial and Industrial Sector

Year	l/c/d	2010	2017	2020	2030	2035
Population	**l/c/d**	134,234	167,433	183,139	241,188	276,110
Water Demand Commercial / Industrial	**3**	**403**	**502**	**549**	**724**	**828**

4.5.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which is currently estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035. The Overall Water Demand is shown in Table 4-55 on page 4-35.

Table 4-55: Overall Water Demand for Karuri

Year	2010	2017	2020	2030	2035
Population	**134,234**	**167,433**	**183,139**	**241,188**	**276,110**
Domestic	5,229	7,322	8,490	13,368	17,014
Education	1,074	1,339	1,465	1,930	2,209
Health	260	338	374	513	600
Administration	134	167	183	241	276
Commercial / Industrial	403	502	549	724	828
Total Water demand, m^3/d	**7,099**	**9,669**	**11,062**	**16,775**	**20,927**
UfW	53%	40%	37%	37%	37%
Required Water Production	**10,854**	**13,515**	**15,100**	**22,898**	**28,566**

The current production capacity is **1,667m^3/day** plus 1,100m^3/d taken from the Sasumua pipeline, which is only 14% of the current (year 2010) water demand of 12,133m^3/d.

4.5.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

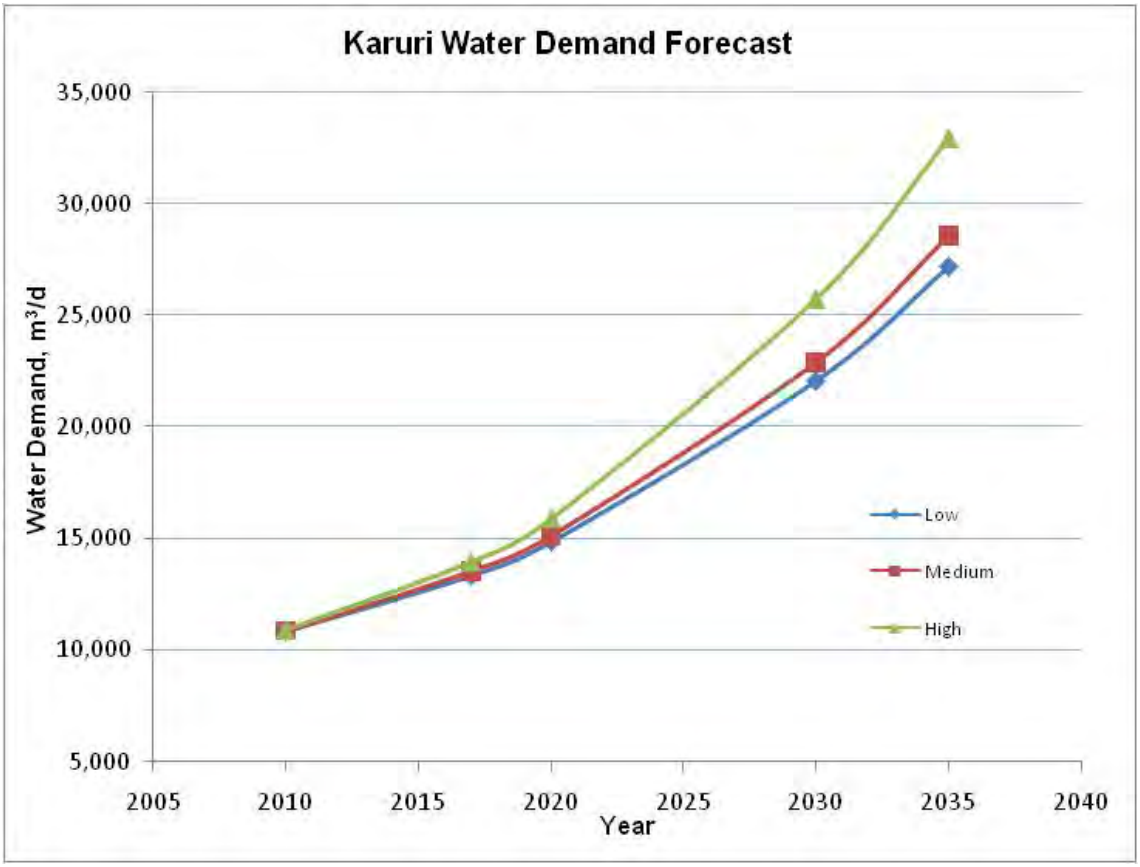
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-56 on page 4-36 and presented in graphical form as shown in **Figure 4-6** on page 4-36.

Table 4.56: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	134,064	164,957	179,945	231,832	261,906
	Growth Rate	3.2%	3.0%	2.9%	2.6%	2.5%
Medium scenario	Population	134,234	167,433	183,139	241,188	276,110
	Growth Rate	3.3%	3.2%	3.0%	2.8%	2.7%
High scenario	Population	134,705	171,986	191,277	267,230	313,845
	Growth Rate	3.7%	3.6%	3.6%	3.4%	3.3%
Income Distribution						
Low Income - 25%		Medium Income - 65%		High Income - 10%		
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		20%	28%	32%	48%	58%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		10,838	13,313	14,850	22,050	27,180
Medium scenario		10,854	13,515	15,100	22,898	28,566
High scenario		10,895	13,943	15,879	25,711	32,947

Year 2009 Karuri Area Census Population - 129,934

Figure 4-6: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.6 Water Demand Forecast – Githunguri Town

4.6.1 Domestic Water Demand

Table 4-57 gives the projected Domestic Water Demand for Githunguri Sub-Location.

Table 4-57: Projected Domestic Water Demand

Year	l/c/day	2010	2017	2020	2030	2035
Population Served		18,147	21,279	22,714	27,688	30,570
High Income	150	54	64	68	83	92
Medium Income	100	1,325	1,553	1,658	2,021	2,232
Low income	50	227	266	284	346	382
Total Water Demand, m^3/d		**1,606**	**1,883**	**2,010**	**2,450**	**2,705**

4.6.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities was compiled in previous studies[3]. The population in the Education Sector is expected to grow at the general population growth rate.

The Water Demand Projection for the Education Sector is given in Table 4-58.

Table 4-58: Projected Water Demand for Education Sector

Year	l/c/d	2010	2017	2020	2030	2035
Annual growth rate		2.4%	2.3%	2.2%	2.0%	2.0%
Total Enrolment		**5,684**	**6,665**	**7,114**	**8,672**	**9,575**
Enrolment Day School (75%)		4,263	4,999	5,336	6,504	7,181
Enrolment Boarding School (25%)		1,421	1,666	1,779	2,168	2,394
Water demand Day school	25	107	125	133	163	180
Water demand Boarding school	50	71	83	89	108	120
Total Water Demand		**178**	**208**	**222**	**271**	**299**

Health Sector

At present, there is 1 hospital and 10 Health Centres / Clinics in Githunguri Sub-Location. To calculate the water consumption of the hospital, a bed capacity of 150 beds per hospital has been adopted as per Ministry of Health Guidelines. Table 4-59 on page 4-38 gives the water demand forecast for the Health Sector

[3]Mukuyu River Water Project Design Report – Githunguri Water & Sanitation Co. Ltd. – July 2009

Table 4-59: Projected Water Demand for Health Sector

Year	l/c/d	2010	2017	2020	2030	2035
Growth Rate		2.4%	2.3%	2.2%	2.0%	2.0%
No. of Hospitals		1	1	1	2	2
No. of Clinics		10	12	13	15	17
Water Demand - Hospitals	$30m^3/d$	30	35	38	46	51
Water Demand - Clinics	$5m^3/d$	50	59	63	76	84
Total Demand - Health Sector		**80**	**94**	**100**	**122**	**135**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector. The demand for Administrative Sector has been projected to grow at the general population growth rate. Table 4-60 gives the water demand forecast for the Administrative Sector.

Table 4-60: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Population		18,147	21,279	22,714	27,688	30,570
Water Demand Administration	**1**	**18**	**21**	**23**	**28**	**31**

4.6.3 Commercial & Industrial Water Demand

Commercial activity in Githunguri Sub-Location is concentrated in Githunguri Town and is dominated by small scale enterprises comprising of General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists etc. The main industry in the area is a milk dairy.

It is assumed that the future increase in commercial and industrial activity is likely to be associated with the growth in the population of the Town.

An inventory of existing Commercial / Industries was prepared in a previous Report[2] and projected a water demand of $120m^3$/day by the year 2010.

The projected Commercial and Industrial Water Demand for Githunguri is shown in Table 4-61.

Table 4-61: Projected Water Demand for Commercial and Industrial Sector

Year	2010	2017	2020	2030	2035
Growth	2.4%	2.3%	2.2%	2.0%	2.0%
Commercial Water Demand	100	117	125	153	168
Industrial Water Demand	20	23	25	31	34
Total Commercial/Industrial	**120**	**141**	**150**	**183**	**202**

4.6.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which has been estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035. The Overall Water Demand is shown in Table 4-62 on page 4-39.

Table 4-62: Overall Projected Water Demand for Githunguri Sub-Location

Year	2010	2017	2020	2030	2035
Total Population	**18,147**	**21,279**	**22,714**	**27,688**	**30,570**
Domestic water demand	1,606	1,883	2,010	2,450	2,705
Education water demand	178	208	222	271	299
Health water demand	80	94	100	122	135
Administration water demand	18	21	23	28	31
Commercial water demand	100	117	125	153	168
Industrial water demand	20	23	25	31	34
Total Water demand, m^3/d	**2,002**	**2,347**	**2,506**	**3,054**	**3,372**
UfW	53%	40%	37%	37%	37%
Required Water Production, m^3/d	**3,060**	**3,281**	**3,420**	**4,169**	**4,603**

The current (year 2010) water supply to Githunguri Town is **2,308 m^3/day**, which is only 62% of the water demand of 3,699m^3/d.

4.6.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

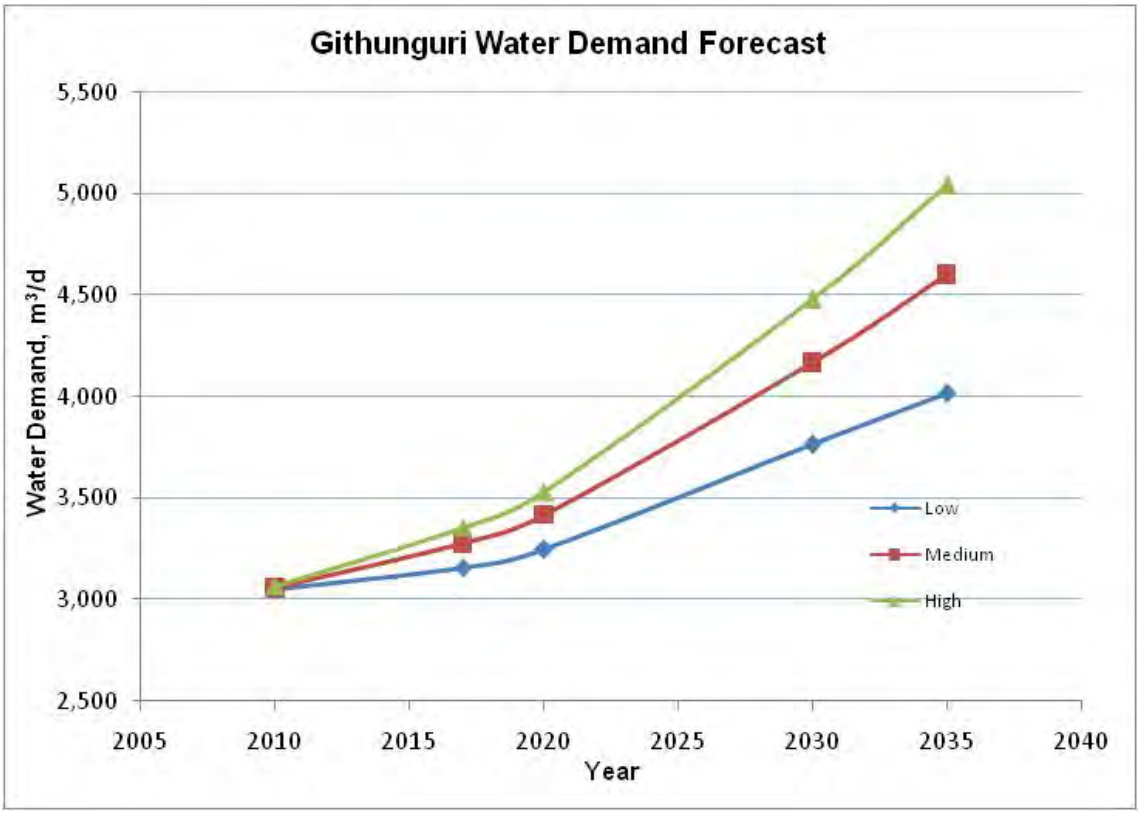
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-63 on page 4-40 and presented in graphical form as shown in **Figure 4-7** on page 4-40.

Table 4-63: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	18,076	20,481	21,543	25,002	26,670
	Growth Rate	2.0%	1.8%	1.7%	1.5%	1.3%
Medium scenario	Population	18,147	21,279	22,714	27,688	30,570
	Growth Rate	2.4%	2.3%	2.2%	2.0%	2.0%
High scenario	Population	18,218	21,804	23,481	29,765	33,513
	Growth Rate	2.8%	2.6%	2.5%	2.4%	2.4%
Income Distribution						
Low Income - 25%		Medium Income - 73%		High Income - 2%		
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		100%	100%	100%	100%	100%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		3,051	3,160	3,246	3,767	4,019
Medium scenario		3,060	3,281	3,420	4,169	4,603
High scenario		3,070	3,359	3,533	4,479	5,042

Year 2009 Githunguri Town Census Population - 17,722

Figure 4-7: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.7 Water Demand Forecast – Mavoko Municipality

4.7.1 Domestic Water Demand

The Category of Peri-Urban areas has been added in Mavoko Municipality whereby Rural areas are developing into Urban areas. The demand per capita for Peri-Urban is the mean between Medium and Low income.

Table 4-64 gives the projected water demand in Mavoko Municipality area.

Table 4-64: Projected Domestic Water Demand

Area	Population Category	l/c/day	Projected Water Demand (m^3/day)				
			2010	2017	2020	2030	2035
Mlolongo	**Population**		60,245	138,521	181,140	346,519	435,706
	Urban Areas						
	High Income	150	48	201	333	1,161	1,601
	Medium Income	100	423	1,765	2,913	10,167	14,021
	Low income	50	147	612	1,011	3,527	4,864
	Peri-urban Areas	90	46	122	267	697	895
	Urban NOT served	30	1,273	2,812	3,443	4,417	4,963
	Peri-urban NOT served	20	196	244	237	232	243
	Water Demand		**2,134**	**5,757**	**8,203**	**20,200**	**26,587**
Athi River	**Population**		56,878	78,685	88,069	117,289	135,344
	Urban Areas						
	High Income	150	117	189	239	413	537
	Medium Income	100	1,027	1,652	2,091	3,622	4,706
	Low income	50	356	573	725	1,256	1,632
	Peri-urban Areas	90	22	75	105	243	325
	Urban NOT served	30	1,013	1,316	1,357	1,393	1,345
	Peri-urban NOT served	20	93	95	93	81	72
	Water Demand		**2,630**	**3,900**	**4,610**	**7,009**	**8,617**
Kitengela	**Population**		26,154	36,633	41,513	58,511	66,955
	Urban Areas						
	High Income	150	30	54	83	154	197
	Medium Income	100	262	473	730	1,352	1,723
	Low income	50	91	164	253	469	598
	Peri-urban Areas	90	34	78	165	336	414
	Urban NOT served	30	418	586	582	718	749
	Peri-urban NOT served	20	144	157	147	139	138
	Water Demand		**979**	**1,513**	**1,962**	**3,167**	**3,819**
	Total Population		**143,278**	**253,840**	**310,722**	**522,319**	**638,005**
	Total Domestic Water Demand, m3/d		**5,743**	**11,170**	**14,775**	**30,376**	**39,023**

4.7.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities has been compiled with the number of schools is expected to grow at the population growth rate. Table 4-65 on page 4-42 summarizes the forecast water demand for Education.

Table 4-65: Water Demand for Education

Area	Year	l/c/day	2010	2017	2020	2030	2035
Mlolongo	Annual growth rate		18.00%	14.00%	10.00%	7.00%	4.80%
	Total Enrolment		**4,402**	**11,014**	**14,660**	**28,838**	**36,456**
	Day School Enrolment(75%)		3,301	8,261	10,995	21,628	27,342
	Boarding School Enrolment (25%)		1,100	2,754	3,665	7,209	9,114
	Day School Water Demand (m3/d)	25	83	207	275	541	684
	Boarding School Water Demand (m3	50	55	138	183	360	456
	Sub-Total Water Demand		**138**	**344**	**458**	**901**	**1,139**
Athi River	Annual growth rate		6.00%	5.00%	4.00%	3.00%	3.00%
	Total Enrolment		**3,445**	**4,847**	**5,452**	**7,327**	**8,494**
	Day School Enrolment(75%)		2,583	3,635	4,089	5,495	6,371
	Boarding School Enrolment (25%)		861	1,212	1,363	1,832	2,124
	Day School Water Demand (m3/d)	25	65	91	102	137	159
	Boarding School Water Demand (m3	50	43	61	68	92	106
	Sub-Total Water Demand		**108**	**151**	**170**	**229**	**265**
Kitengela	Annual growth rate		7.00%	6.00%	5.00%	4.00%	3.00%
	Total Enrolment		**2,917**	**4,387**	**5,078**	**7,517**	**8,714**
	Day School Enrolment(75%)		2,188	3,290	3,808	5,637	6,535
	Boarding School Enrolment (25%)		729	1,097	1,269	1,879	2,178
	Day School Water Demand (m3/d)	25	55	82	95	141	163
	Boarding School Water Demand (m3	50	36	55	63	94	109
	Sub-Total Water Demand		**91**	**137**	**159**	**235**	**272**
	Total Education Water Demand		**336**	**633**	**787**	**1,365**	**1,677**

Health Sector

An inventory of existing facilities was compiled in previous studies and has been projected to grow at the general population growth rate. To calculate the water consumption per hospital, a bed capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-66 gives the projected Health Sector water demand within the study area.

Table 4-66: Projected Water Demand for Health

Area	Year	m^3 / centre / day	2010	2017	2020	2030	2035
Mlolongo	Growth rate		**18.00%**	**14.00%**	**10.00%**	**7.00%**	**4.80%**
	No. Hospitals		-	-	-	-	-
	No. Health Centres		9	23	30	60	76
	Hospitals Water Demand	30	-	-	-	-	-
	Health Centres Water Demand	5	46	114	152	300	379
	Sub-Total		**46**	**114**	**152**	**300**	**379**
Athi River	Growth rate		**6.00%**	**5.00%**	**4.00%**	**3.00%**	**3.00%**
	No. Hospitals		-	-	-	-	-
	No. Health Centres		7	9	11	14	16
	Hospitals Water Demand	30	-	-	-	-	-
	Health Centres Water Demand	5	33	47	53	71	82
	Sub-Total		**33**	**47**	**53**	**71**	**82**
Kitengela	Growth rate		**7.00%**	**6.00%**	**5.00%**	**4.00%**	**3.00%**
	No. Hospitals		-	-	-	-	-
	No. Health Centres		3	4	5	7	8
	Hospitals Water Demand	30	-	-	-	-	-
	Health Centres Water Demand	5	14	21	24	36	42
	Sub-Total		**14**	**21**	**24**	**36**	**42**
Total Health Water Demand, m^3/d			**205**	**402**	**506**	**896**	**1,107**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector water demand. The demand for Administrative Sector has been projected to grow at the general population growth rate.

Table 4-67 gives the water demand forecast for Administrative Sector for the study area.

Table 4-67: Projected Water Demand for Public Administration

Area	Year	l/c/d	2010	2017	2020	2030	2035
Mlolongo	Population		60,245	138,521	181,140	346,519	435,706
	Sub-Total	**1**	**60**	**139**	**181**	**347**	**436**
Athi River	Population		56,878	78,685	88,069	117,289	135,344
	Sub-Total	**1**	**57**	**79**	**88**	**117**	**135**
Kitengela	Population		26,154	36,633	41,513	58,511	66,955
	Sub-Total	**1**	**26**	**37**	**42**	**59**	**67**
Total Admin. Water Demand, m^3/d			**143**	**254**	**311**	**522**	**638**

4.7.3 Commercial & Industrial Water Demand

The commercial activities within the study area include shops, offices, banks, hotels and restaurants. At present most of the commercial activities are located along the major highways and within Athi River Town Centre. It is however envisaged that the commercial centres will be mixed with residential areas in future.

The Study Area is an industrial hub and hosts the EPZA (Export Processing Zone) and several other major industries. An inventory of existing Commercial Institutions / Industries was prepared by a previous study[1] in year 2005 and the water demand estimates given. The water demands given in year 2005 have been projected based on population growth rates to achieve the present and future water demand estimates.

The EPZA at Athi River was established in 1992 and the first industrial operation began in 1995. In order to meet the immediate water supply requirements, the Nairobi City Council water supply system was extended to serve EPZ and parts of the Athi River and Kitengela Urban Centres. The phase 1 was built with a design capacity of 20,000 m^3/d.

EPZA water demand has been estimated separately from the other industrial water demands because it prefers to retain its own independent water supply system. The projected water demands have been obtained from the Pre-Final Design Report (1998) prepared by Mangat I B Patel & Partners for EPZA. The report projected the water demands based on medium growth to year 2015 as shown in Table 4-68.

Table 4-68: Mangat I B Patel & Partners, 1998 EPZA Water Demand Estimates

Design Year	1999	2003	2010	2015
Area Developed (ha)	17	46	110	160
Water Demands (m^3/d)	2,571	6,857	16,500	24,000
Unit Water Consumption ($m^3/d/ha$)	151	149	150	150

At present, the EPZA development has been slower than projected in the report with only 60ha of the zone developed. Thus EPZA industrial development lags behind by about 5 years. To take into account the slow development and the lower unit water demands for the industrial

zone, the industrial area growth has been projected to attain the full development of 160 ha by year 2035 and taking the present unit consumption rate of 50m^3/d/ha.

Table 4-69 gives the water demand forecast for the Industrial and Commercial Sector in the study area.

Table 4-69: Water demand for Industrial and Commercial (m^3/d)

Area	Year	2010	2017	2020	2030	2035
Mlolongo	Annual growth rate	**18.0%**	**14.0%**	**10.0%**	**7.0%**	**4.8%**
	Commercial Water Demand	348	870	1,158	2,278	2,880
	Industrial Water Demand	405	1,013	1,349	2,653	3,354
	Sub-Total	**753**	**1,884**	**2,507**	**4,932**	**6,235**
Athi River	Annual growth rate	**6.0%**	**5.0%**	**4.0%**	**3.0%**	**3.0%**
	Commercial Water Demand	414	582	654	880	1,020
	Industrial Water Demand	522	735	826	1,110	1,287
	Sub-Total	**936**	**1,316**	**1,481**	**1,990**	**2,307**
Kitengela	Annual growth rate	**7.0%**	**6.0%**	**5.0%**	**4.0%**	**3.0%**
	Commercial Water Demand	113	170	196	291	337
	Industrial Water Demand	17	25	29	44	51
	Sub-Total	**130**	**195**	**226**	**334**	**387**
EPZA	Area developed	60	75	105	145	160
	EPZA Water Demand	**3,000**	**3,750**	**5,250**	**7,250**	**8,000**
Total Commercial & Industrial Water Demand, m^3/d		**4,818**	**7,145**	**9,464**	**14,506**	**16,929**

4.7.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which is currently estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035.

The Overall Water Demand for Mlolongo, Athi River and Kitengela areas is shown in the Table 4-70 on page 4-45.

Table 4-70: Water Demands for Mavoko Municipality

Area	Year	2010	2017	2020	2030	2035
Mlolongo	**Population**	**60,245**	**138,521**	**181,140**	**346,519**	**435,706**
	Domestic Water Demand	2,134	5,757	8,203	20,200	26,587
	Education Water Demand	138	344	458	901	1,139
	Health Water Demand	46	114	152	300	379
	Administration Water Demand	60	139	181	347	436
	Commercial Water Demand	348	870	1,158	2,278	2,880
	Industrial Water Demand	405	1,013	1,349	2,653	3,354
	Total Water demand	**3,130**	**8,237**	**11,502**	**26,679**	**34,776**
	UfW	53%	40%	37%	37%	37%
	Required Production	**4,786**	**11,514**	**15,700**	**36,417**	**47,469**
Athi River	**Population**	**56,878**	**78,685**	**88,069**	**117,289**	**135,344**
	Domestic Water Demand	2,630	3,900	4,610	7,009	8,617
	Education Water Demand	108	151	170	229	265
	Health Water Demand	33	47	53	71	82
	Administration Water Demand	57	79	88	117	135
	Commercial Water Demand	414	582	654	880	1,020
	Industrial Water Demand	522	735	826	1,110	1,287
	EPZA	3,000	3,750	5,250	7,250	8,000
	Total Water demand	**6,764**	**9,244**	**11,652**	**16,666**	**19,407**
	UfW	53%	40%	37%	37%	37%
	Required Production	**10,340**	**12,921**	**15,905**	**22,750**	**26,491**
Kitengela	**Population**	**26,154**	**36,633**	**41,513**	**58,511**	**66,955**
	Domestic Water Demand	979	1,513	1,962	3,167	3,819
	Education Water Demand	91	137	159	235	272
	Health Water Demand	14	21	24	36	42
	Administration Water Demand	26	37	42	59	67
	Commercial Water Demand	113	170	196	291	337
	Industrial Water Demand	17	25	29	44	51
	Total Water demand	**1,240**	**1,903**	**2,412**	**3,831**	**4,587**
	UfW	53%	40%	37%	37%	37%
	Required Production	**1,896**	**2,660**	**3,292**	**5,229**	**6,261**
	Total Population	**143,278**	**253,840**	**310,722**	**522,319**	**638,005**
	Total Water Demand, m3/d	**11,134**	**19,384**	**25,566**	**47,176**	**58,770**
	Total Production Required, m3/d	**17,022**	**27,094**	**34,897**	**64,396**	**80,222**

The current production capacity is **2,608m^3/day**, which is only 13.3% of the current (year 2010) water demand of 19,551m^3/d.

4.7.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

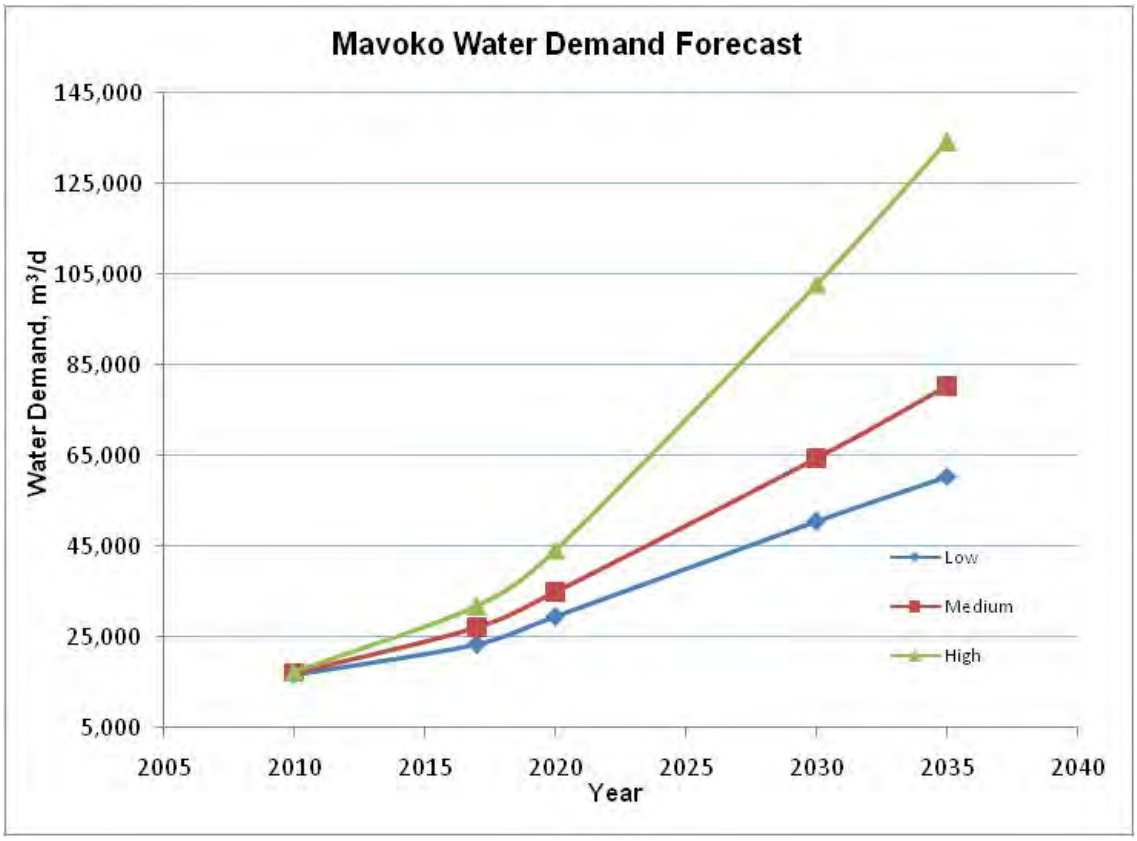
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-71 on Page 4-46 and presented in graphical form as shown in **Figure 4-8** on page 4-46.

Table 4-71: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	139,890	211,232	250,016	389,625	457,594
	Growth Rate	7.0%	6.1%	5.8%	4.5%	3.3%
Medium scenario	Population	143,278	253,840	310,722	522,319	638,005
	Growth Rate	9.6%	8.5%	7.0%	5.3%	4.1%
High scenario	Population	145,662	306,620	413,935	883,001	1,126,028
	Growth Rate	11.4%	11.2%	10.5%	7.9%	5.0%
Income Distribution						
Low Income - 39%			Medium Income - 57%		High Income - 4%	
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		22%	28%	35%	54%	60%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		16,727	23,397	29,473	50,342	60,438
Medium scenario		17,022	27,094	34,897	64,396	80,222
High scenario		17,238	31,728	44,226	102,853	134,123

Year 2009 Mavoko Municipality Area Census Population - 130,768

Figure 4-8: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.8 Water Demand Forecast – Ongata Rongai / Ngong / Kiserian Urban Centres

4.8.1 Domestic Water Demand

The Category of Peri-Urban areas has been added in Ngong, Ongata Rongai and Kiserian study areas whereby Rural areas are developing into Urban areas. The demand per capita for Peri-Urban areas is the mean between Medium and Low income.

Table 4-72 gives the projected water demand in Ngong, Ongata Rongai and Kiserian areas.

Table 4-72: Projected Domestic Water Demand

Area	Population Category	l/c/day	Projected Water Demand (m^3/day)				
			2010	2017	2020	2030	2035
Ngong	**Population**		65,594	85,785	95,344	126,732	146,252
	Urban Areas						
	High Income	150	29	80	134	307	395
	Medium Income	100	256	698	1,178	2,689	3,463
	Low income	50	89	242	409	933	1,201
	Peri-urban Areas	90	91	216	466	1,135	1,567
	Urban NOT served	30	1,225	1,482	1,459	1,428	1,504
	Peri-urban NOT served	20	384	432	414	378	348
	Water Demand		**2,075**	**3,151**	**4,059**	**6,871**	**8,479**
Ongata Rongai	**Population**		123,711	184,078	213,565	313,961	374,802
	Urban Areas						
	High Income	150	52	132	215	774	1,041
	Medium Income	100	458	1,157	1,881	6,780	9,120
	Low income	50	159	401	652	2,352	3,164
	Peri-urban Areas	90	0	239	515	1,256	1,560
	Urban NOT served	30	2,797	4,111	4,550	4,772	5,246
	Peri-urban NOT served	20	447	478	458	419	424
	Water Demand		**3,914**	**6,519**	**8,271**	**16,353**	**20,555**
Kiserian	**Population**		34,019	45,155	50,734	69,013	80,609
	Urban Areas						
	High Income	150	15	42	72	187	243
	Medium Income	100	133	370	634	1,640	2,125
	Low income	50	46	129	220	569	737
	Peri-urban Areas	90	0	1,113	1,199	1,461	1,613
	Urban NOT served	30	638	787	786	712	752
	Peri-urban NOT served	20	208	223	213	195	197
	Water Demand		**1,041**	**2,664**	**3,124**	**4,765**	**5,667**
	Total Population		**223,324**	**315,018**	**359,643**	**509,706**	**601,663**
	Total Domestic Water Demand, m^3/d		**7,029**	**12,333**	**15,454**	**27,989**	**34,701**

4.8.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities has been compiled with the number of schools expected to grow at the population growth rate. Table 4-73 on page 4-48 summarizes the forecast water demand for Education.

Table 4-73: Water Demand for Education

Area	Year	l/c/day	2010	2017	2020	2030	2035
Ngong	Annual growth rate		4.80%	4.50%	4.00%	3.20%	3.20%
	Total Enrolment		**9,388**	**12,775**	**14,371**	**19,691**	**23,050**
	Day School Enrolment(75%)		7,041	9,582	10,778	14,768	17,287
	Boarding School Enrolment (25%)		2,347	3,194	3,593	4,923	5,762
	Day School Water Demand (m3/	25	176	240	269	369	432
	Boarding School Water Demand	50	117	160	180	246	288
	Sub-Total Water Demand		**293**	**399**	**449**	**615**	**720**
Ongata Rongai	Annual growth rate		2.70%	2.50%	2.50%	2.00%	2.00%
	Total Enrolment		**7,181**	**8,537**	**9,193**	**11,206**	**12,372**
	Day School Enrolment(75%)		5,386	6,402	6,895	8,405	9,279
	Boarding School Enrolment (25%)		1,795	2,134	2,298	2,802	3,093
	Day School Water Demand (m3/	25	135	160	172	210	232
	Boarding School Water Demand	50	90	107	115	140	155
	Sub-Total Water Demand		**224**	**267**	**287**	**350**	**387**
Kiserian	Annual growth rate		5.20%	4.80%	4.50%	3.50%	3.50%
	Total Enrolment		**5,492**	**7,625**	**8,701**	**12,274**	**14,577**
	Day School Enrolment(75%)		4,119	5,719	6,526	9,205	10,933
	Boarding School Enrolment (25%)		1,373	1,906	2,175	3,068	3,644
	Day School Water Demand (m3/	25	103	143	163	230	273
	Boarding School Water Demand	50	69	95	109	153	182
	Sub-Total Water Demand		**172**	**238**	**272**	**384**	**456**
Total Education Water Demand, m3/d			**689**	**904**	**1,008**	**1,349**	**1,562**

Health Sector

An inventory of existing facilities was compiled in previous studies and has been projected to grow at the general population growth rate. To calculate the water consumption per hospital, a bed capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-74 gives the projected Health water demand within the study area.

Table 4-74: Water Demand for Health

Area	Year	m^3 / day	2010	2017	2020	2030	2035
Ngong	Growth rate		**4.80%**	**4.50%**	**4.00%**	**3.20%**	**3.20%**
	No. Hospitals		-	-	-	-	-
	No. Health Centres		20	28	31	42	50
	Hospitals Water Demand	30	-	-	-	-	-
	Health Centres Water Demand	5	101	138	155	212	248
	Sub-Total		**101**	**138**	**155**	**212**	**248**
Ongata Rongai	Growth rate		**8.50%**	**6.50%**	**5.50%**	**4.20%**	**3.80%**
	No. Hospitals		-	-	-	-	-
	No. Health Centres		15	23	27	41	50
	Hospitals Water Demand	30	-	-	-	-	-
	Health Centres Water Demand	5	75	117	137	207	249
	Sub-Total		**75**	**117**	**137**	**207**	**249**
Kiserian	Growth rate		**5.20%**	**4.80%**	**4.50%**	**3.50%**	**3.50%**
	No. Hospitals		-	-	-	-	-
	No. Health Centres		6	9	10	14	17
	Hospitals Water Demand	30	-	-	-	-	-
	Health Centres Water Demand	5	32	45	51	72	86
	Sub-Total		**32**	**45**	**51**	**72**	**86**
Total Health Water Demand, m^3/d			**459**	**658**	**755**	**1,081**	**1,283**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector. The demand for Administrative Sector has been projected to grow at the general population growth rate.

Table 4-75 gives the water demand forecast for Administrative Sector for the Study Area.

Table 4-75: Projected Water Demand for Public Administration

Area	Year	l/c/d	2010	2017	2020	2030	2035
Ngong	Population		65,594	85,785	95,344	126,732	146,252
	Sub-Total	**1**	**66**	**86**	**95**	**127**	**146**
Ongata Rongai	Population		123,711	184,078	213,565	313,961	374,802
	Sub-Total	**1**	**124**	**184**	**214**	**314**	**375**
Kiserian	Population		34,019	45,155	50,734	69,013	80,609
	Sub-Total	**1**	**34**	**45**	**51**	**69**	**81**
Total Admin. Water Demand, m^3/d			**223**	**315**	**360**	**510**	**602**

4.8.3 Commercial & Industrial Water Demand

The commercial activity in Ngong, Ongata Rongai and Kiserian areas is dominated by small scale enterprises engaged in trade and services. The main Business Entities comprises of General Shops / Hardware, Bars / Restaurants, Petrol Stations, Chemists etc. It is assumed that the future increase in commercial activity is likely to be associated with the general population growth of areas. Presently there are no industries within the study area.

An inventory of existing Commercial Institutions / Industries was prepared in a previous study in year 2005 and the water demand estimates given. The water demands given in year 2005 have been projected based on population growth rates to achieve the present and future water demand estimates.

Table 4-76 gives the water demand forecast for the Industrial and Commercial Sector in the study area.

Table 4-76: Projected Industrial and Commercial Water Demand (m^3/d)

Area	Year	2010	2017	2020	2030	2035
Ngong	Annual growth rate	**4.8%**	**4.5%**	**4.0%**	**3.2%**	**3.2%**
	Commercial Water Demand	316	393	478	560	656
	Industrial Water Demand	-	-	-	-	-
	Sub-Total	**316**	**393**	**478**	**560**	**656**
Ongata Rongai	Annual growth rate	**8.5%**	**6.5%**	**5.5%**	**4.2%**	**3.8%**
	Commercial Water Demand	343	470	615	755	910
	Industrial Water Demand	-	-	-	-	-
	Sub-Total	**343**	**470**	**615**	**755**	**910**
Kiserian	Annual growth rate	**5.2%**	**4.8%**	**4.5%**	**3.5%**	**3.5%**
	Commercial Water Demand	143	180	225	267	317
	Industrial Water Demand	-	-	-	-	-
	Sub-Total	**143**	**180**	**225**	**267**	**317**
Total Comm. & Indu. Water Demand, m3/d		**801**	**1,044**	**1,318**	**1,582**	**1,882**

4.8.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which is currently estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035.

The Overall Water Demand for Ngong, Ongata Rongai and Kiserian Areas is shown in the following Table 4-77.

Table 4-77: Overall Projected Water Demands for Ngong, Ongata Rongai & Kiserian Areas

Area	Year	2010	2017	2020	2030	2035
Ngong	**Population**	**65,594**	**85,785**	**95,344**	**126,732**	**146,252**
	Domestic Water Demand	2,075	3,151	4,059	6,871	8,479
	Education Water Demand	293	399	449	615	720
	Health Water Demand	101	138	155	212	248
	Administration Water Demand	66	86	95	127	146
	Commercial Water Demand	316	429	483	662	775
	Industrial Water Demand	-	-	-	-	-
	Total Water demand, m^3/d	**2,851**	**4,203**	**5,241**	**8,487**	**10,368**
	UfW	53%	40%	37%	37%	37%
	Required Production, m^3/d	**4,358**	**5,874**	**7,154**	**11,585**	**14,153**
Ongata Rongai	**Population**	**123,711**	**184,078**	**213,565**	**313,961**	**374,802**
	Domestic Water Demand	3,914	6,519	8,271	16,353	20,555
	Education Water Demand	224	267	287	350	387
	Health Water Demand	75	117	137	207	249
	Administration Water Demand	124	184	214	314	375
	Commercial Water Demand	343	534	626	945	1,139
	Industrial Water Demand	-	-	-	-	-
	Total Water demand, m^3/d	**4,680**	**7,620**	**9,535**	**18,169**	**22,705**
	UfW	53%	40%	37%	37%	37%
	Required Production, m^3/d	**7,156**	**10,651**	**13,016**	**24,801**	**30,992**
Kiserian	**Population**	**34,019**	**45,155**	**50,734**	**69,013**	**80,609**
	Domestic Water Demand	1,041	2,664	3,124	4,765	5,667
	Education Water Demand	172	238	272	384	456
	Health Water Demand	32	45	51	72	86
	Administration Water Demand	34	45	51	69	81
	Commercial Water Demand	143	198	226	319	378
	Industrial Water Demand	-	-	-	-	-
	Total Water demand, m^3/d	**1,421**	**3,190**	**3,724**	**5,608**	**6,667**
	UfW	53%	40%	37%	37%	37%
	Required Production, m^3/d	**2,172**	**4,459**	**5,083**	**7,655**	**9,101**
	Total Population	**223,324**	**315,018**	**359,643**	**509,706**	**601,663**
	Total Water Demand, m3/d	**8,952**	**15,013**	**18,500**	**32,264**	**39,740**
	Total Production Required, m3/d	**13,686**	**20,984**	**25,253**	**44,041**	**54,246**

The current production capacity is **4,246m^3/day**, which is only 27.1% of the current (year 2010) water demand of 15,693m^3/d.

4.8.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

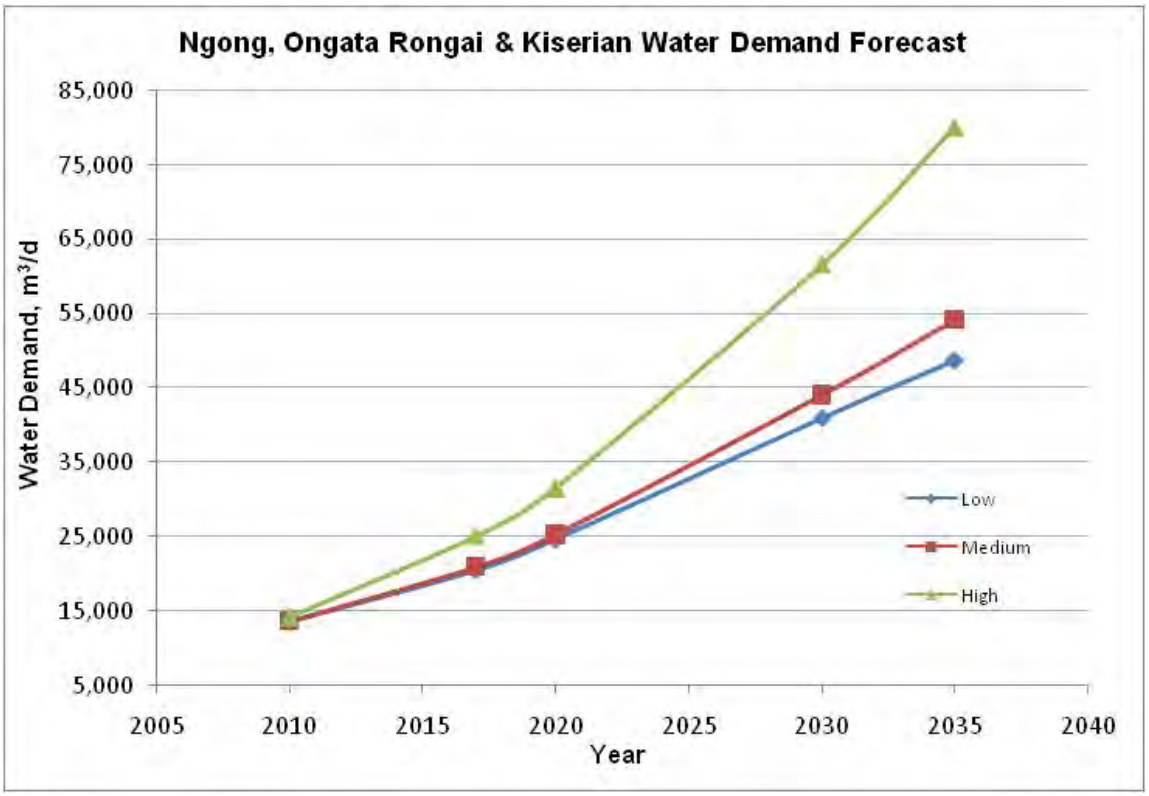
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-78 on Page 4-52 and presented in graphical form as shown in **Figure 4-9** on page 4-52.

Table 4-78: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	221,923	307,807	350,925	472,144	537,249
	Growth Rate	5.3%	4.8%	4.5%	3.0%	2.6%
Medium scenario	Population	223,324	315,018	359,643	509,706	601,663
	Growth Rate	6.0%	5.0%	4.5%	3.5%	3.4%
High scenario	Population	230,509	379,022	454,383	725,542	905,534
	Growth Rate	9.4%	7.4%	6.2%	4.8%	4.5%
Income Distribution						
Low Income - 39%		Medium Income - 57%		High Income - 4%		
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		7%	15%	22%	45%	50%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		13,580	20,537	24,698	41,051	48,806
Medium scenario		13,686	20,984	25,253	44,041	54,246
High scenario		14,230	25,168	31,602	61,764	80,112

Year 2009 Ngong, Ongata Rongai & Kiserian Areas Census Population - 210,746

Figure 4-9: Graph showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.9 Water Demand Forecast – Thika Municipality

4.9.1 Domestic Water Demand

Table 4-79 gives the projected Domestic Water Demand for Thika Municipality.

Table 4-79: Domestic Water Demand for Thika Municipality

Year	l/c/day	2010	2017	2020	2030	2035
Total Population		145,133	197,633	222,425	311,501	360,777
Urban Areas						
High Income	150	613	954	1,150	1,797	2,147
Medium Income	100	4,823	7,505	9,044	14,140	16,891
Low income	50	1,472	2,290	2,759	4,314	5,153
Rural Areas	60	1,031	1,296	1,475	2,002	2,282
Urban NOT served	30	613	673	568	459	452
Rural NOT served	20	515	528	512	464	428
Total Water Demand, m^3/d		**9,067**	**13,245**	**15,509**	**23,176**	**27,353**

4.9.2 Institutional Water Demand

Education Sector

Numbers of students in schools and universities was obtained from the District Education Office. The population in the Education Sector is expected to grow at the general population growth rate. The Water Demand Projection for the Education Sector is given in Table 4-80.

Table 4-80: Projected Water Demand for Education Sector

Year	l/c/d	2010	2017	2020	2030	2035
Annual growth rate		5.8%	5.6%	4.8%	4.0%	3.4%
Total Enrolment - Schools and Universities		**42,390**	**62,074**	**71,449**	**105,762**	**125,006**
Enrolment Day Schools & Non-resident Students (75%)		31,793	46,556	53,587	79,321	93,754
Enrolment Boarding Schools & Resident Students (25%)		10,598	15,519	17,862	26,440	31,251
Water demand Day schools and Non-resident students	25	795	1,164	1,340	1,983	2,344
Water demand - Boarding schools & Resident Students	50	530	776	893	1,322	1,563
Total Water Demand, m^3/d		**1,325**	**1,940**	**2,233**	**3,305**	**3,906**

Health Sector

Numbers of health facilities including hospitals, health centres and clinics in the Municipality was obtained from the District Health Office. To calculate the water consumption per hospital, a bed capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-81 on page 4-54 gives the water demand forecast for the Health Sector.

Table 4-81: Projected Water Demand for Health Sector

Year	m^3/d	2010	2017	2020	2030	2035
Growth Rate		5.8%	5.6%	4.8%	4.0%	3.4%
No. of Hospitals		2	3	3	5	6
No. of Clinics		43	63	72	107	127
Water Demand - Hospitals	30	60	88	101	150	177
Water Demand - Clinics	5	215	315	362	536	634
Total Water Demand, m^3/d		**275**	**403**	**464**	**686**	**811**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector. The demand for Administrative Sector has been projected to grow at the general population growth rate. Table 4-82 gives the water demand forecast for the Administrative Sector.

Table 4-82: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Population		145,133	197,633	222,425	311,501	360,777
Total Water Demand, m^3/d	**1**	**145**	**198**	**222**	**312**	**361**

4.9.3 Commercial & Industrial Water Demand

Thika Town is the main commercial hub in the study area. The main Business Entities comprises of General Shops / Hardwares, Bars / Restaurants, Petrol Stations, Chemists etc

There are about 30 manufacturing / processing Industries established in the Town. The Manufacturing / Processing Industries mainly comprise of car assembly, edible oil refining, food processing, tobacco processing, leather products, textiles, etc.

An inventory of existing Commercial Institutions / Industries was compiled in a previous study [4] and projected a water demand of 4,165m^3/day by the year 2010.

Growth in commercial and industrial activity in Thika Municipality is likely to be associated with the growth in the population of the Municipality. With the completion of the on-going Thika-Nairobi Highway construction, it is anticipated that Thika Municipality will attract an upsurge of commercial and industrial activity. The commercial and industrial water demand for Thika Municipality has been projected to grow at the general population growth rate as shown in Table 4-83 on page 4-55.

[4]Thika Sewerage Masterplan– Mangat I.B. Patel &Partners – April 1997

Table 4-83: Projected Water Demand for Commercial and Industrial Sector

Year	2010	2017	2020	2030	2035
Growth	5.8%	5.6%	4.8%	4.0%	3.4%
Commercial Water Demand	630	923	1,062	1,572	1,858
Industrial Water Demand	3,165	4,635	5,335	7,897	9,333
Total Water Demand, m^3/d	**3,795**	**5,557**	**6,397**	**9,468**	**11,191**

4.9.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (Year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which is currently estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035. The Overall Water Demand is shown in Table 4-84.

Table 4-84: Overall Projected Water Demand for Thika Municipality

Year	2010	2017	2020	2030	2035
Population	**145,133**	**197,633**	**222,425**	**311,501**	**360,777**
Domestic water demand	9,067	13,245	15,509	23,176	27,353
Education water demand	1,325	1,940	2,233	3,305	3,906
Health water demand	275	403	464	686	811
Administration water demand	145	198	222	312	361
Commercial water demand	630	923	1,062	1,572	1,858
Industrial water demand	3,165	4,635	5,335	7,897	9,333
Total Water demand, m^3/d	**14,607**	**21,343**	**24,824**	**36,947**	**43,622**
UfW	53%	40%	37%	37%	37%
Total Production Required, m^3/d	**22,331**	**29,832**	**33,885**	**50,432**	**59,545**

The installed production capacity in the Thika Water Supply System is 36,000m^3/day. Actual production is currently approximately 26,000m^3/day. The installed capacity of the Thika Water Supply System is sufficient to meet the current (year 2010) water demand of the Municipality, estimated to be 25,508m^3/day.

4.9.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

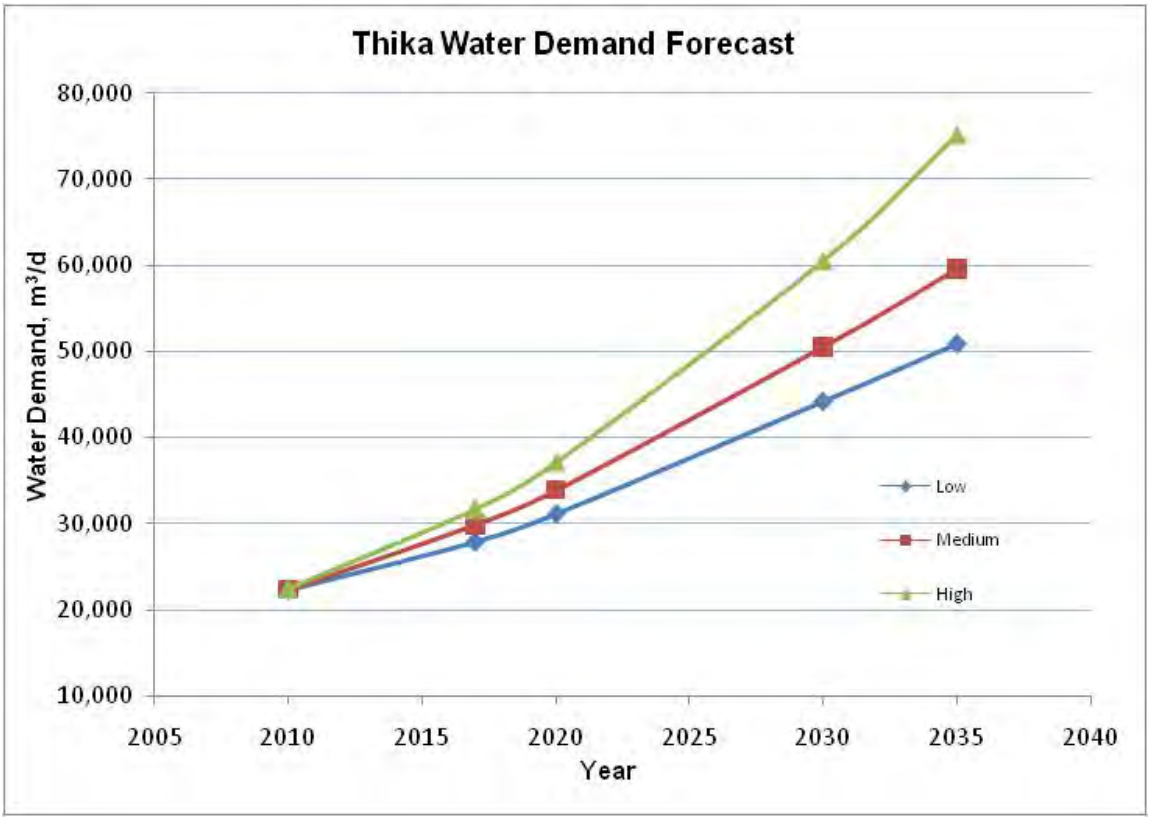
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-85 on Page 4-56 and presented in graphical form as shown in **Figure 4-10** on page 4-56.

Table 4-85: Water Demand Forecast at High, Medium and Low Population Growth Rates

Year		2010	2017	2020	2030	2035
Low scenario	Population	144,361	186,005	206,328	276,799	312,941
	Growth Rate	4.0%	3.7%	3.5%	3.0%	2.5%
Medium scenario	Population	145,133	197,633	222,425	311,501	360,777
	Growth Rate	4.6%	4.5%	4.0%	3.4%	3.0%
High scenario	Population	145,990	208,754	241,846	368,188	447,553
	Growth Rate	5.2%	5.2%	5.0%	4.3%	4.0%
Income Distribution						
Low Income - 36%			Medium Income - 59%		High Income - 5%	
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		68%	75%	80%	88%	90%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		22,243	27,795	31,064	44,157	50,903
Medium scenario		22,331	29,832	33,885	50,432	59,545
High scenario		22,424	31,669	37,152	60,559	75,235

Year 2009 Thika Town Census Population - 138,772

Figure 4-10: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.10 Water Demand Forecast – Limuru Town

4.10.1 Domestic Water Demand

In Limuru another category is added, namely Peri-Urban, where Rural areas are developing into Urban areas. The demand per capita for Peri-Urban is the mean between Medium and Low Income. Table 4-86 gives the projected water demand in Limuru Demand Area

Table 4-86: Projected Domestic Water Demand

Year	l/c/day	2010	2017	2020	2030	2035
Population served		38,739	47,372	51,449	63,233	69,814
Urban Areas						
High Income	150	27	38	48	69	82
Medium Income	100	652	922	1,161	1,682	2,005
Low income	50	112	158	199	288	343
Rural Areas	90	148	358	579	1,080	1,324
Urban NOT served	30	402	445	423	406	388
Rural NOT served	20	295	319	300	293	294
Total Water Demand, m^3/d		**1,635**	**2,240**	**2,710**	**3,818**	**4,437**

4.10.2 Institutional Water Demand

Education Sector

An inventory of the existing Education Facilities has been compiled and is expected to have a similar growth rate as the population.

School attendance has been estimated from the demographic data (population in age of attending school) and from enrolment information collected from the relevant offices. The projected water demands for the Education Sector is given in Table 4-87.

Table 4-87: Projected Water Demand for Education Sector

Year	l/c/d	2010	2017	2020	2030	2035
Annual growth rate		3.0%	3.0%	3.0%	2.0%	2.0%
Total Enrolment		**11,622**	**14,293**	**15,619**	**19,039**	**21,021**
Enrolment Day School (75%)		8,716	10,720	11,714	14,279	15,766
Enrolment Boarding School (25%)		2,905	3,573	3,905	4,760	5,255
Water demand Day school	25	218	268	293	357	394
Water demand Boarding school	50	145	179	195	238	263
Total Water Demand, m^3/d		**363**	**447**	**488**	**595**	**657**

Health Sector

An inventory of existing facilities has been compiled and is considered to have a similar growth rate as the population. To calculate the water consumption per hospital, a bed occupancy of 150 has been adopted as per Ministry of Health Guidelines. Table 4-88 on page 4-58 gives the water demand forecast for Health Sector

Table 4-88: Projected Water Demand for Health Sector

Year	m³/d	2010	2017	2020	2030	2035
Growth Rate		3.0%	3.0%	3.0%	2.0%	2.0%
No. of Hospitals		3	4	4	5	5
No. of Clinics		23	28	31	38	42
Water Demand - Hospitals	30	90	111	121	147	163
Water Demand - Clinics	5	115	141	155	188	208
Total Demand - Health Sector, m³/d		**205**	**252**	**276**	**336**	**371**

Administration

A consumption rate of 1 litre/capital per day for Administrative Sector has been applied, based on the Ministry of Water and Irrigation Practices Manual, since there were no available data. The demand for the Administrative Sector is projected to grow at the same growth rate as for the general population. Table 4-89 gives the water demand forecast for Public Administrations.

Table 4-89: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Population		38,739	47,372	51,449	63,233	69,814
Total Water Demand, m³/d	**1**	**39**	**47**	**51**	**63**	**70**

4.10.3 Commercial & Industrial Water Demand

The commercial activity in Limuru is dominated by small scale enterprises engaged in trade and services. These enterprises mainly consist of general shops offering a variety of goods and services for the general needs of the Town and the peri-urban inhabitants. There are four main Industries within the Study area i.e. Bata Shoe Factory, Limuru Fresh Milk Processing Factory Polypipes which manufacture uPVC pipes and Limuru Dairy Farmers. These industries have their own source of water, mainly boreholes but have been included in estimating the water demand requirement. It is assumed that the future increase in commercial / industrial activities is likely to be associated with the growth in the population of the Town. An inventory of existing Commercial Institutions / Industries has been prepared for the purpose of working out the current commercial / industrial demand based on the per capita consumption.

The present Industrial and Commercial water demand for the Study area is estimated at 426m³/ day, based on the information obtained from Limuru Water and Sewerage Company. When expressed as a per capita demand based on the total 2010 projected population of 38,739, the Commercial / Industrial Demand works out to be **11l/capita/day.** Table 4-90 shows the estimated Commercial / Industrial Water Demand.

Table 4-90: Projected Industrial and Commercial Water Demand (m³/d)

Year	l/c/day	2010	2015	2020	2025	2030
Population		38,739	47,372	51,449	63,233	69,814
Commercial Water Demand		180	255	304	452	536
Industrial Water Demand	11	426	521	566	696	768
Total Water Demand, m³/d		**426**	**521**	**566**	**696**	**768**

4.10.4 Overall Water Demand

The overall water demand of the Study Area has been estimated for the Present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the population growth. Unaccounted for Water (UfW) currently estimated at 53 The UfW has however been assumed to progressively decrease to 37% by Year 2035. The Overall Projected water demands are given in Table 4-91.

Table 4-91: Water Demand for Limuru Study Area

Year	2010	2017	2020	2030	2035
Population	**38,739**	**47,372**	**51,449**	**63,233**	**69,814**
Domestic	1,635	2,240	2,710	3,818	4,437
Education	363	447	488	595	657
Health	205	252	276	336	371
Administration	39	47	51	63	70
Commercial	164	224	271	382	444
Industrial	426	521	566	696	768
Total Water demand, m^3/d	**2,832**	**3,731**	**4,362**	**5,890**	**6,746**
UfW	53%	40%	37%	37%	37%
Total Production Required, m^3/d	**4,330**	**5,215**	**5,954**	**8,039**	**9,208**

The current production capacity for Limuru Water Supply is 3,070 m^3/day, which is not adequate to cover the present water demand estimated at 4,777 m^3/day. It covers only 64% of the required present demand.

4.10.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

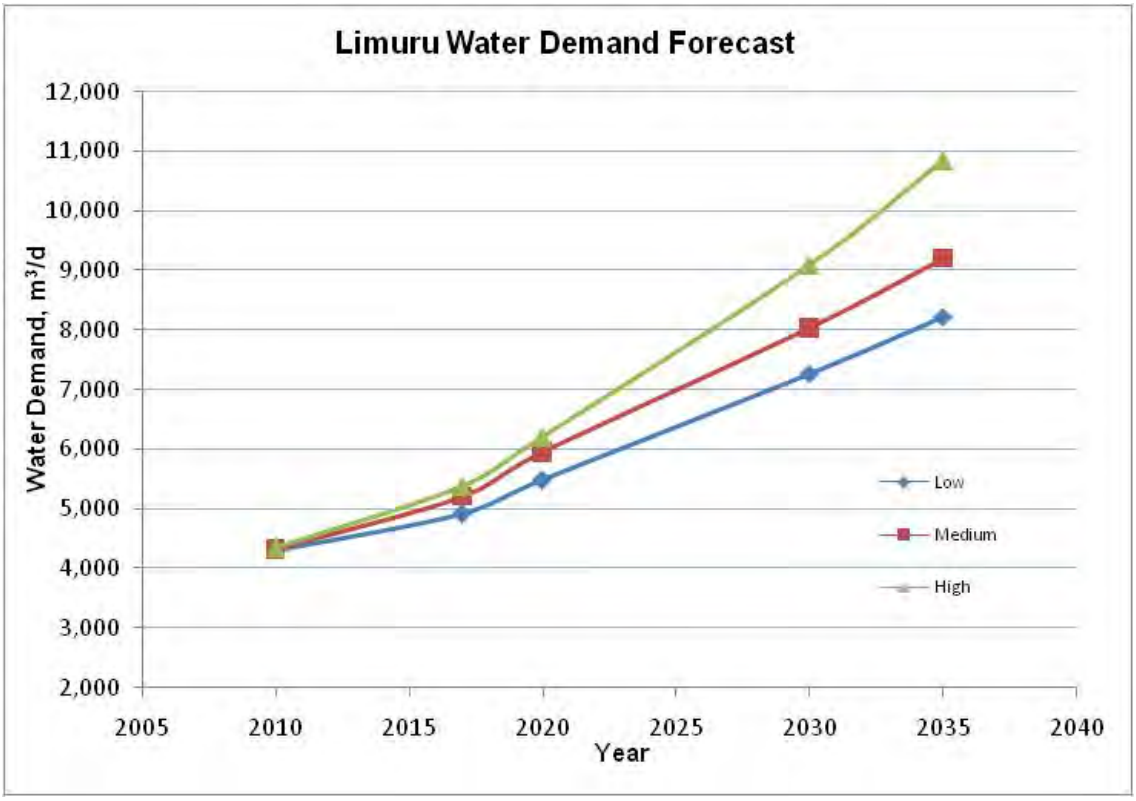
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-92 on page 4-60 and presented in graphical form as shown in **Figure 4-11** on page 4-60.

Table 4-92: Water Demand Forecast at High, Medium and Low Population Growth Rates

Year		2010	2017	2020	2030	2035
Low scenario	Population	38,541	44,624	47,401	56,854	61,910
	Growth Rate	2.5%	2.1%	2.0%	1.8%	1.7%
Medium scenario	Population	38,739	47,372	51,449	63,233	69,814
	Growth Rate	3.0%	2.9%	2.8%	2.1%	2.0%
High scenario	Population	38,880	48,768	53,435	70,426	80,622
	Growth Rate	3.4%	3.3%	3.1%	2.8%	2.7%
Income Distribution						
Low Income - 25%			Medium Income - 73%		High Income - 2%	
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		27%	35%	43%	55%	60%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		4,310	4,915	5,486	7,276	8,225
Medium scenario		4,330	5,215	5,954	8,039	9,208
High scenario		4,345	5,386	6,200	9,087	10,847

Year 2009 Limuru Town Census Population - 37,611

Figure 4-11: Graph showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.11 Water Demand Forecast – Gatundu Town

4.11.1 Domestic Water Demand

It is anticipated that the Rural Areas added in the study area are likely to develop into urban areas in future. The per capita demand for rural areas has been taken to be the same as Low income per capita rate for urban areas. Table 4-93 gives the projected domestic water demand in Gatundu Town Study Area.

Table 4-93: Projected Domestic Water Demand

Category	l/c/day	Projected Water Demand (m^3/day)				
		2010	2017	2020	2030	2035
Population served		15,474	16,799	17,352	18,968	19,799
Urban Areas						
High Income	150	125	139	145	163	173
Medium Income	100	500	555	578	652	692
Low income	50	125	139	145	163	173
Rural Areas	60	429	453	463	486	496
Total Water Demand, m^3/d		**1,178**	**1,285**	**1,330**	**1,464**	**1,534**

4.11.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities has been compiled with the number of schools is expected to grow at the population growth rate. Table 4-94 below summarizes the forecast water demand for Education.

Table 4-94: Projected Education Sector Water Demand

Year	l/c/d	2010	2017	2020	2030	2035
Annual growth rate		1.0%	1.5%	1.4%	1.2%	1.2%
Total Enrolment		**4,334**	**4,810**	**5,014**	**5,650**	**5,997**
Day School Enrolment (75%)		3,250	3,607	3,761	4,237	4,498
Boarding School Enrolment (25%)		1,083	1,202	1,254	1,412	1,499
Day School Water Demand (m^3/d)	25	81	90	94	106	112
Boarding School Water Demand (m^3/d)	50	54	60	63	71	75
Total Water Demand, m^3/d		**135**	**150**	**157**	**177**	**187**

Health Sector

An inventory of existing facilities was compiled in previous studies and has been projected to grow at the general population growth rate. To calculate the water consumption per hospital, a bed capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-95 on page 4-62 gives the projected Health water demand within the study area.

Table 4-95: Projected Health Sector Water Demand

Year		2010	2017	2020	2030	2035
Growth rate		1.00%	1.50%	1.40%	1.20%	1.20%
No. Hospitals		1	1	1	1	1
No. Health Centres		1	1	1	1	1
Hospitals Water Demand	$30m^3/d$	30	33	35	39	42
Health Centres Water Demand	$5m^3/d$	5	6	6	7	7
Total Water Demand, m^3/d		**35**	**39**	**40**	**46**	**48**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector water demand. The demand for Administrative Sector has been projected to grow at the general population growth rate. Table 4-96 gives the water demand forecast for Administrative Sector for the study area.

Table 4-96: Projected Water Demand for Public Administration

Year	l/c/d	2010	2017	2020	2030	2035
Growth rate		1.00%	1.50%	1.40%	1.20%	1.20%
Population		15,474	16,694	17,223	18,832	19,660
Total Water Demand, m^3/d	**1**	**15**	**17**	**17**	**19**	**20**

4.11.3 Commercial & Industrial Water Demand

The commercial activities in Gatundu Urban Centre are dominated by small scale enterprises engaged in trade and services. These enterprises mainly consist of general shops offering a variety of goods and services for the general needs of the town and the rural inhabitants. It is assumed that the future increase in commercial activity is likely to be associated with the growth in the population of towns.

An inventory of existing Commercial / Institution / Industries was prepared by a previous study[5] in year 2009 and the water demand estimates given. The water demands given in year 2009 have been projected based on population growth rates to achieve the present and future water demand estimates.

Table 4.97: Projected Commercial and Industrial Water Demand (m^3/d)

Year	2010	2017	2020	2030	2035
Annual growth rate	**1.0%**	**1.5%**	**1.4%**	**1.2%**	**1.2%**
Commercial water Demand	311	345	360	406	431
Industrial Water Demand	63	70	73	82	87
Total Water Demand, m^3/d	**374**	**415**	**433**	**488**	**518**

[5] Lujo, 2009 study

4.11.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which is currently estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035.

The Overall Water Demand for Gatundu Study Area is shown in Table 4-98.

Table 4-98: Projected Water Demands for Gatundu Town Study Area

Year	2010	2017	2020	2030	2035
Total Population	**15,474**	**16,799**	**17,352**	**18,968**	**19,799**
Domestic Water Demand	1,178	1,285	1,330	1,464	1,534
Education Water Demand	135	150	157	177	187
Health Water Demand	35	39	40	46	48
Administration Water Demand	15	17	17	19	20
Commercial Water Demand	311	345	360	406	431
Industrial Water Demand	63	70	73	82	87
Total Water demand, m^3/d	**1,738**	**1,907**	**1,978**	**2,193**	**2,307**
UfW	53%	40%	37%	37%	37%
Total Production Required, m^3/d	**2,658**	**2,665**	**2,700**	**2,993**	**3,149**

The existing distribution system serving Gatundu Town supplies approximately 3,000m^3/d, which is about 100% of the current (year 2010) water demand of 3,024m^3/d.

4.11.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the High and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

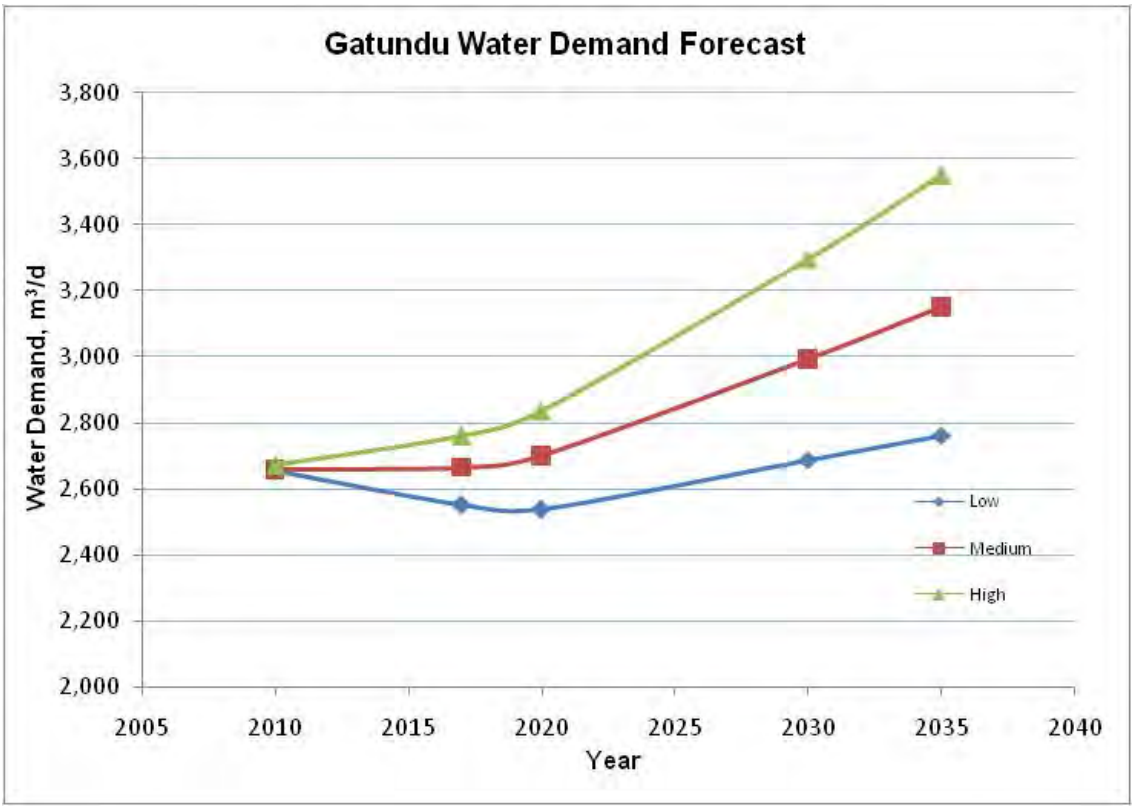
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-99 and presented in graphical form as shown in **Figure 4-12 on** page 4-64.

Table 4-99: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	15,429	16,253	16,570	17,511	17,960
	Growth Rate	0.6%	0.7%	0.6%	0.6%	0.5%
Medium scenario	Population	15,474	16,799	17,352	18,968	19,799
	Growth Rate	0.9%	1.2%	1.1%	0.9%	0.9%
High scenario	Population	15,571	17,338	18,115	20,519	21,788
	Growth Rate	1.5%	1.5%	1.5%	1.3%	1.2%
Income Distribution						
Low Income - 30%		Medium Income - 60%		High Income - 10%		
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		100%	100%	100%	100%	100%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		2,652	2,551	2,538	2,688	2,763
Medium scenario		2,658	2,665	2,700	2,993	3,149
High scenario		2,673	2,760	2,837	3,296	3,550

Year 2009 Gatundu Town Census Population - 15,335

Figure 4-12: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



4.12 Water Demand Forecast – Tala & Kangundo Towns

4.12.1 Domestic Water Demand

It is anticipated that the rural areas added in the study area are likely to develop into urban areas in future. The per capita demand for rural areas has been taken to be the same as Low income per capita rate for urban areas.

Table 4-100 gives the projected domestic water demand for Tala and Kangundo urban areas.

Table 4-100: Domestic Water Demand

Area	Population Category	l/c/day	Projected Water Demand (m^3/day)				
			2010	2017	2020	2030	2035
Tala	**Population**		3,170	4,746	6,234	11,983	15,827
	Urban Areas						
	High Income	150	8	11	14	27	36
	Medium Income	100	146	206	275	516	679
	Low income	50	52	74	99	186	244
	Rural Areas	60	37	68	85	176	235
	Urban NOT served	30	115	132	118	68	27
	Rural NOT served	20	70	68	66	48	34
	Sub-Total Water Demand		**427**	**559**	**657**	**1,020**	**1,254**
Kangundo	**Population**		3,462	4,493	5,230	7,792	8,645
	Urban Areas						
	High Income	150	8	10	11	14	15
	Medium Income	100	151	184	202	270	291
	Low income	50	54	66	73	97	105
	Rural Areas	60	49	75	102	183	213
	Urban NOT served	30	65	52	45	16	8
	Rural NOT served	20	65	59	51	26	18
	Sub-Total Water Demand		**392**	**447**	**483**	**607**	**649**
	Total Population		**6,632**	**9,238**	**11,464**	**19,775**	**24,472**
	Total Domestic Water Demand, m^3/d		**820**	**1,006**	**1,140**	**1,627**	**1,903**

4.12.2 Institutional Water Demand

Education Sector

An inventory of the existing education facilities has been compiled with the number of schools expected to grow at the population growth rate. Table 4-101 on Page 4-66 summarizes the forecast water demand for Education.

Table 4-101: Projected Water demand for Education

Area	Year	l/c/day	2010	2017	2020	2030	2035
Tala	Annual growth rate		3.20%	3.30%	3.00%	2.60%	2.50%
	Total Enrolment		**4,370**	**5,485**	**5,993**	**7,747**	**8,765**
	Day School Enrolment (75%)		3,277	4,113	4,495	5,810	6,574
	Boarding School Enrolment (25%)		1,092	1,371	1,498	1,937	2,191
	Day School Water Demand (m^3/d)	25	82	103	112	145	164
	Boarding School Water Demand (m^3/d)	50	55	69	75	97	110
	Sub-Total Water Demand		**137**	**171**	**187**	**242**	**274**
Kangundo	Annual growth rate		0.60%	0.50%	0.50%	0.40%	0.40%
	Total Enrolment		**3,684**	**3,815**	**3,872**	**4,030**	**4,111**
	Day School Enrolment (75%)		2,763	2,861	2,904	3,023	3,084
	Boarding School Enrolment (25%)		921	954	968	1,008	1,028
	Day School Water Demand (m3/d)	25	69	72	73	76	77
	Boarding School Water Demand (m^3/d)	50	46	48	48	50	51
	Sub-Total Water Demand		**115**	**119**	**121**	**126**	**128**
	Total Water Demand, m^3/d		**252**	**291**	**308**	**368**	**402**

Health Sector

An inventory of existing Health facilities was compiled in previous studies and has been projected to grow at the general population growth rate. To calculate the water consumption per hospital, a bed capacity of 150 beds per hospital was adopted as per Ministry of Health Guidelines. Table 4-102 gives the projected Health sector water demand within the study area.

Table 4-102: Projected Water Demand for Health

Area	Year	m^3/day	2010	2017	2020	2030	2035
Tala	Growth rate		**3.20%**	**3.30%**	**3.00%**	**2.60%**	**2.50%**
	No. Hospitals		-	-	-	-	-
	No. Health Centres		2	3	3	4	4
	Hospitals Water Demand	30	-	-	-	-	-
	Health Centres Demand	5	10	13	14	18	21
	Sub-Total		**10**	**13**	**14**	**18**	**21**
Kangundo	Growth rate		**0.60%**	**0.50%**	**0.50%**	**0.40%**	**0.40%**
	No. Hospitals		1	1	1	1	1
	No. Health Centres		1	1	1	1	1
	Hospitals Water Demand	30	30	31	32	33	34
	Health Centres Demand	5	5	5	5	6	6
	Sub-Total		**35**	**36**	**37**	**39**	**39**
	Total Health Water Demand, m^3/d		**95**	**104**	**107**	**120**	**126**

Administration

A consumption rate of 1 litre/capita/day has been applied for the Administrative Sector water demand. The demand for Administrative Sector has been projected to grow at the general population growth rate.

Table 4-103 gives the water demand forecast for Administrative Sector for the study area.

Table 4-103: Projected Water Demand for Public Administration

Area	Category	l/c/d	2010	2017	2020	2030	2035
Tala	Population		10,492	12,572	13,482	16,643	18,402
	Sub-Total	**1**	**10**	**13**	**13**	**17**	**18**
Kangundo	Population		8,894	9,166	9,285	9,628	9,800
	Sub-Total	**1**	**9**	**9**	**9**	**10**	**10**
Total Admin. Water Demand, m^3/d			**19**	**22**	**23**	**26**	**28**

4.12.3 Commercial & Industrial Water Demand

The commercial activities in Tala and Kangundo urban areas are dominated by small scale enterprises engaged in trade and services. These enterprises mainly consist of general shops offering a variety of goods and services for the general needs of the town and the rural inhabitants. It is assumed that the future increase in commercial activity is likely to be associated with the growth in the population of the towns. Presently there are no industries within the study area.

The present commercial water demand has been estimated at between 5-10% of the present domestic water demand as it has shown to give similar reserves in other Kenyan towns. Projections on the present Commercial Water Demand have been made by considering similar growth rate as the population and are as shown in Table 4-104.

Table 4-104: Projected Water Demand for Commercial and Industrial (m^3/d)

Area	Year	2010	2017	2020	2030	2035
Tala	Annual growth rate	**3.2%**	**3.3%**	**3.0%**	**2.6%**	**2.5%**
	Commercial Water Demand	43	54	59	76	86
	Industrial Water Demand	-	-	-	-	-
	Sub-Total	**43**	**54**	**59**	**76**	**86**
Kangundo	Annual growth rate	**0.6%**	**0.5%**	**0.5%**	**0.4%**	**0.4%**
	Commercial Water Demand	31	32	33	34	35
	Industrial Water Demand	-	-	-	-	-
	Sub-Total	**31**	**32**	**33**	**34**	**35**
Total Comm. & Indu. Water Demand, m^3/d		**74**	**86**	**92**	**110**	**121**

4.12.4 Overall Water Demand

The Overall Water Demand of the Study Area has been estimated for the present (year 2010), Short Term (Year 2017) and the Ultimate (Year 2035) based on the projected population growth.

The Overall Water Demand includes Unaccounted for Water (UfW), which is currently estimated at 53%. The UfW has however been assumed to progressively decrease to 37% by Year 2035.

The Overall Water Demand for Tala and Kangundo urban areas is shown in Table 4-105.

Table 4-105: Overall Projected Water Demands for Tala & Kangundo Towns

Area	Year	2010	2017	2020	2030	2035
Tala	**Population**	**10,492**	**12,572**	**13,482**	**16,643**	**18,402**
	Domestic Water Demand	427	559	657	1,020	1,254
	Education Water Demand	137	171	187	242	274
	Health Water Demand	10	13	14	18	21
	Administration Water Demand	10	13	13	17	18
	Commercial Water Demand	43	54	59	76	86
	Industrial Water Demand	-	-	-	-	-
	Total Water demand	**627**	**810**	**931**	**1,373**	**1,653**
	UfW	53%	40%	37%	37%	37%
	Required Production	**959**	**1,132**	**1,270**	**1,874**	**2,256**
Kangundo	**Population**	**8,894**	**9,166**	**9,285**	**9,628**	**9,800**
	Domestic Water Demand	392	447	483	607	649
	Education Water Demand	115	119	121	126	128
	Health Water Demand	35	36	37	39	39
	Administration Water Demand	9	9	9	10	10
	Commercial Water Demand	31	32	33	34	35
	Industrial Water Demand	-	-	-	-	-
	Total Water demand	**583**	**644**	**683**	**815**	**862**
	UfW	53%	40%	37%	37%	37%
	Required Production	**891**	**900**	**932**	**1,112**	**1,176**
	Total Population	**19,386**	**21,738**	**22,767**	**26,271**	**28,202**
	Total Water demand, m3/d	**1,210**	**1,454**	**1,614**	**2,188**	**2,515**
	Total Production Required, m3/d	**1,850**	**2,032**	**2,202**	**2,987**	**3,432**

The current production capacity is **250m^3/day**, which is only 11.8% of the current (year 2010) water demand of 2,123m^3/d.

4.12.5 Test of Sensitivity (Scenarios)

The population growth trends have been analysed based on projecting the population at three variants - High, Medium and Low growth rates up to the ultimate planning period, year 2035. Projections based on the Medium growth rates have been adopted for planning purposes while the Medium and Low variants have been used for comparison purposes.

The population distribution is expected to remain the same within the planning period while the population served by the public Water Service Provider is expected to increase within the planning period as more investments are mobilised in increasing the public water supply coverage.

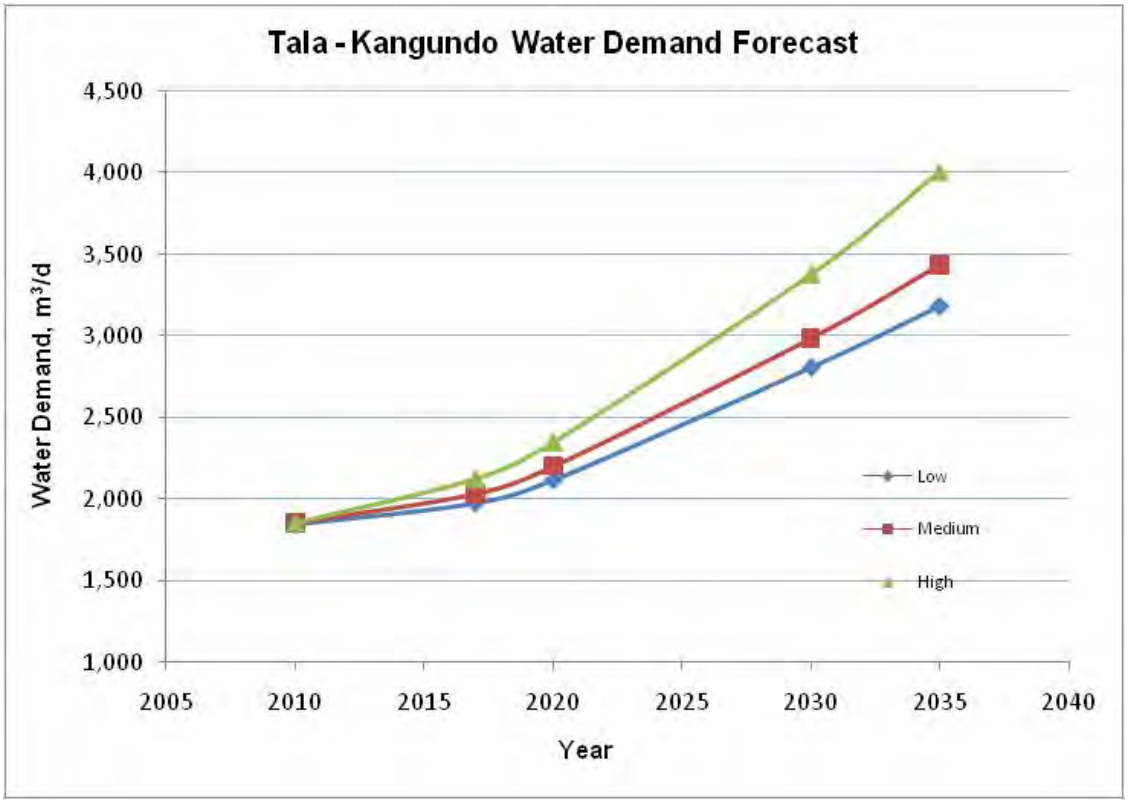
A sensitivity analysis of water demand variation based on the high, medium and low population projection scenarios is given in Table 4-106 on Page 4-69 and presented in graphical form as shown in **Figure 4-13** on page 4-69.

Table 4-106: Water Demand Forecast at High, Medium and Low Population Growth Rates

Population Projections						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario	Population	19,343	21,205	22,049	24,888	26,418
	Growth Rate	1.4%	1.3%	1.3%	1.2%	1.2%
Medium scenario	Population	19,386	21,738	22,767	26,271	28,202
	Growth Rate	1.6%	1.6%	1.6%	1.4%	1.4%
High scenario	Population	19,444	22,484	23,918	29,043	32,110
	Growth Rate	1.9%	2.1%	2.1%	2.0%	2.0%
Income Distribution						
Low Income - 41%			Medium Income - 27%		High Income - 2%	
Population Served by Public Water Service Provider						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Percentage		34%	42%	50%	75%	87%
Water Demand Forecast, m^3/d						
Year		**2010**	**2017**	**2020**	**2030**	**2035**
Low scenario		1,845	1,971	2,118	2,804	3,182
Medium scenario		1,850	2,032	2,202	2,987	3,432
High scenario		1,856	2,123	2,346	3,377	4,010

Year 2009 Tala-Kangundo Towns Census Population - 19,084

Figure 4-13: Graph Showing Water Demand Forecast at High, Medium and Low Population Growth Rates



5 Water Demand Forecast for Nairobi and Satellites Towns

Based on the Methodology and Criteria outlined in Section 2 of this Chapter, the Water Demand Forecast for Nairobi and Satellite Towns is summarized in spreadsheet on page 4-71.

Table 4-107: Water Demand Spreadsheet – Nairobi and Satellite Towns

Town/Area	District	Income Level			Area	Pop. Census	Growth rate		Population Growth Rate Forecast						Population Forecast					% Population supplied by Public Network (IC)					Water Demand Forecast, m^3/d				
		Low	Medium	High	km^2	2009	1989-1999	1999-2009	Scenario	2010	2017	2020	2030	2035	2010	2017	2020	2030	2035	2010	2017	2020	2030	2035	2010	2017	2020	2030	2035
Nairobi City	Nairobi	45%	49%	6%	695	3,138,369	4.9%	3.9%	L	3.4%	3.0%	2.7%	2.2%	2.0%	3,245,311	3,982,348	4,318,845	5,383,064	5,952,250	65%	68%	72%	78%	80%	577,967	659,306	710,792	954,415	1,101,186
									M	3.6%	3.2%	2.9%	2.6%	2.5%	3,250,338	4,040,325	4,403,791	5,693,457	6,444,969						578,643	671,018	728,309	1,018,528	1,205,322
									H	3.8%	3.4%	3.2%	3.0%	3.0%	3,257,615	4,107,466	4,517,800	6,086,401	7,063,903						579,621	680,497	744,669	1,083,572	1,314,493
Satellite Towns within Nairobi Envelop																													
Kikuyu area	Kikuyu	33%	57%	10%	105	216,578	3.6%	3.7%	L	3.3%	3.0%	2.9%	2.6%	2.5%	223,670	275,198	300,268	390,030	441,639	20%	28%	35%	51%	58%	17,940	23,245	26,983	42,767	52,322
									M	3.5%	3.3%	3.2%	3.0%	3.0%	224,117	281,951	309,911	416,280	481,423						17,959	23,604	27,540	44,716	55,526
									H	3.8%	3.7%	3.6%	3.5%	3.4%	224,834	290,529	322,882	453,398	535,738						18,001	24,062	28,278	47,390	59,686
Kiambu area	Kiambu East	25%	65%	10%	58.5	88,971	3.2%	3.3%	L	3.2%	3.0%	2.8%	2.6%	2.5%	91,834	112,944	122,765	158,972	180,024	32%	40%	45%	55%	60%	8,279	10,068	11,328	16,069	19,059
									M	3.1%	3.1%	3.1%	2.7%	2.7%	91,769	114,011	125,071	163,598	187,040						8,280	10,317	11,753	17,175	20,730
									H	3.9%	3.8%	3.6%	3.6%	3.6%	92,400	119,843	133,415	190,640	228,049						8,326	10,968	12,715	20,268	25,610
Karuri area	Kiambu East	25%	65%	10%	46.7	129,934	3.8%	3.5%	L	3.2%	3.0%	2.9%	2.6%	2.5%	134,064	164,957	179,945	231,832	261,906	20%	28%	32%	48%	58%	10,838	13,313	14,850	22,050	27,180
									M	3.3%	3.2%	3.0%	2.8%	2.7%	134,234	167,433	183,139	241,188	276,110						10,854	13,515	15,100	22,898	28,566
									H	3.7%	3.6%	3.6%	3.4%	3.3%	134,705	171,986	191,277	267,230	313,845						10,895	13,943	15,879	25,711	32,947
Ruiru-Juja area	Ruiru/Thika East	28%	68%	4%	527.9	320,779	7.4%	7.8%	L	6.0%	5.5%	5.3%	4.6%	3.0%	339,956	495,454	579,224	905,181	1,050,058	16%	25%	33%	53%	59%	26,064	38,239	47,032	88,080	106,835
									M	6.6%	6.6%	6.0%	5.2%	4.0%	342,086	534,564	637,178	1,060,559	1,289,990						26,193	41,416	51,937	103,759	131,978
									H	8.1%	8.0%	7.5%	6.0%	5.0%	346,841	595,655	740,454	1,329,561	1,698,895						26,476	45,933	60,091	128,969	172,646
Mavoko Municipality	Machakos	39%	57%	4%	340	130,768		11.0%	L	7.0%	6.1%	5.8%	4.5%	3.3%	139,890	211,232	250,016	389,625	457,594	22%	28%	35%	54%	60%	16,727	23,397	29,473	50,342	60,438
									M	9.6%	8.5%	7.0%	5.3%	4.1%	143,278	253,840	310,722	522,319	638,005						17,022	27,094	34,897	64,396	80,222
									H	11.4%	11.2%	10.5%	7.9%	5.0%	145,662	306,620	413,935	883,001	1,126,028						17,238	31,728	44,226	102,853	134,123
Ngong, Ongata Rongai & Kiserian	Kajiado North	39%	57%	4%	141.2	210,746	4.6%	9.5%	L	5.3%	4.8%	4.5%	3.0%	2.6%	221,923	307,807	350,925	472,144	537,249	7%	15%	22%	45%	50%	13,580	20,537	24,698	41,051	48,806
									M	6.0%	5.0%	4.5%	3.5%	3.4%	223,324	315,018	359,643	509,706	601,663						13,686	20,984	25,253	44,041	54,246
									H	9.4%	7.4%	6.2%	4.8%	4.5%	230,509	379,022	454,383	725,542	905,534						14,230	25,168	31,602	61,764	80,112
Sub-Total		***32%***	***62%***	***6%***	***1,219***	***1,097,776***		***6.8%***	L	***4.9%***	***4.6%***	***4.4%***	***3.7%***	***2.8%***	***1,151,337***	***1,567,594***	***1,783,143***	***2,547,783***	***2,928,468***	***18%***	***25%***	***32%***	***51%***	***57%***	***93,428***	***128,799***	***154,364***	***260,359***	***314,640***
									M	***5.6%***	***5.5%***	***5.0%***	***4.3%***	***3.6%***	***1,158,809***	***1,666,817***	***1,925,664***	***2,913,651***	***3,474,231***						***93,994***	***136,930***	***166,480***	***296,985***	***371,267***
									H	***7.1%***	***7.1%***	***6.7%***	***5.6%***	***4.6%***	***1,174,950***	***1,863,654***	***2,256,347***	***3,849,371***	***4,808,090***						***95,167***	***151,802***	***192,791***	***386,954***	***505,125***
TOTAL Nairobi Envelop		***42%***	***52%***	***6%***	**1,914**	**4,236,145**		***4.7%***	L	**3.8%**	**3.4%**	**3.2%**	**2.7%**	**2.3%**	**4,396,648**	**5,549,942**	**6,101,988**	**7,930,848**	**8,880,718**	**53%**	**56%**	**60%**	**69%**	**72%**	**671,396**	**788,105**	**865,156**	**1,214,774**	**1,415,827**
									M	**4.1%**	**3.8%**	**3.5%**	**3.2%**	**2.9%**	**4,409,147**	**5,707,142**	**6,329,455**	**8,607,108**	**9,919,200**						**672,636**	**807,948**	**894,789**	**1,315,513**	**1,576,589**
									H	**4.7%**	**4.5%**	**4.4%**	**4.0%**	**3.6%**	**4,432,565**	**5,971,119**	**6,774,148**	**9,935,772**	**11,871,992**						**674,787**	**832,299**	**937,460**	**1,470,526**	**1,819,618**

Other Satellite Towns		Income Level			Area	Pop. Census	Growth rate		Population Growth Rate Forecast						Population Forecast					% Population supplied by Public Network (IC)					Water Demand Forecast, m^3/d				
		Low	Medium	High	km^2	2009	1989-1999	1999-2009		2010	2017	2020	2030	2035	2010	2017	2020	2030	2035	2010	2017	2020	2030	2035	2010	2017	2020	2030	2035
Limuru	Kiambu West	25%	73%	2%	34.2	37,611		3.0%	L	2.5%	2.1%	2.0%	1.8%	1.7%	38,541	44,624	47,401	56,854	61,910	27%	35%	43%	55%	60%	4,310	4,915	5,486	7,276	8,225
									M	3.0%	2.9%	2.8%	2.1%	2.0%	38,739	47,372	51,449	63,233	69,814						4,330	5,215	5,954	8,039	9,208
									H	3.4%	3.3%	3.1%	2.8%	2.7%	38,880	48,768	53,435	70,426	80,622						4,345	5,386	6,200	9,087	10,847
Githunguri	Githunguri	25%	73%	2%	14.9	17,722	3.0%	2.4%	L	2.0%	1.8%	1.7%	1.5%	1.3%	18,076	20,481	21,543	25,002	26,670	100%	100%	100%	100%	100%	3,051	3,160	3,246	3,767	4,019
									M	2.4%	2.3%	2.2%	2.0%	2.0%	18,147	21,279	22,714	27,688	30,570						3,060	3,281	3,420	4,169	4,603
									H	2.8%	2.6%	2.5%	2.4%	2.4%	18,218	21,804	23,481	29,765	33,513						3,070	3,359	3,533	4,479	5,042
Gatundu	Gatundu	30%	60%	10%	27	15,335	1.4%	0.7%	L	0.6%	0.7%	0.6%	0.6%	0.5%	15,429	16,253	16,570	17,511	17,960	100%	100%	100%	100%	100%	2,652	2,551	2,538	2,688	2,763
									M	0.9%	1.2%	1.1%	0.9%	0.9%	15,474	16,799	17,352	18,968	19,799						2,658	2,665	2,700	2,993	3,149
									H	1.5%	1.5%	1.5%	1.3%	1.2%	15,571	17,338	18,115	20,519	21,788						2,673	2,760	2,837	3,296	3,550
Thika	Thika West	36%	59%	5%	90.9	138,772	3.8%	4.5%	L	4.0%	3.7%	3.5%	3.0%	2.5%	144,361	186,005	206,328	276,799	312,941	68%	75%	80%	88%	90%	22,243	27,795	31,064	44,157	50,903
									M	4.6%	4.5%	4.0%	3.4%	3.0%	145,133	197,633	222,425	311,501	360,777						22,331	29,832	33,885	50,432	59,545
									H	5.2%	5.2%	5.0%	4.3%	4.0%	145,990	208,754	241,846	368,188	447,553						22,424	31,669	37,152	60,559	75,235
Tala-Kangundo	Machakos	41%	57%	2%	77	19,084		1.6%	L	1.4%	1.3%	1.3%	1.2%	1.2%	19,343	21,205	22,049	24,888	26,418	34%	42%	50%	75%	87%	1,845	1,971	2,118	2,804	3,182
									M	1.6%	1.6%	1.6%	1.4%	1.4%	19,386	21,738	22,767	26,271	28,202						1,850	2,032	2,202	2,987	3,432
									H	1.9%	2.1%	2.1%	2.0%	2.0%	19,444	22,484	23,918	29,043	32,110						1,856	2,123	2,346	3,377	4,010
Sub-Total		***33%***	***62%***	***4%***	***244***	***228,524***		***3.6%***	L	***3.2%***	***3.0%***	***2.9%***	***2.5%***	***2.2%***	***235,750***	***288,568***	***313,892***	***401,054***	***445,899***	***63%***	***70%***	***75%***	***84%***	***87%***	***34,101***	***40,392***	***44,453***	***60,692***	***69,092***
									M	***3.7%***	***3.7%***	***3.4%***	***2.9%***	***2.6%***	***236,880***	***304,820***	***336,706***	***447,661***	***509,162***						***34,229***	***43,025***	***48,161***	***68,621***	***79,937***
									H	***4.2%***	***4.3%***	***4.2%***	***3.7%***	***3.5%***	***238,103***	***319,147***	***360,794***	***517,942***	***615,586***						***34,368***	***45,296***	***52,067***	***80,798***	***98,685***
GRAND TOTAL		**41%**	**53%**	**6%**	**2,158**	**4,464,669**		***4.6%***	L	**3.8%**	**3.4%**	**3.2%**	**2.7%**	**2.3%**	**4,632,399**	**5,838,510**	**6,415,879**	**8,331,901**	**9,326,618**	**53%**	**56%**	**61%**	**70%**	**73%**	**705,497**	**828,497**	**909,609**	**1,275,467**	**1,484,919**
									M	**4.1%**	**3.8%**	**3.5%**	**3.2%**	**2.9%**	**4,646,027**	**6,011,962**	**6,666,161**	**9,054,769**	**10,428,362**						**706,865**	**850,972**	**942,950**	**1,384,134**	**1,656,526**
									H	**4.7%**	**4.5%**	**4.4%**	**4.0%**	**3.6%**	**4,670,668**	**6,290,267**	**7,134,942**	**10,453,714**	**12,487,579**						**709,155**	**877,595**	**989,527**	**1,551,325**	**1,918,303**

L - Low Population Growth Rate, M - Medium Population Growth Rate, H - High Population Growth Rate
IC - Individual Connections

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Chapter 5 - Surface Water Hydrology

1 Introduction

The hydrological study was designed to comply with the Terms of Reference. This was made possible by the availability of very extensive and conclusive hydrological studies undertaken for the Nairobi Water Supply over a 20-year period between 1970 and 1990. These studies presented data since the late 1940s, and some very good quality databases and analyses were reported in detail.

Based on the conclusive findings of the previous studies, this Project focussed on the Northern Collector River System from the Eastern Aberdare Mountain Forests and Moorland. It was established many years ago that these rivers are amongst the most productive in the country, with very high unit runoff, and with strong baseflow components primarily due to the boggy catchment in the upper parts and forest cover. The potential of these rivers to supply Nairobi with water was beyond doubt, and this project set out to confirm that these facts had not changed since the conclusive studies reported some years ago.

Since the last major reports were produced nearly 20 years ago, the hydrological database and analysis was in need of updating to confirm yields established at that time. This Project therefore sought all available river flow data collected since that time for the Northern Collector Rivers. Although, hydrometric data collection systems have collapsed in Kenya in recent years (to an alarming extent), sufficient data was obtained by this Study (and by a parallel AWSB study in the Sasumua / Chania catchment), which allowed data infilling and the derivation of extended flow sequences. The analysis of these flow sequences established (within the data constraints) that the hydrological yield of the Northern Collector Rivers has not changed. This was as anticipated, as the rivers in question drain exclusively from the Eastern Aberdares, whose catchments are within the “Aberdare Conservation Area”. The “Aberdare Conservation Area” very effectively protects one of Kenya’s principal and most important water towers. The Aberdare water tower serves a very large proportion of Kenya’s population, both directly and indirectly, and the Kenya Government is totally committed to its protection, and there is no prospect of any change in this position. The conservation area comprises high altitude moorland with lower altitude bamboo and forest belts. Whilst there has been forest destruction in the past, especially in the northern Aberdares, this catchment destruction has been halted, and in some cases, is being reversed.

A very detailed review of previous hydrological studies was conducted for the Northern Collector Rivers. Particular attention was placed on studying the yield performance of the existing Thika Dam at Ndakaini, as this provided a very useful benchmark for the Nairobi water sources.

The hydrological analysis produced extended continuous daily flow sequences for the all-important Northern Collector Rivers. These sequences were then input to the WEAP Water Balance Model for the purpose of deriving conjunctive use yields of the rivers and reservoirs under study. Many different water source combinations were studied. The yield methodology is conventional, and the reliability criterion is also conventional, with 90% reliability being adopted, as per the earlier studies on Nairobi’s water supply (based on annual event failure

methodology). The yield studies have been conducted with appropriate compensation flow allowances into the rivers downstream of the proposed diversion intakes and reservoirs.

In addition, the Study was required to study the yields of a large number of water sources in closer proximity to Nairobi (for master planning purposes). It was beyond the Scope of this Study to conduct detailed hydrological studies to the same level as for the Northern Collector Rivers. This was fully appreciated during the Project's Inception Phase, and in order to fulfil the Master Planning requirements, general hydrological characteristics were established for all rivers close to Nairobi. As these rivers have unit runoff 1/10th of the Northern Collector Rivers, they are hydrologically far less attractive, and are only likely to be feasible for local water supplies provided there is adequate storage provision. It was agreed during the Inception Phase that a generalised method of reservoir yield analysis would be adopted. Hence, a previously developed generalised non-dimensional reservoir yield method was re-worked for the purpose of this report, and results were verified using modern methods (Mein & McMahon). If any of these schemes are chosen for implementation by AWSB, the scheme's individual hydrology must be subjected to proper feasibility study. The results presented under this Study are for Master Planning purposes.

There are naturally concerns about the sustainability of the water sources with the evolving challenges of climate change. In southern Africa, very large runoff reductions are being forecast. In Kenya, some warming is expected, which will increase evaporation. Rainfall variability is also expected, but annual rainfall totals are not expected to decline. The Northern Collector Rivers flow database studied by this project did not show any reductions in annual average flows in recent years. There are ongoing climate change studies being undertaken by the team updating Kenya's National Water Master Plan. Discussion with this team indicated that the Studies being carried out are primarily based on data from climate stations at National Level and is not specific to any catchment or drainage area.

It is known that Kenya has a poor record of Water Resource Management (World Bank, 2006), and this is an ongoing concern. There are upstream community water supply intakes that continue to be constructed within the protected Aberdare Forest Area, with little control. If these abstractions are not "managed", water quality will be affected, the river low flows will reduce and this will alter the hydrology and affect planned run-of-river abstractions. This Project assumes that the water sources for Nairobi will be afforded careful resource management to optimise the considerable investment in the infrastructure. It also assumes effective catchment protection to ensure the sustainability of the flow resource and its quality.

In mitigation, and consistent with World Bank Studies (World Bank, 2006), this Study has recommended a Scheme that exploits the considerable run-of-river potential in the immediate term, but with substantial storage provision added in the early stages of Project Implementation. The storage provision is fundamental to providing a buffer against the variability associated with climate change, and also the consequences of upstream run-of-river abstraction needs. However, these buffer zones are not designed to buffer poor water resource management that alters the natural hydrology, and causes deterioration in water quality.

This Chapter presents a thorough review of past hydrological analyses. Revised hydrological characteristics are presented, and the safe yield of various water source combinations are presented.

2 Review of the Previous Hydrological Studies

2.1 Introduction to the Various Previous Hydrological Studies

This section reviews the various hydrological studies that have been undertaken. These earlier studies were detailed, and the studies were all undertaken over several years by Howard Humphreys. The data up to the early 1980s captured the naturalised hydrology of the Eastern Aberdare Rivers, which is important. Since that time, river flows have been variously affected by abstractions.

In the 1960s, the population of Nairobi was 300,000, with water demand satisfied by supplies from Kikuyu Springs, Ruiru Dam, and Sasumua dam with a raised spillway. At that time various dam sites on the Chania, Kimakia, and Thika Rivers were explored.

The subsequent 1970's studies continued investigating dam sites in the Chania and Kimakia Rivers, as well as the Ndarugu, Thiririka, Ruiru-Bathi, Nairobi and Athi Rivers. At that time, water sources as far afield as Lake Naivasha were also explored.

In 1979, under "Stage 1", a detailed hydrological study was presented.

In 1980, the "Chania/Thika Study Stage 2 & 3 Report" was submitted. This looked at numerous run-of-river and storage possibilities within the Thika catchment, and recommended development of the Thika Dam (Thika 6).

In 1984, a "Supplement" was issued, which extended the study area to rivers north of Thika into Tana Basin, to investigate alternative potential dam sites to Thika Dam. This "Supplement" extended study as far north as the Gura River.

In 1986, the "Short Term Plan to 1995" was presented, focused on development of the Thika Dam at Ndakaini. A period of concentrated hydrological measurement within the Chania and Thika catchments continued for ten years thereafter. Several "Hydrological Yearbooks" were presented, culminating in the "Hydrology Review" dated 1995.

In 1986, just after the "Short Term Plan", the "Long Term Development Plan" was presented, in which the sources within the Tana catchment were studied in detail to meet longer-term water demand in Nairobi. The "Northern Collector Scheme" was presented. This scheme proposed diverting part of several northern rivers in Tana Basin through tunnels in order to supplement natural river inflows to the Thika Dam in the Athi Basin. The Northern Collector Scheme was further developed in the "Northern Collector Scheme Feasibility Report" in 1998. The 1998 report was the last in the series of Howard Humphreys reports on water resources development in the Thika and Tana catchments.

Figure 5-1 on page 5-4 shows the River and Hydrometric Network in the Thika / Chania and the Northern Collector Rivers.

The previous water supply studies have been reviewed, report-by-report. A summary of the Review is given in **Appendix 5.1**.

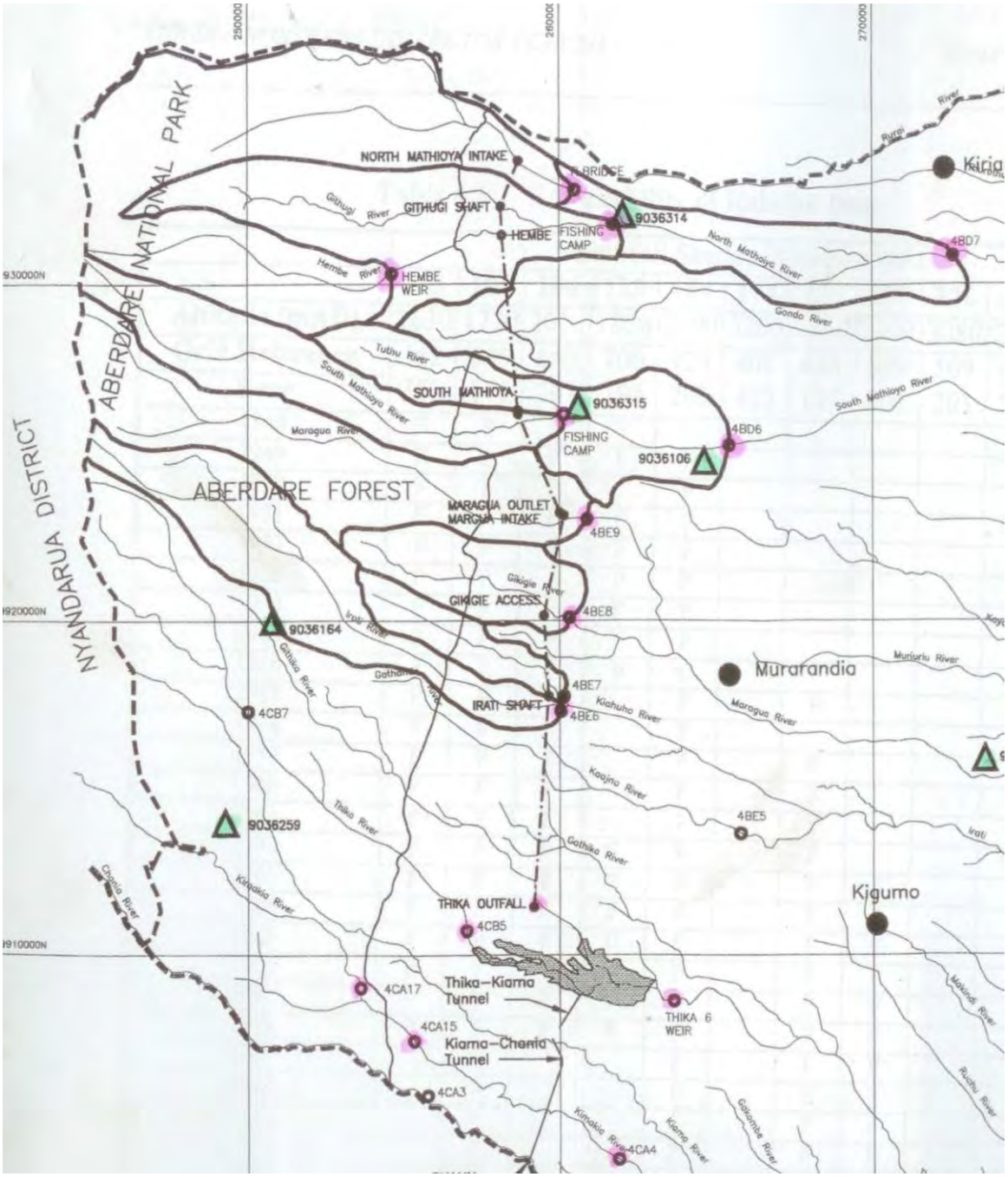


Figure 5-1: River and Hydrometric Network (lower catchments not shown)

(Source: Figure 4.1, Northern Collector Scheme, Feasibility Report, HH, 1998)

The series of reports provide details of the Chania/Thika and Tana catchments, and the associated hydrometric networks. The available hydrometric data finally presented in the reports was infilled / extended / simulated from 1946 to 1992, and that database is summarised variously in the reports either as daily, 10-day, or monthly summaries, in hard copy. Unfortunately, the corrected daily data was not published in its entirety, and soft copy is not available.

2.2 Hydrological Study and Water Management for Ngethu – Sasumua System, BRLi / Seureca, June 2011

The Objective of the Study as defined in the Contract was to maximize the water production from the existing water system composed principally of three dams (Sasumua, Tana and Ruiru Dams) and the three water treatment plants at Ngethu, Sasumua and Kabete.

The Study Area according to the deliverables of the study comprised of the Ngethu-Sasumua hydrological system which lies within the upper Thika and Chania River system which is located on the southern slopes of the Aberdare Ranges. The study provided an overview of the geographical, hydro-meterological and general physical catchment conditions including land use, geology of soils, drainage and vegetation cover.

The core of the study focused on hydrological assessment in which daily inflows to Sasumua Dam, Kiama Intake, Kimakia Intake and Mwagu Intake were derived from year 1946 to 2010. A Water Balance Analysis on the Sasumua-Thika-Ngethu System was then carried out primarily to determine the safe yield from Sasumua Dam and at Mwagu Intake to Ngethu Treatment Plant and to make proposals for management options to be used for the system.

The study determined that the 90% reliable yield from Thika-Kiama-Kimakia-Chania System (excluding Sasumua Dam) is 5.5m^3/s (475,200m^3/d) and from Sasumua Dam is 1.01m^3/s (87,260m^3/d). The yield values were higher than the treatment plant design capacities of 5.3m^3/s (457,920m^3/d) at Ngethu and 0.79m^3/s (68,400m^3/d) at Sasumua Dam.

An Addendum to the Study (Addendum No. 1) carried out flow measurements on the Ngethu System and determined that the optimal operating capacity of the system is 4.8m^3/s (414,720m^3/d).

2.3 Criteria Used in Previous Hydrological and Yield Assessment

2.3.1 Criteria for Reliability of Supply - MoWD

The Ministry of Water Development (MoWD) Design Manual (1984) specifies the safe yield for water supply in terms of flow frequency as follows:

- Urban centres with population > 10,000: Safe yield = 96% probability daily low flow (based on frequency analysis of lowest low daily flow in each year of record).
- Rural areas and urban centres with population <10,000, safe yield = 96% probability monthly low flow (based on frequency analysis of lowest average flow in a calendar month for each year of record).

The above yield analysis is undertaken through abstraction of the minimum recorded flow from each year of record, ranking the series, and then assigning probability values.

2.3.2 Criteria for Reliability of Supply – Nairobi Water Supply Projects

The very early HH studies adopted a reliability of municipal water supply for Nairobi based on the “98% Probability” criterion widely adopted at that time as “general waterworks practice” (HH, Chania – Thika Study, Vol. 1, Section 3.7, 1980). The 98% criterion was later reviewed.

The reliability criteria for water supply were proposed in the Long Term Development Plan as follows (LTDP, Vol.II, Section 6.1):

- Reservoir yield – 90% reliability;
- Reservoir will release to meet downstream water and irrigation needs;
- Intake diversion flow limit set at 10% average flow with additional storage provision to meet downstream water supply and irrigation needs;

- Intake run-of-river water supply yield = 96% probability monthly flow.

The MoWD low flow probability criteria specify the daily and monthly low flow frequency (probability analysis) as the applicable low flow indices. Whilst these indices were considered "appropriate" by Howard Humphreys, "because of their rarity", they were correctly considered "more subject to error".

Howard Humphreys therefore correctly introduced the "flow duration" as a third low flow index. This index is less prone to error and spurious data, and is derived through a simple process of ranking the entire daily or monthly flow data series for a station. The "flow duration" is very useful where flow data sequences are short and insufficient for the frequency analysis specified in the MoWD Design Manual.

Howard Humphreys compared run-of-river yields in terms of the 95% flow exceedence (flow duration), 96% Min. Flow Daily, and 96% Min. Flow Monthly (HH, LTDP, Table 4.5, 1986) – summarised in Table 5-1. The 95% flow duration is more "relaxed" than either the MoWD daily or monthly frequency criteria, and HH recommended the 95% flow duration be adopted as "this statistic gives an approximate indication of the order of magnitude of yield which would be obtained from run-of-river abstractions (LTDP, Vol.II, Draft Report, Hydrology, 1986)".

Sixteen river gauging stations were initially selected for analysis based on the need for geographical spread, and sufficiency of data for analysis. The observed data sets were of varying length, and all had periods of missing or questionable data. The analysis presented in the Long Term Development Plan to 1995 (LTDP) included data up to 1984 from as early as 1946. Data validation and infilling was accordingly undertaken (LTDP, Hydrology, Chapter 3, 1986).

For reservoir supplies, as summarised above, the 90% Probability reliability criterion was recommended "for planning purposes (Project Definition, Short Term Plan to 1995, HH, 1986, Section 5.8)". This means that "full water supply will be maintained in 9 out of every 10 years, whereas in 1 year out of 10 years, on average, there would be periods when insufficient water is available to enable the full design yield to be supplied (HH, LTDP, Vol.II Draft Report, Section 6.1)".

The impact of adopting different reliability criteria is demonstrated in Table 5-2 on page 5-7.

Table 5-1: Comparison of Flow Frequency and Flow Duration Indices

River	Station Number	95% Daily Flow Duration (m^3/sec) (1)	96% Prob Min Flow Daily (m^3/sec) (2)	96% Prob Min Flow Monthly (m^3/sec) (3)	Ratio (1) / (2)	Ratio (1) / (3)
N.Mathioya	4BD7	2.700	1.700	2.150	1.59	1.26
S.Mathioya	4BD6	1.110	0.664	0.862	1.67	1.29
Maragua	4BE1	0.600	0.239	0.381	2.51	1.57
Gikigie	4BE8	0.110	0.046	0.074	2.41	1.50
Maragua	4BE9	0.640	0.351	0.471	1.82	1.36
Mbagathi	3AA4	0.032	0.000	0.011	0.00	2.91
Nairobi	3BA32	1.190	0.510	0.670	2.33	1.78
Bathi	3BC9	0.065	0.014	0.022	4.64	2.95
Thiririka	3BD8	0.059	0.024	0.035	2.46	1.69
Ndarugu	3CB2	0.318	0.167	0.208	1.90	1.53
Ndarugu	3CB5	0.389	0.170	0.251	2.29	1.55
Athi	3DA2	1.650	0.680	1.090	2.43	1.51

Source: TNWSP-Long Term Development Plan (Regional Studies), Hydrology, Table 4.5, July 1986

Table 5-2: Effect of Reliability Criterion

Reliability %	Regulated Yield (m^3/sec)	Total Supply (m^3/day)
98	3.4	369,000
95	3.6	386,000
90	3.8	403,000
80	4.1	429,000

Source: TNWSP-Project Definition, Short Term Plan to 1995, Vol. II, Final Report, Table 5-6, P.61, 1986

2.3.3 Flow Naturalisation

Naturalisation is the process whereby measured river flows are adjusted for upstream water supply and irrigation abstractions. The upstream abstractions are computed and added to the measured flow to generate the "naturalised" flow sequence that would have been measured had there been no abstractions above the point of measurement.

In their 1986 report on the Northern Collector Scheme, HH reported that "the majority of the proposed run-of-river abstraction schemes are located upstream of irrigated areas". HH also assessed the public water abstractions upstream of the gauging stations of interest to the Northern Collector Scheme (4BE1, 4BE3, 4BD7, and 4BD6), all of which commenced operation in 1981 or 1983. HH hence concluded that only small adjustments were required for the latter part of the record only, and that the effect on synthesised low flow statistics was very small (LTDP, Hydrology, Sec.4.2, 1986).

Table 5-3: Public Water Supply Abstractions in 1986

River	River Gauging Station	Scheme Name	Abstracted Flow (m^3/sec)	Start Date Of Scheme
Maragua	4BE1	Kigumo+Muranga	0.125 + 0.064 = 0.189	1981
Irati	4BE3	Kigumo	0.125	1981
N.Mathioya	4BD7	Mathioya	0.072	1983
S.Mathioya	4BD6	Kahuti	0.071	1981

Source: TNWSP-Long Term Development Plan, Hydrology, 1986, Table 4.1

2.3.4 Study Area Water Demand and Yield Comparison in 1986

Howard Humphreys in 1986 compared the study area yield with the corresponding area forecast 2010 water demand – see Table 5-4 on page 5-8. This showed that based on the 95% Probability Min. Daily Flow run-of-river criterion, the surface water resources would supply less than 50% of the forecast 2010 demand. The demands for the Mathioya and Maragua Rivers were not included, and have been inserted from a later HH Report (NCS-FR, 1998). Even after extending to the Mathioya and Maragua rivers, there was still a shortfall that could only be met through storage.

Howard Humphreys adopted the criterion that through storage provision, 50% of the mean annual flow can be realised as yield. On a basin-wide basin, the basin water demand (exclusive of HEP) could be met, but this was based on the unlikely scenario that storage was available at the lower point of each basin. If HEP requirements were included, there was a shortfall, even with storage.

In the Howard Humphreys studies, the HEP provisions were excluded.

Table 5-4: Balance Between Surface Water Resources and Water Demand.

Drainage Area Reference Column 1	Main River System Column 2	Total 2010 Demand (10^3m^3/day) Column 3	Low Flow Index 95% Daily Flow Probability (10^3m^3/day) Column 4	95% Prob Daily Flow Less Demand 10^3m^3/day) Column 5	Reservoir Yield Index 50% Mean Flow 10^3m^3/day) Column 6	50% Mean Flow less demand 10^3m^3/day) Column 7
3AA	Embakasi	102	4	-98	39	-63
3AB	Stony Athi	2	<1	-2	43	+41
3AC	Athi	51	31	-20	259	+208
3BA	Nairobi	678	12	-666	39	-639
3BB	Kamiti	71	14	-57	86	+15
3BC	Ruiru	88	134	+46	238	+150
3BD	Thiririka	66	22	-44	125	+59
3CB	Ndarugu	64	51	-13	168	+104
3DA	Athi (lower)	34	<1	-34	1	-34
4CA	Chania	41	259	+218	376	+335
4CB	Thika (upper)	40	145	+105	264	+224
4CC	Thika (lower)	279	35	-244	86	-193
	Total	1,516	709	-809	1,724	+207
4BD	Mathioya	32[1] (32)	259	+211[1]	631	+583[1]
4BE	Maragua	46[1] (1,623)[2]	207	+161[1](-1,416)[2]	501	+455[1] (-1,122)[2]
	Total	1,594 (3,171)[2]	1,175	-437[1](-1,175)[2]	2,856	1,245(-315)[2]

Source: TNWSP-Long Term Development Plan, Hydrology, 1986, Table 7.1, P.64
Note 1: TNWSP-Northern Collector Feasibility Report, Table 3.15, Chapter 3-13, HEP excluded
Note 2: TNWSP-Northern Collector Feasibility Report, Table 3.4 and 3.15, Chapter 3-13, HEP included

2.3.5 Transposition Equations for Diversion and Storage Sites

As the potential diversion and dam sites do not coincide with the gauging station locations, it is necessary to determine the diversion / storage site hydrology from the nearest gauging station by catchment area proportioning.

The key gauging stations for the northern area were RGS 4BD6 (S.Mathioya), RGS 3BE3 (Irati), and RGS 4BE9 (Maragua) (LTDP, Hydrology, 1986, Section 5.8).

The key gauging stations for the southern area were RGS 3CB2 (Ndarugu), RGS 3BD8 (Thiririka), and RGS 4BE9 (Maragua) (ibid).

The diversion factors proposed in 1986 are reproduced in Table 5-5 on page 5-9 (ibid).

The diversion factors proposed in 1998 for the Northern Collector are included in Table 5-6 on page 5-9 (Feasibility Report, 1998). There have been adjustments to the ratios, and in one case (I2), the reference gauging stations were changed. The NM1 ratio in particular has increased. The Report does not provide explanations. In this Study, the adopted ratios will be

based on the previous studies adjusted appropriately, to take account of the natural reduction in unit catchment runoff as one progresses downstream.

Table 5-5: Storage and Diversion Site Transposition Equations (1986 Report)

Name	Ref.	Type	Area km²	Grid Ref	Transposition Equation
S.Mathioya 1	SM1	D	39	BK596261	0.755 x 4BD6
S.Mathioya 2	SM2	D	21	BK543260	0.390 x 4BD6
N.Mathioya 1	NM1	D	52	BK595330	0.340 x 4BD7
Maragua 4	M4	S	72	BK643178	1.102 x (4BE8 + 4BE9)
Maragua 8	M8	S	214	BK840137	0.845 x (M4 + 4BE3) + (0.155 x 4BE1)
Ndarugu 1	N1	S	411	BJ964765	3CB5 + 0.033 x (3DA2 - 3CB5 - 3BA32)
Ndarugu 2	N2	S	72	BJ645950	0.752 x 3CB5
Irati 1	I1	D	27	BK590177	0.371 x 4BE3
Maragua 9	M9	D	26	BK552246	0.538 x 4BE9
Maragua 10	M10	D	36	BK594228	0.841 x 4BE9
Ruiru 1	R1	S	125	BJ529856	1.11 x (Ruiru + 3BC9)
Ndurire 1	NDU1	D	88	BJ512890	1.99 x 3BC9
Karimenu	KA1	D	95	BJ627983	0.80 x 4CA23
Gikigie 1	G1	D	15	BK598203	1 x 4BE8
Githugi-Hembe 1	GH1	D	42	BK592317	0.33 x 4BD7
Iratu 2	I2	D	35	BK596178	0.47 x 4BE3

Source: Table 5-11, Long Term Development Plan, Hydrology, HH, July 1986

Table 5-6: Flow Transposition Ratios for Diversion Sites (1998 Report)

Diversion Number	River	Associated RGS	Ratio
D1 (I2)	Irati	4BE6+4BE7	1.000
D2 (G1)	Gikigie	4BE8	1.000
D3 (M10)	Maragua	4BE9	0.917
D4 (SM1)	S. Mathioya	4BD6	0.677
D5	Hembe	4BD7	0.227
D6	Githugi	4BD7	0.192
D7 (NM1)	N.Mathioya	4BD7	0.513

Source: Table 4.7, Northern Collector Scheme, Draft Report, HH, June 1998

2.3.6 Compensation Flows and Resultant Yields

In the 1986 Long Term Development Plan, compensation flow was set to "around" 10% of MAR, as this equated to the 95% daily low flow based on the low flow study.

In the Northern Collector Feasibility Report dated 1998, the compensation flow was set such that flow below any diversion point would never fall below the 95% exceedence flow calculated from a daily flow duration analysis for the naturalised flow at the diversion point. This is the natural flow that is exceeded on average 95% of the time (Section 3.4.5, Feasibility Report, 1998).

Table 5-7 analyses the previously published reliable yield calculated at three diversion points. On average, the final adopted "90% Reliable Yield" of the river equated to the flow exceeded 39 to 50% of the time, and this typically amounted to between 33 and 36% of the mean annual runoff. The expected impact on the river flow regime was thus significant. "In effect, the flow in the river downstream of the diversion will be at the compensation level for most of the year only rising above this value during flood events in the rainy seasons (Section 4.8.10, N. Collector Feasibility Report)". The acceptability of this is uncertain.

The Northern Collector Phase I yields are reproduced in Table 5-8 on page 5-11.

The Northern Collector Phase II yields are reproduced in Table 5-9 on page 5-11.

The compensation flows in Table 5-8 and Table 5-9 did not allow for the compensation flows that were needed to sustain hydropower needs at that time downstream of the various diversion sites. The loss of hydropower as a consequence was assumed to be a "project cost" (Section 4.8.7, Northern Collector Scheme Feasibility Report).

If there were to be no restrictions on hydropower needs, the compensation flows would need to be increased to the levels shown in Table 5-10 on page 5-11. These figures relate to 1998, and they need to be updated as the number of small hydro schemes on these rivers is increasing. An example is "Greening the Tea Industry in East Africa", an initiative being executed by the East African Tea Trade Association (EATTA). One of the EATTA schemes currently being designed is on the North Mathioya River, very close to and downstream of the diversion point proposed in the Northern Collector Scheme Feasibility Report.

Table 5-7: Reliable Yields Relative to MAR and Flow Duration Exceedence

	Gikigie Diversion	Maragua Diversion	Irati Diversion
Catchment area sq km(2)	14.4	36.4	35.2
Transposition Equations	1 x 4BE8(4) 1 x 4BE8 (1)	*M10:* 0.841 x 4BE9 (4) 0.917 x 4BE9(1)	*I2:* 0.47 x4 BE3 (4) 4BE3 + 4BE7 (1)
Mean annual runoff (MAR) m^3/s(2)	0.77	2.28	1.77
Diversion Ref (2)	D2	D3	D1
Diversion capacity m^3/s(1)	1.00	3.00	2.00
90% Reliable Gross Yield m^3/s(3)	0.28	1.16	0.81
Yield Exceedence %	49% Exc.(5)	39% Exc.(6)	50% Exc.(7)
90% yield as %MAR	33% MAR	36% MAR	34% MAR

Date Sources:
1: Table 4.7, Northern Collector Feasibility Study, June 1998
2: Table 4.14, Northern Collector Feasibility Study, June 1998
3: Table 4.15, Northern Collector Feasibility Study, June 1998
4. Table 5-11, Long Term Development Plan, Hydrology, July 1986
5: Figure 4.37, Northern Collector Feasibility Study, June 1998
6: Figure 4.38, Northern Collector Feasibility Study, June 1998
7: Figure 4.36 Northern Collector Feasibility Study, June 1998

Table 5-8: Recommended Northern Collector Phase I Configuration

Diversion Number	River	Available MAR (m^3/sec)	Diversion Capacity (m^3/sec)	Compensation Flow (m^3/sec)
3	Maragua	2.056	3.0	0.502
2	Gikigie	0.769	1.0	0.076
1	Irati	1.693	2.0	0.322
	TOTAL	**4.518**	**6.0**	**0.900**

Source: Table 4.19, Northern Collector Scheme, Feasibility Report, Volume 1, July 1998

Table 5-9: Recommended Northern Collector Phase II Configuration

Diversion Number	River	Available MAR (m^3/sec)	Diversion Capacity (m^3/sec)	Compensation Flow (m^3/sec)
7	N. Mathioya	3.905	2.5	1.093
6	Githugi	1.497	1.0	0.411
5	Hembe	1.696	1.0	0.484
4	S.Mathioya	2.056	1.5	0.655
3	Maragua	2.056	3.0+6.0	0.502
2	Gikigie	0.769	1.0	0.076
1	Irati	1.693	2.0	0.322
	TOTAL	**17.577**	**12.0**	**3.543**

Source: Table 4.21, Northern Collector Scheme, Feasibility Report, Volume 1, July 1998

Table 5-10: Compensation flows at diversion sites, with and without HEP

Diversion Number	River	Compensation Flow With HEP (m^3/sec)	Compensation Flow Without HEP (m^3/sec)
7	N. Mathioya	1.787	1.093
6	Githugi	0.709	0.411
5	Hembe	0.826	0.484
4	S.Mathioya	1.250	0.655
3	Maragua	1.125	0.502
2	Gikigie	0.256	0.076
1	Irati	0.788	0.322
	TOTAL	**6.741**	**3.543**

Source: Table 4.16, Northern Collector Scheme, Feasibility Report, Volume 1, July 1998

Note: HEP = Hydro-electric power stations (these refer to stations in 1998)

3 Recent Legislation Governing Water Resources Management

3.1 The Water Act, 2002

In 2002, the current Water Act was enacted, and under Section 7, the Water Resources Management Authority (WRMA) was established for the effective management of all water resources in Kenya. The country was divided into six regions based on the natural drainage basins. WRMA took over the role formerly vested within the Ministry of Water Development.

This project's potential water resources fall within the jurisdiction of two of the six designated WRMA regions, as follows:

- Athi River Catchment Area;
- Tana River Catchment Area.

The Athi River drains from Nairobi to the Indian Ocean, and the Athi region of WRMA covers Kiambu, Thika, Machakos, Makueni, Kajiado, Taita, Taveta, Kwale and Kilifi Districts.

The Tana River drains from Mt Kenya and the Aberdare Mountains, and discharges to the Indian Ocean north of the Athi River.

3.2 Water Resources Management Rules, 2007

In 2007, the Water Resources Management Rules were issued under Legal Notice 171. The Rules state *inter alia* "…apply to all policies, plans, programmes and activities that are subject to the Water Act, 2002…", and are "…applicable to all water resources and water bodies in Kenya…".

In order to manage the water resources, WRMA is required to develop water management and allocation plans. This process is in its early stages of development. WRMA offices have been established, and the draft Athi Water Catchment Area Catchment Management Strategy was produced in 2008. There is nothing yet produced with which to specifically guide the water supply interventions in the water sector in the Study area.

The design, construction and monitoring of water supply schemes is governed entirely by the provisions of the Water Act, and the Rules issued under the Act. Permits are required for water resource interventions, all of which are detailed in the various Schedules in the Rules.

The utilisation of the riparian zone of all rivers, both perennial and seasonal, is governed by restrictions in the Rules. No tillage or cultivation is permitted, and the draining of wetlands and swamps is subject to permits issued by the Authority (WRMA).

3.3 Water Resource Users Associations (WRUA)

The Study area falls within the Athi River Catchment Area, and there are also water resources under investigation further afield within the Tana River Catchment Area.

The Water Resources Management Authority (WRMA) was formed under the Water Act to "concentrate on water resources management" (WRMA, 2008).

The formation of Water Resource Users Associations (WRUAs) is provided within the Water Act (Rules Part I, 2007). The WRUA is defined as "…an association of water users, riparian land owners, or other stakeholders which have formally and voluntarily associated for the purposes of cooperatively sharing, managing and conserving a common water resource…" (Rules, Part I).

The WRUA is seen as essential "…towards building a water-secure Kenya…" (WRMA, 2008).

The WRUA is the means whereby the community participates in water resources management (WRMA, 2008).

The formation and capacity building of WRUAs within the Project Area is an essential step in the process of effective water resources management.

The importance of the WRUA lies in being a legal entity with access to funds from the Water Services Trust Fund.

3.4 The WRUA Development Cycle

The WRUA Development Cycle (WDC), developed by WRMA, includes the following within its key principles (WRMA 2008):

- Catchment Management Strategy (CMS): To provide overall strategy for the management of water resources at catchment level.
- Sub-Catchment Management Plan (SCMP):
  - Developed by stakeholders (WRMA, WRUA, and others)
  - Sets plan to address sub-catchment water resources management problems

3.5 Strategic Actions

The following strategic actions are listed in the Athi Water Catchment Area CMS Draft (WRMA, 2008):

- Establishment of water allocation threshold
- Determination of Reserve
- Determination of allocatable surface water
- Determination of allocatable ground water
- Determination of collectable rainwater
- Developing an efficient water use plan
- Assess major water users and their water uses
- Establish the status of water abstraction
- Develop and implement water use enforcement plan
- Develop a database for water allocated.

In 2007, “existing” permit holders were required to regularise their abstraction permits through submission of all details to WRMA.

Whilst a draft catchment management strategy (CMS) for the Athi River Water Catchment Area has been obtained, there are as yet no water management and allocation plans.

4 Physical Characteristics of the Eastern Aberdare Catchments

4.1 Introduction

The rivers of interest to this study all rise from the moorlands and forests of the Aberdare Mountain Range. The uppermost drainage comprises undulating moorland with swamps, and areas of heather, and patches of Hagenia woodland, all within the National Park. The Eastern Aberdare Rivers formed within the high altitude moorland, tumble eastwards over spectacular waterfalls into deeply incised forest-clad valleys within the Forest Reserve surrounding the National Park.

The highest peak in the southern Aberdares is Kinangop Peak, at 3,906 masl. The upper forest zone is typically bamboo, changing to forest in the lower slopes. The Forest Reserve boundary, at about 2,200 masl, is demarcated by an electric fence, 420 km long, encircling the entire Aberdare Conservation Area (ACA). This is the longest electrified game-proof fence in Africa.

The Eastern Aberdare forest boundary comprises a zone of smallholder tea plantations on the slopes of the deeply incised valleys, mainly developed in the 1950s to 70s.

"The numerous perennial streams not only provide domestic supplies for a densely populated smallholder farming area, but also are the source of dry season irrigation for Kenya's major coffee and pineapple plantations. In addition, these streams provide water supplies for the rapidly expanding capital city of Nairobi and help maintain the flow of the two major rivers in Eastern Kenya, the Tana and Sabaki, on which the people of these drier areas depend (Blackie & Edwards, 1979)".

The forested catchment area is protected, as it lies within the National Park and Forest Reserve. The importance of the forests to the catchment hydrology has long been recognised, and the Government is committed to forest conservation. "The indigenous forests clothing the mountains play an important role in maintaining dry season flow by stabilizing the soils, maintaining high infiltration rates and reducing surface water runoff in the wet season (Blackie & Edwards, 1979)".

4.2 Soil Hydrological Characteristics – Eastern Aberdare Catchments

The capacity of the soil to absorb water is a key factor in modelling rainfall / runoff.

The soil characteristics of the Eastern Aberdare catchments are summarised in Table 5-11. The table presents the catchment soil profile for the Thika catchment from its source near the peak called "The Elephant" at the southern end of the Aberdare Mountain Range, to this river's confluence with the Chania River at Thika.

Earlier scientific publications describe the predominant soil type to be predominantly "humic Andosols". The later study results presented in Table 5-18 on page 5-62 are consistent. The key soil characteristics in terms of capacity to accept water through infiltration are the soil depth and high porosity, and hence high permeability.

Table 5-11: Soil Characteristics – Eastern Aberdare Catchments

Zone	Soil Type	Zone Characteristics	Soil Description	Soil Permeability
Mountain top and Upper Catchment	M2	Moorland/Forest	Well drained, very deep, clay loam to clay, with thick acid humic topsoil – ANDOSOLS	Volcanic red soils. Very porous.
Upper Middle	R1	Tea/smallholder Highly dissected valleys.	Well drained, extremely deep, friable and slightly smeary clay, with acid humic topsoil – (and humic NITISOLS; with humic ANDOSOLS)	Red volcanic soils. NITISOLS - porous throughout. ANDOSOLS – Very porous
Lower Middle	R2	Farms Highly dissected valleys.	Well drained, extremely deep, friable clay, with acid humic topsoil (humic NITOSOLS)	Red volcanic soils. Porous throughout.
Lower	R3	Farms. Deep valleys with broad ridges.	Well drained, deep to extremely deep, friable to firm, clay, in places gravelly	

Source: Exploratory Soil Map of Kenya, Kenya Soil Survey, 1980

4.3 Soil infiltration Characteristics of Eastern Aberdare Catchments

The Kimakia Research Project summarised the soil hydrological characteristics as follows (East African Agricultural and Forestry Journal, Special Issue 1979):

- The soils developed on the volcanics are uniform over the catchments (Blackie & Edwards, 1979, citing others);
- Profiles show low bulk density with a high organic content for the first metre depth, and dark friable clay below (ibid.);
- Both horizons are porous and have high hydraulic conductivities (500 to 1,500 mm/hr) (ibid.);
- Moisture retention in the top 3.2 m at field capacity (1/3 atmosphere) is 1.525 mm and at wilting point (15 atmospheres) the profile contains 760 mm (ibid.).

4.4 Physiography of Eastern Aberdare Catchments

The widespread physiography of the Eastern Aberdare catchments is described as "mountainous", or more specifically "narrow ridges with 17^{o} to 30^{o} slopes (Nyandat, 1979)". This description reflects very accurately the physiography of the Eastern Aberdare River valleys.

The valleys are deeply dissected, the valley side slopes are very steep, often hard to negotiate, and the rivers typically meander within narrow flood plains, some of which are swampy. Within the forest, the rivers are generally steep flowing, with rocky cascades and waterfalls. The channels are typically shallow with boulder-strewn beds.

In this steep terrain, the vegetation cover is crucial for slope protection, soil stability and management of soil erosion.

5 Review and Update of Rainfall Data

The rainfall data available today is summarised in Table 5-13 on page 5-18 and Figure 5-8. The simulated rainfall database generated in the 1998 Feasibility Report was for the period 1958-92. Hence, there are potentially 19 extra years of data available.

The daily rainfall data available from the Kenya Meteorological Department (KMD) has been entered into the Consultant's HYDATA database. HYDATA is the UK Institute of Hydrology's Hydrological Database and Analysis Package, and is available under license.

Stations 104, 106, 314 and 315 are the four key stations selected for the detailed rainfall runoff modelling that formed the basis of the hydrology of the Northern Collector Feasibility Report.

5.1 Rainfall Data Integrity

The following comments apply to the database summarised in Table 5-13 on page 5-18:

- The digital database available from KMD does not extend back to when the stations were first established, for example:
    - Station 9037007, Muranga District Office, has records dating from 1901, whereas the data from KMD dates from 1960.
    - Station 9036025, N. Kinangop, has records dating from 1915, whereas the data from KMD dates from 1981 only.

This is simply because priority was given by KMD to later data entry.

- The period for which data is available is very variable. Data in two cases extends to 2010. The fragmentation of data is most apparent in recent years.
- The continuity of data within a period is variable. The percent of months with missing data varies between 1.5% and 46%.
- In two cases (….314 and ….315), no data has been received by KMD since the Feasibility Report commenced. These two stations were important for the generation of flow sequences, and were amongst the four stations selected in the Feasibility Report. However, manuscript data has been requested as the measurements continue to be recorded by the Kenya Flyfishers' Club. Through cross correlation, infilling should be possible, if the data books can be found.
- Unfortunately, although measurements have been taken for the last three years at the Club's two camps, the record books for the intervening period since 1992 have not been located.
- There is no rainfall data in the upper reaches of the Northern Collector Rivers. The Karura rain gauge is an example. This gauge is remote, within the Aberdare National Park, and data is missing altogether. Hence the 1998 Feasibility Report flow generation was based on rain gauges close to the river gauging stations, all of which are located beyond the Forest / National Park boundaries.

The daily rainfall data has been input to HYDATA was subjected to preliminary double-mass-curve analysis in Working Paper No.2. This provided a useful indicator of data consistency, as stations within the same vicinity should convey comparable hydrological phenomena. The analysis also showed the data gaps. An example is provided in **Figure 5-2**. There was no data beyond 2004. There were no discontinuities, but there were many data gaps.

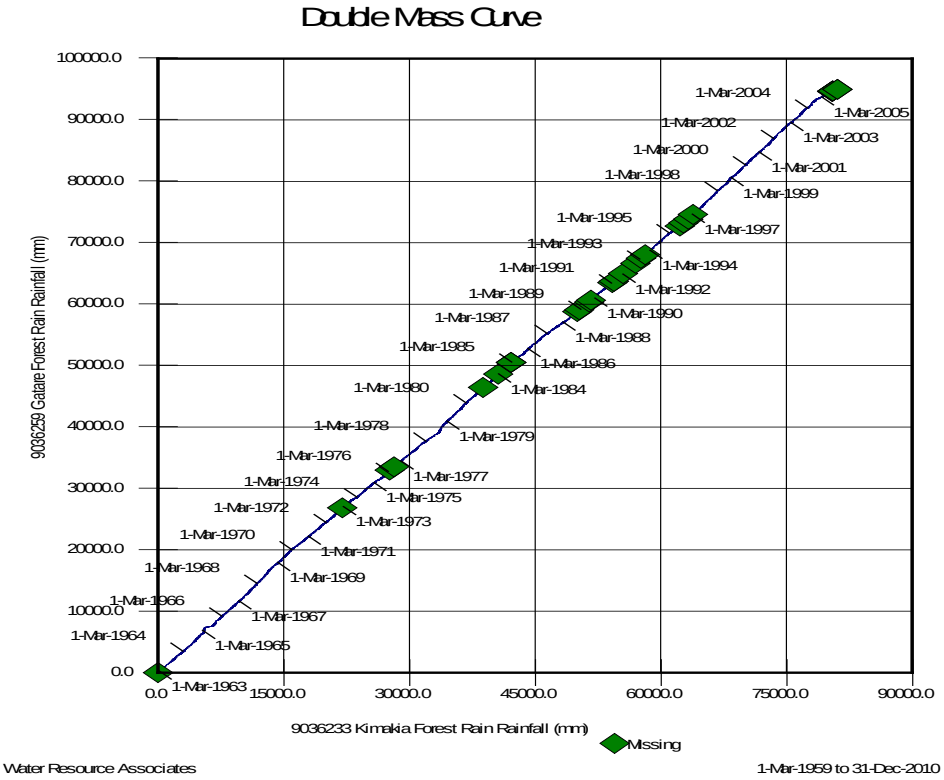


Figure 5-2: Double Mass Curve – Rainfall Stations …233 and …259

5.2 Annual Rainfall Averages

The annual rainfall averages are calculated and presented in Table 5-13 on page 5-18. The North and South Mathioya rain gauges record the highest rainfall, for instance more than double the annual rainfall within Nairobi. These gauges represent the Northern Collector Rivers.

Rainfall contour maps are provided in earlier studies, based on very many more stations than have been available for this study, for instance Drawing No. 3.4 in the Long Term Development Plan, Hydrology Report, dated July 1986. The above mentioned contour map shows the Eastern Aberdare slopes enjoying the highest rainfall, with the Northern Collector Rivers within the wettest zone. The combination of high rainfall and forested upper catchments, results in numerous valuable rivers flowing off the Eastern Aberdares, forming the upper reaches of Kenya's Thika and Tana Basins.

5.3 Long Term Annual Rainfall Change

The KMD annual rainfall data series has been extended back to the early 1900s through addition of annual data abstracted from an early report (Future Water Supply Study, City of Nairobi, HH, April 1970). The data thus obtained for two stations is presented as follows:

- **Figure 5-4** on page 5-19 for Muranga District Office;
- **Figure 5-5** on page 5-19 for North Kinangop.

Figure 5-6 on page 5-20 presents data for Kahuhia, a station with data from the 1960s, illustrating the fragmented data in recent years.

Figure 5-7 on page 5-20 presents data for Gatare Forest Station. Also dating from the early 1960s, this station has a relatively complete record, but daily data is only available at KMD from 1963 up to 2003.

Figure 5-9 on page 5-21 presents Thika Dam rainfall since measurement started in 1996. There has been no recorded reduction in annual rainfall since the very dry year of 2000.

Data for all stations show variation about the mean, sometimes above, sometimes below. Rainfall at these stations averaged generally below the long-term means in the previous two decades, but this may not be unusual. Recent rainfall is not captured at these longer-term stations. Reference to Figure 5-9 shows no decline over the recent period to 2008. Interestingly, the Gatare rainfall record in Figure 5-7 shows that 2006 was drier than 2000, which is contrary to the Thika record in Figure 5-9.

5.4 Seasonal Rainfall Change

The seasonal rainfall pattern is described in earlier reports. There are four seasons within each year, as summarised in Table 5-12 on page 5-18, with January to February on average very dry, followed typically by the "Long Rains" season, during which 56% of the year's rainfall falls on average.

The characteristic bi-modal rainfall pattern of the study area is graphically illustrated in **Figure 5-8** on page 5-21, using data from Gatare Forest Station data.

Table 5-12: Rainfall Seasons

Months	Season	Percent of the Annual Rainfall Falling Within Each Season
January to February	Warm dry season	6 to 11 %
March to June	Long rains	50 to 56 %
July to September	Cool dry rains	3 to 12 %
October to December	Short rains	24 to 38 %

Source: Section 3.4.3, Long Term Development Plan, Hydrology, July 1986

Table 5-13: Rainfall Data Availability

Station Code	Station Location	Elevation m	Start Date	End Date	Data Years	Missing Data Months %	Annual Mean Rainfall mm
9036314	North Mathioya Fishing Camp	2,132	1973	1993	20	1.7%	2397
9036315	Tuso Camp (S. Mathioya)	2,080	1973	1990	17	3.0%	2530
9036330	Wanjerere Forest Station	2,526	1979	2005	26	14.5%	2226
9036106	Kanyenyani - Muranga	2,165	1960	1994	34	20.9%	2085
9036233	Kimakia Forest Station	2,624	1959	2006	47	8.8%	2128
9036259	Gatare Forest Station	2,788	1963	2008	45	1.5%	2493
9036104	Muranga Muriranja	1,902	1960	2000	40	9.7%	1559
9037007	Muranga District Office	1,378	1963	2000	37	4.4%	1229
9037042	Kahuhia Girls	1,640	1960	2010	50	8.8%	1579
9037109	Muranga Water Supply	1,410	1959	2000	41	2.7%	1372
9037216	Kandara Agric. Office	1,739	1984	2010	26	4.5%	1246
90363644	Thika Dam		1996	2009	13	3.6%	1918
9036025	North Kinangop	2,831	1981	2009	28	1.2%	1085
9036152	South Kinangop Njabini	2,788	1959	2000	41	9.9%	1224
9036157	Kiandongoro Hydromet Station	2,558	1981	2010	29	45.9%	1660
9036271	Kiandongoro Gate (Aberdare)	2,558	1965	1999	34	8.7%	2556
9036276	Karura River (Aberdare NP)	3,313	1962	m	m	m	

Source: Kenya Meteorological Department (KMD)
m signifies "missing" data

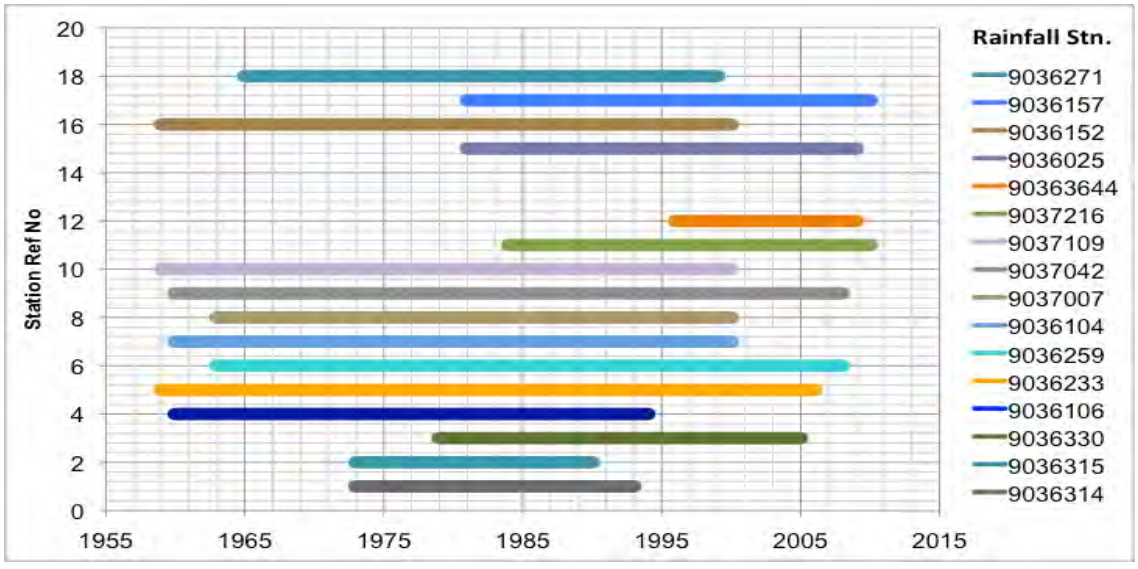


Figure 5-3: Rainfall Data Availability from KMD

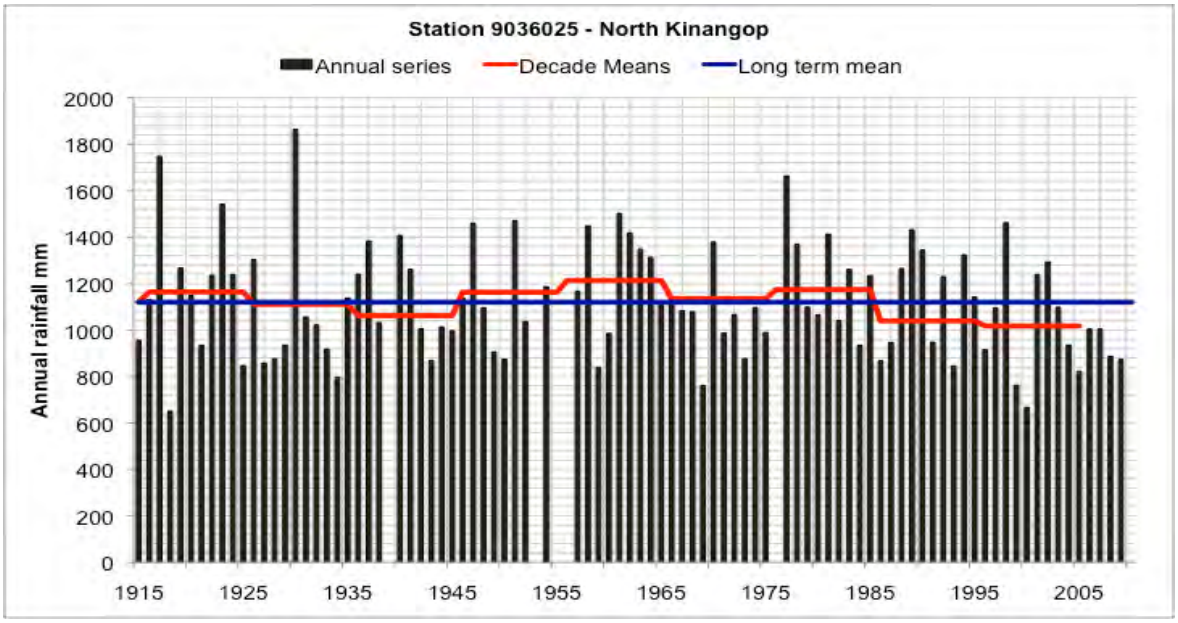


Figure 5-4: Long Term Rainfall at Muranga District Office
(Data Source: KMD)

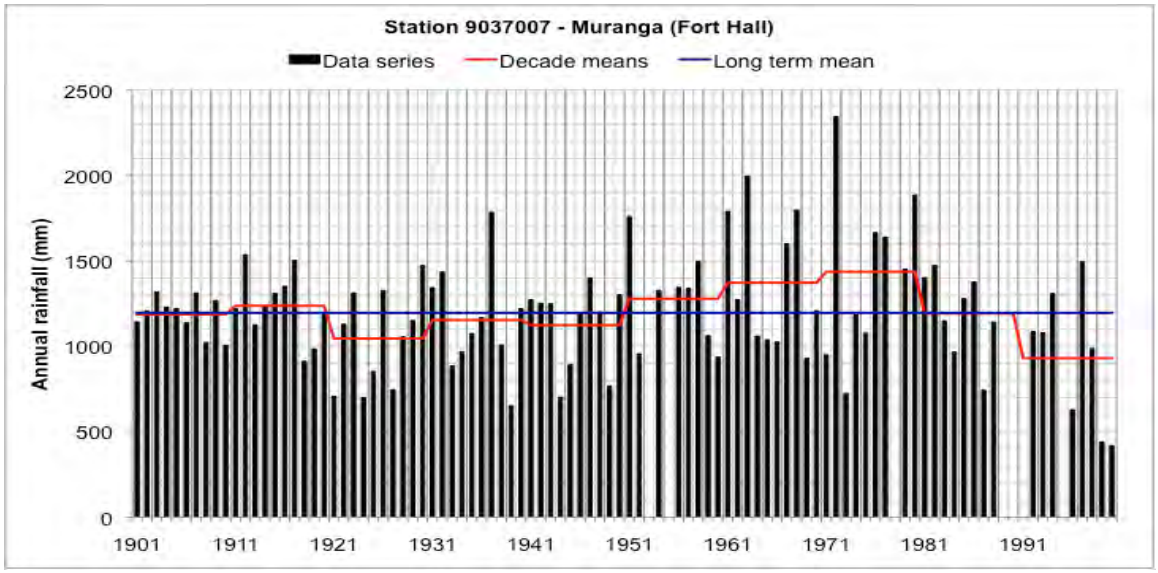


Figure 5-5: Long Term Rainfall at North Kinangop
(Data Source: KMD)

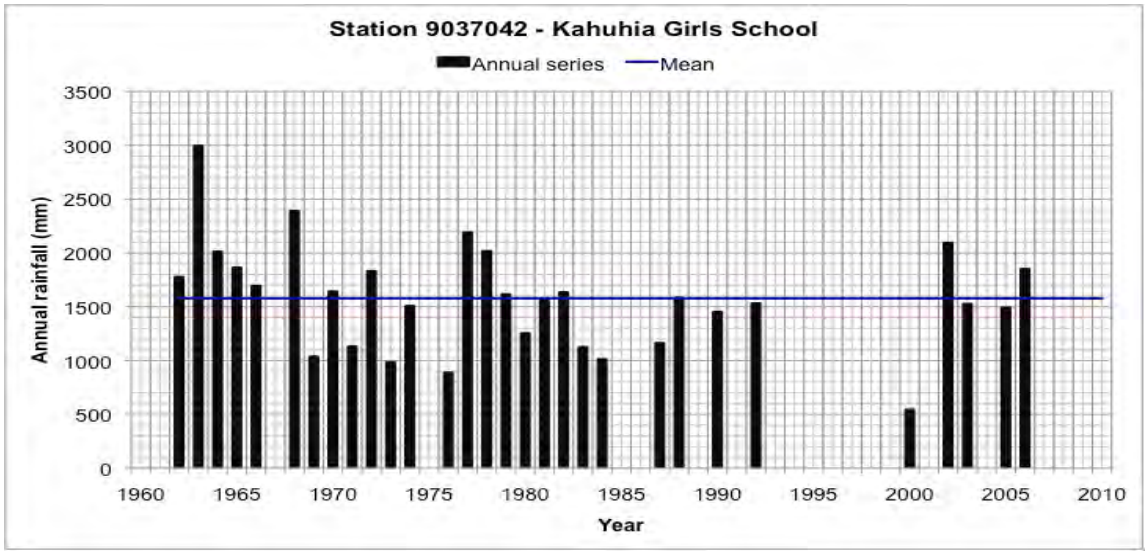


Figure 5-6: Rainfall at Kahuhia
(Data Source: KMD)

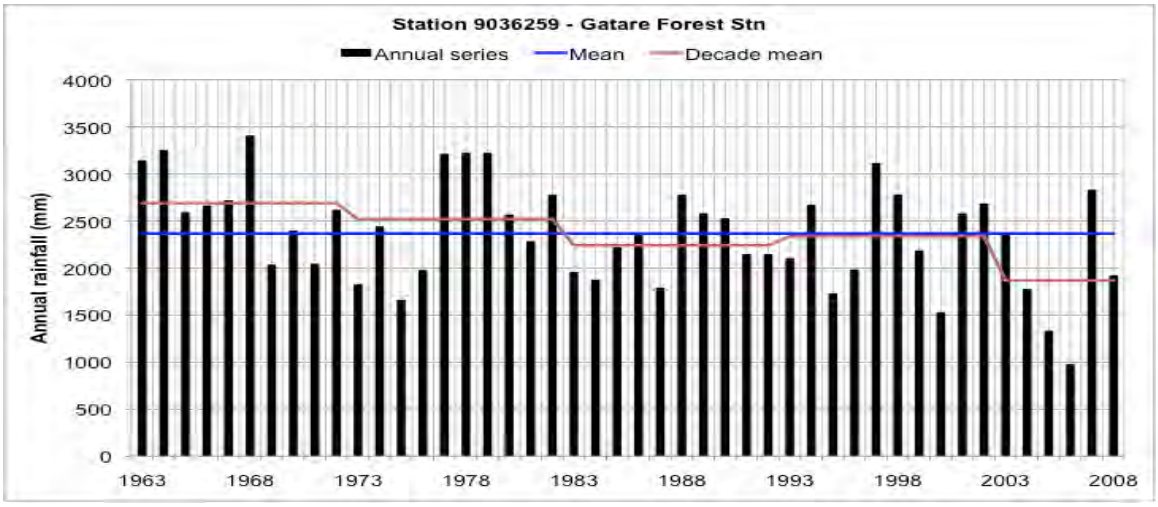


Figure 5-7: Annual Rainfall Variation at Gatare Forest Station
(Data Source: KMD)

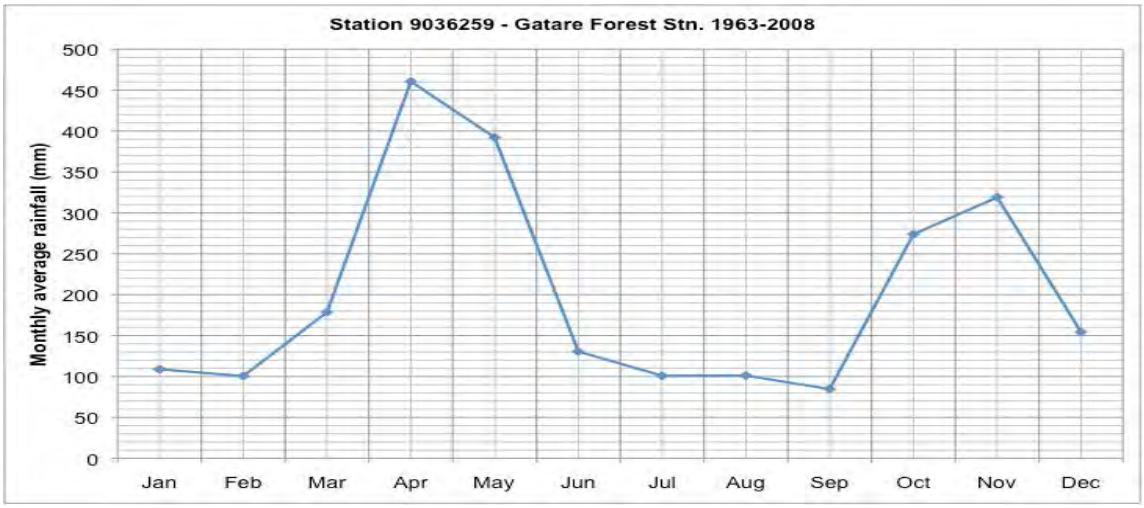


Figure 5-8: Monthly Rainfall Variation at Gatare Forest Station

(Data Source: KMD)

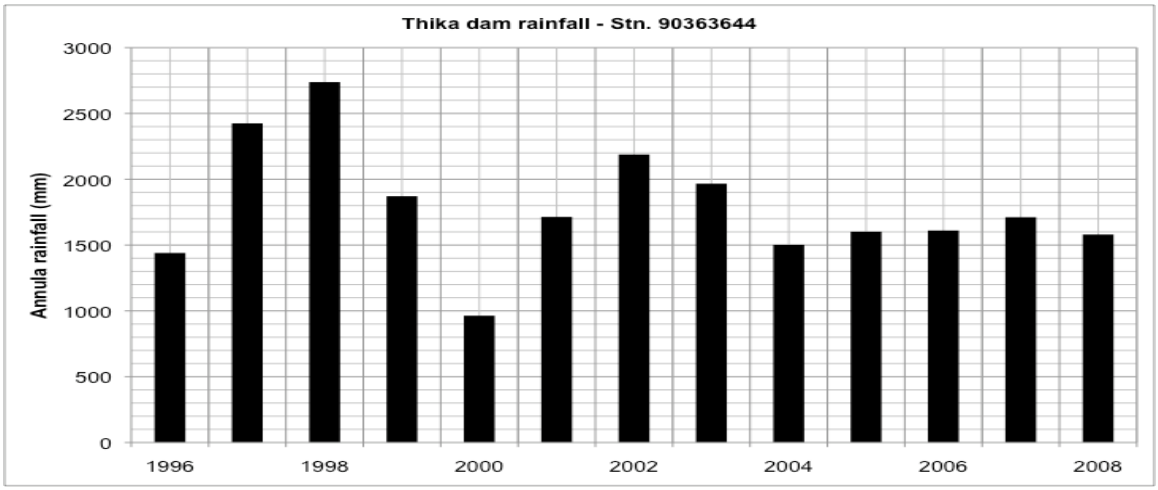


Figure 5-9: Thika Dam Rainfall

(Data Source: KMD)

6 Review and Update of River Flow Data

6.1 Mean Annual Runoff Distribution

In 1973, the World Health Organisation published their very useful Report No.16, Surface Water Resources of Kenya (WHO, 1973). River gauging station records were analysed and flow distribution maps were produced. An extract of Map No.5 is included in **Figure 5-10** on **page 5-23**. This shows the unit runoff variation for all rivers from Nairobi to Nyeri, expressed as Litre/sec/km^2. These are the Eastern Aberdare Rivers that were the focus of previous water resources study for Nairobi.

The Long Term Development Plan in 1986 updated the runoff distribution map for the project area of the Third Nairobi Water Supply Project, using the WHO map as a basis, and the resultant map is reproduced in **Figure 5-11** on page 5-24. Mean annual runoff is in this case shown in mm.

Figure 5-12 on page 5-25 presents the variation in mean runoff between the various sub-basins from south of Nairobi in Athi Basin to the Northern Collector Rivers in Tana Basin. The curves are derived from gauging station data (LTDP Hydrology, Table 3.5) to show the general trend of variation from south to north along the Eastern Aberdare catchments. Detailed plots are included later in this report. Although the historic flow data in the figure is from previous studies, the current studies have shown that the data remains applicable for the Northern Collector Rivers, and the southern river hydrology was "confirmed" by the parallel BRLi/Seureca study. Hence, in the absence of detailed studies beyond the scope of this work, the previous data is relevant to convey useful trends for the analysis.

Figure 5-13 on page 5-25 expresses the same data in terms of mean runoff per unit catchment area. This unit value increases as one progresses up a river, as would be expected with increasing rainfall with altitude.

The Third Nairobi Water Supply Project looked towards the "Northern Rivers" for future water supply to the city. It is easy to see from the figures described above why this is. These "Northern Rivers" have unit runoff rates that are an order of magnitude higher than the unit runoff of rivers in the Nairobi area. The Northern Collector Scheme was proposed as the next stage of water supply development for Nairobi based on the Northern Rivers.

Various individual graphs have been developed as follows:

- Figure 5-14: Mean Annual Inflow in Sub-Basin 4BD (various data sources)
- Figure 5-15: Mean Annual Inflow in Sub-Basins 4CB and 4BE (various data sources)
- Figure 5-16: Mean Annual Inflow in Sub-Basins 3CB and 4CA (various data sources)
- Figure 5.17: Mean Annual Inflow in Sub-Basin 3BB, 3BC and 3BD (various data sources)
- Figure 5-18: Mean Annual Inflow in Sub-Basin 3BA (various data sources)
- Figure 5-19: Mean Annual Inflow in Sub-Basin 3AA (various data sources)

Several data sources are referenced in producing the above graphs, including the following:

- WHO Report No.16, Surface Water Resources in Kenya (WHO, 1973)
- Howard Humphreys Long Term Development Plan dated 1986 (LTDP, 1986)
- JICA National Water Master Plan Sectoral Report B (JICA, 1992)
- BRLi/Seureca Hydrological Study & Water Management Study for the Ngethu-Sasumua System Final Report (BRLi/Seureca, 2010)
- Egis/MIBP Water Sources Options Review Report Version 02 (Egis/MIBP, August 2011)

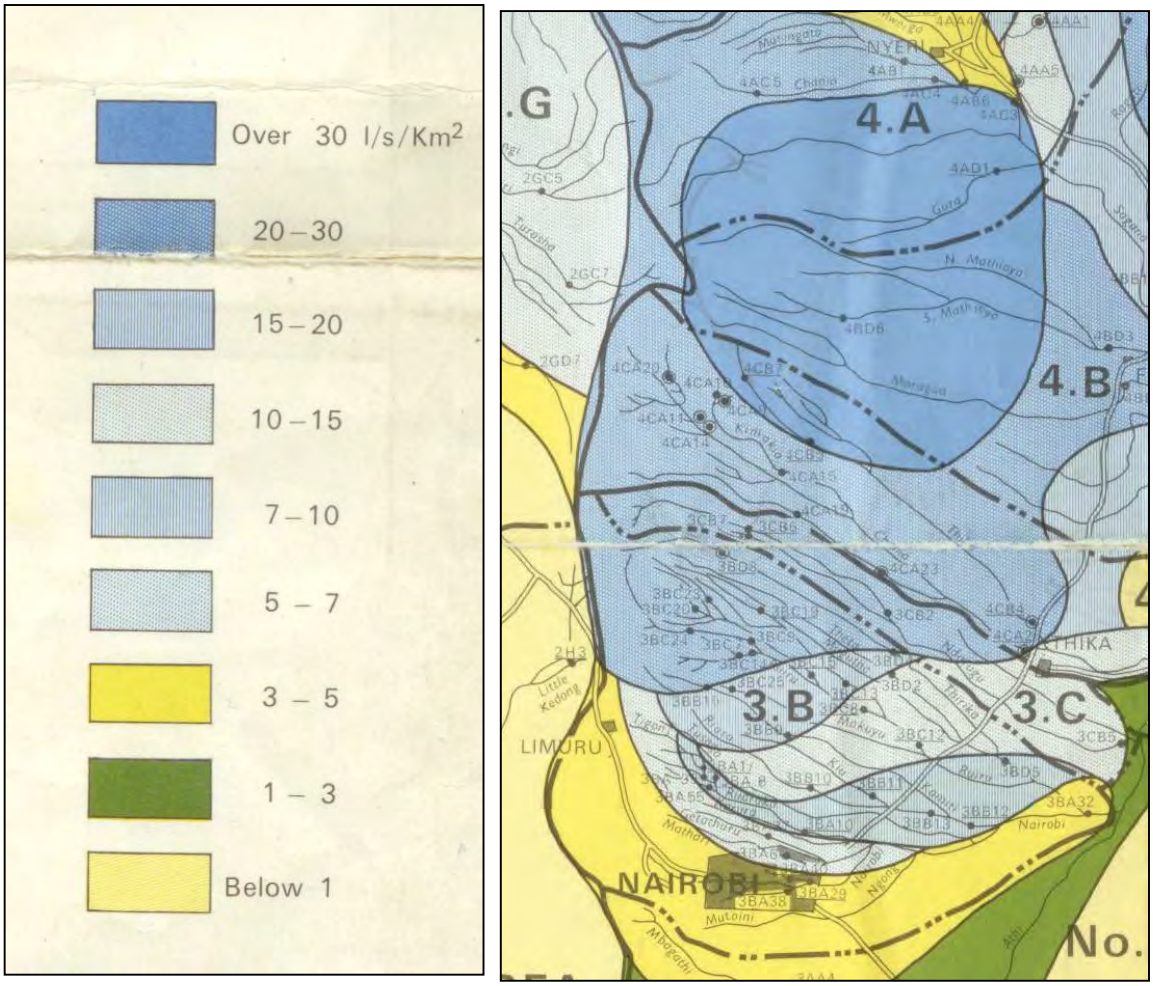


Figure 5-10: Mean Annual Runoff

Source: WHO, 1973 (Map No.5)

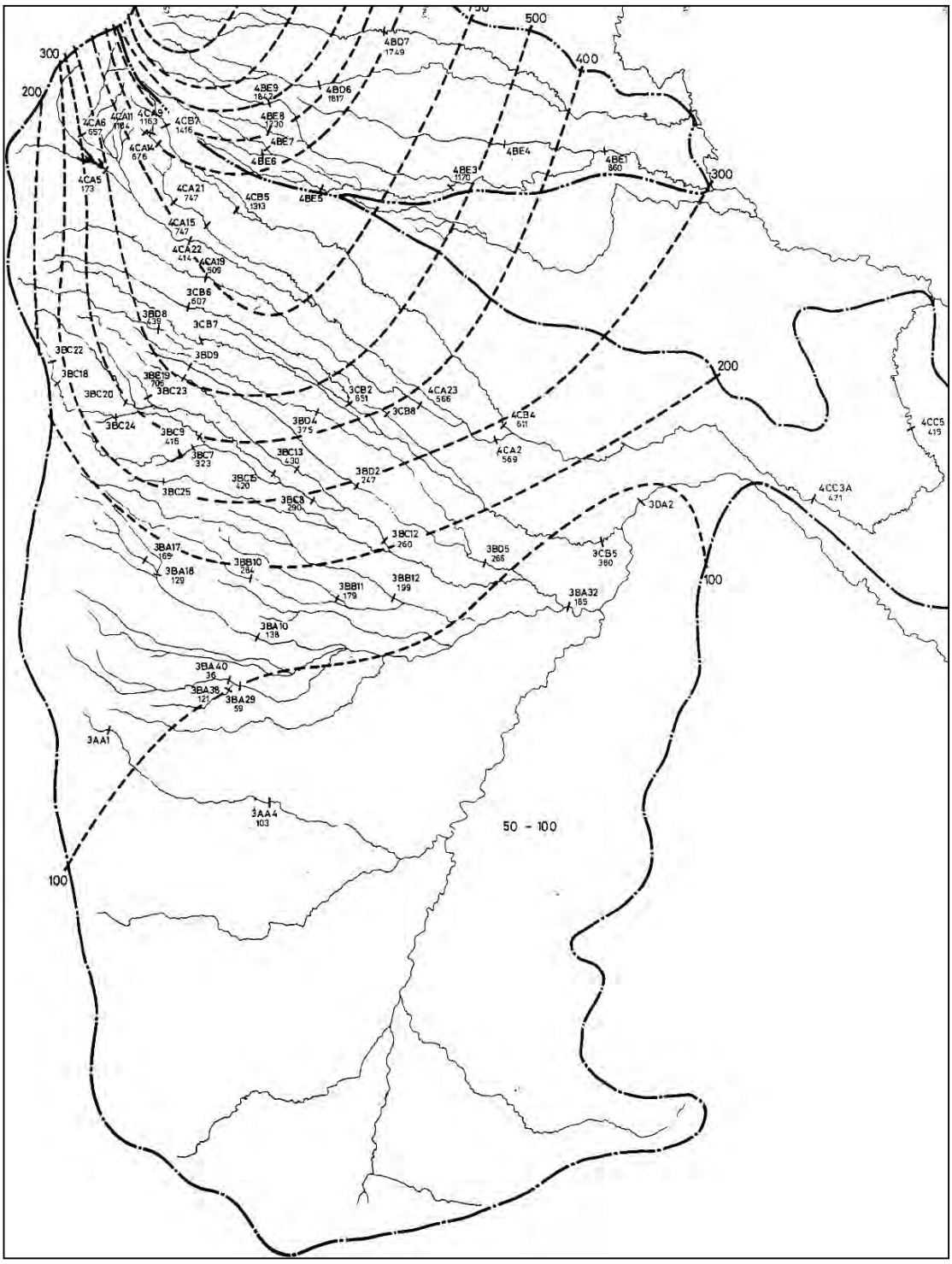


Figure 5-11: Mean Annual Runoff Distribution in millimetres

Source: Long Term Development Plan, Hydrology (Drawing No.3.2), 1986

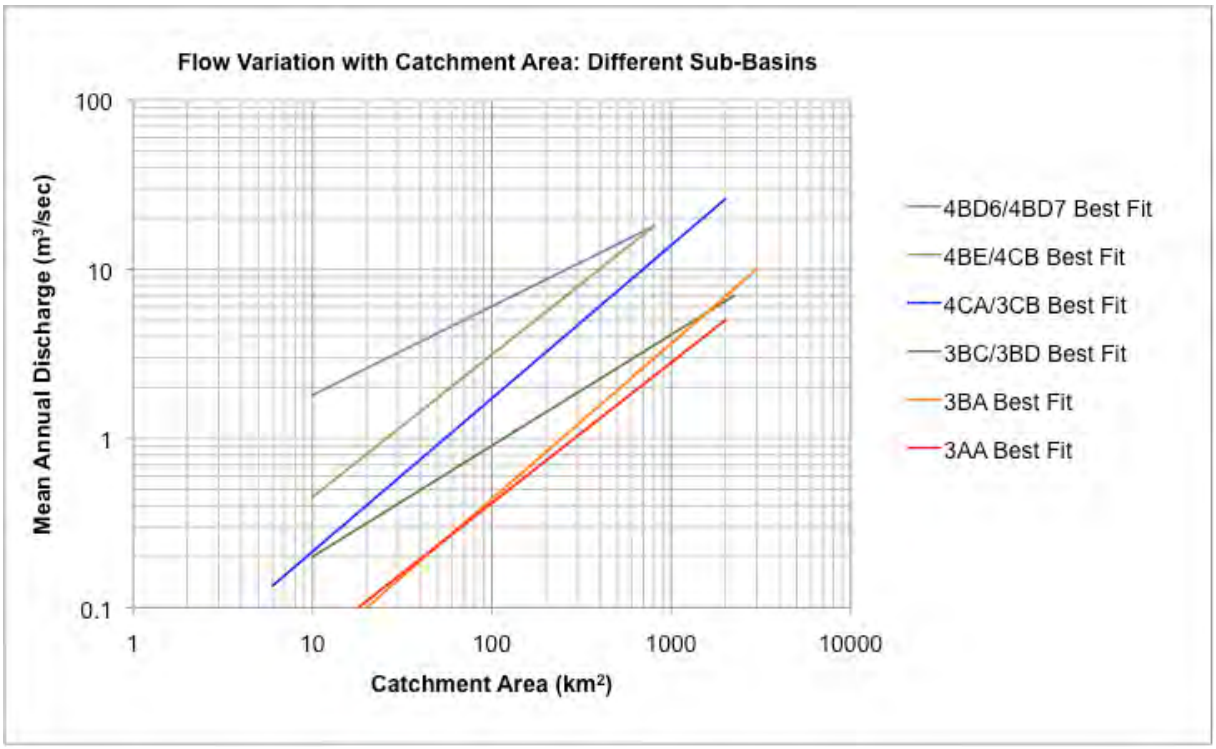


Figure 5-12: Variation in Mean Runoff between Sub-Basins
Data Source for graph: Long Term Development Plan, Hydrology,Table 3.5

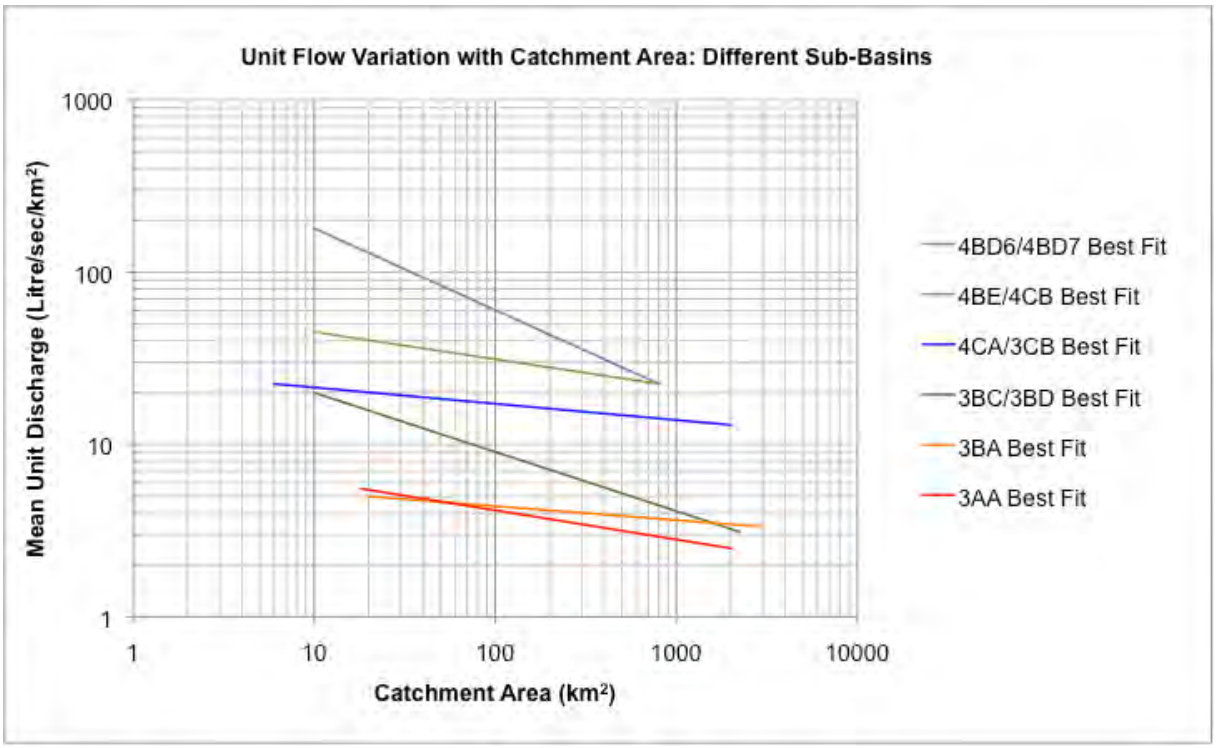


Figure 5-13:Variation in Mean Unit Runoff between Sub-Basins
Data Source for graph: Long Term Development Plan, Hydrology, Table 3.5

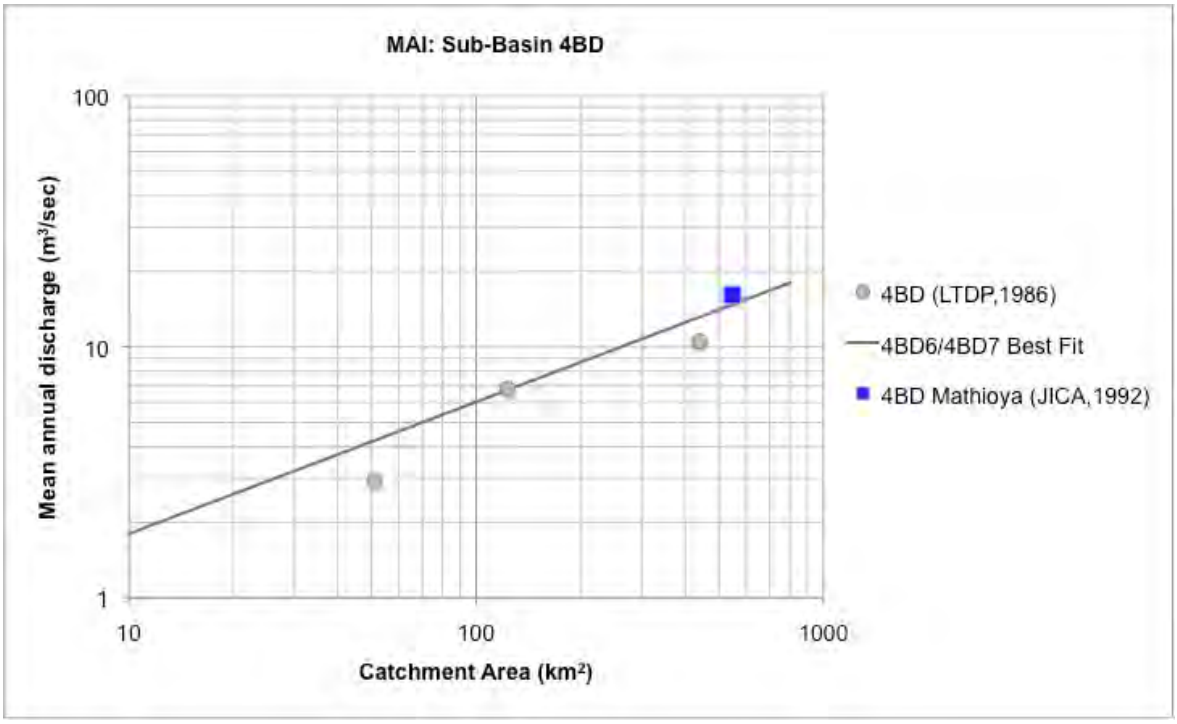


Figure 5-14: Mean Annual Inflow in Sub-Basin 4BD (various data sources)

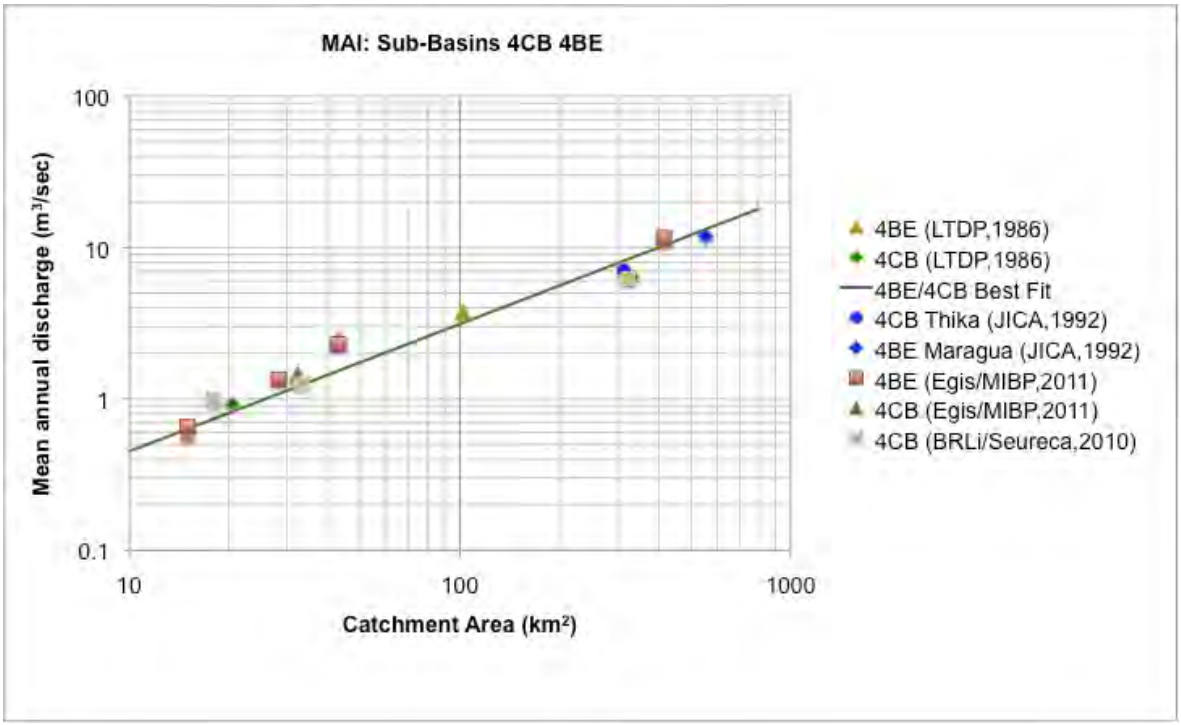


Figure 5-15: Mean Annual Inflow in Sub-Basins 4CB and 4BE (various data sources)

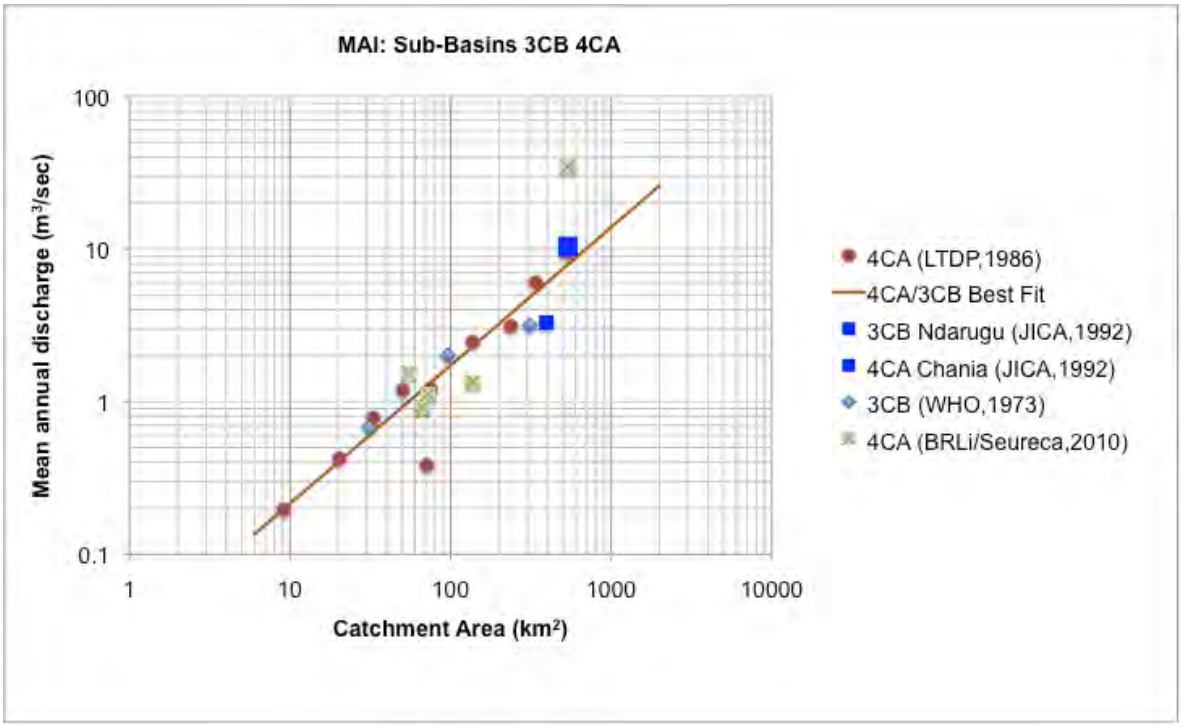


Figure 5-16: Mean Annual Inflow in Sub-Basins 3CB and 4CA (various data sources)

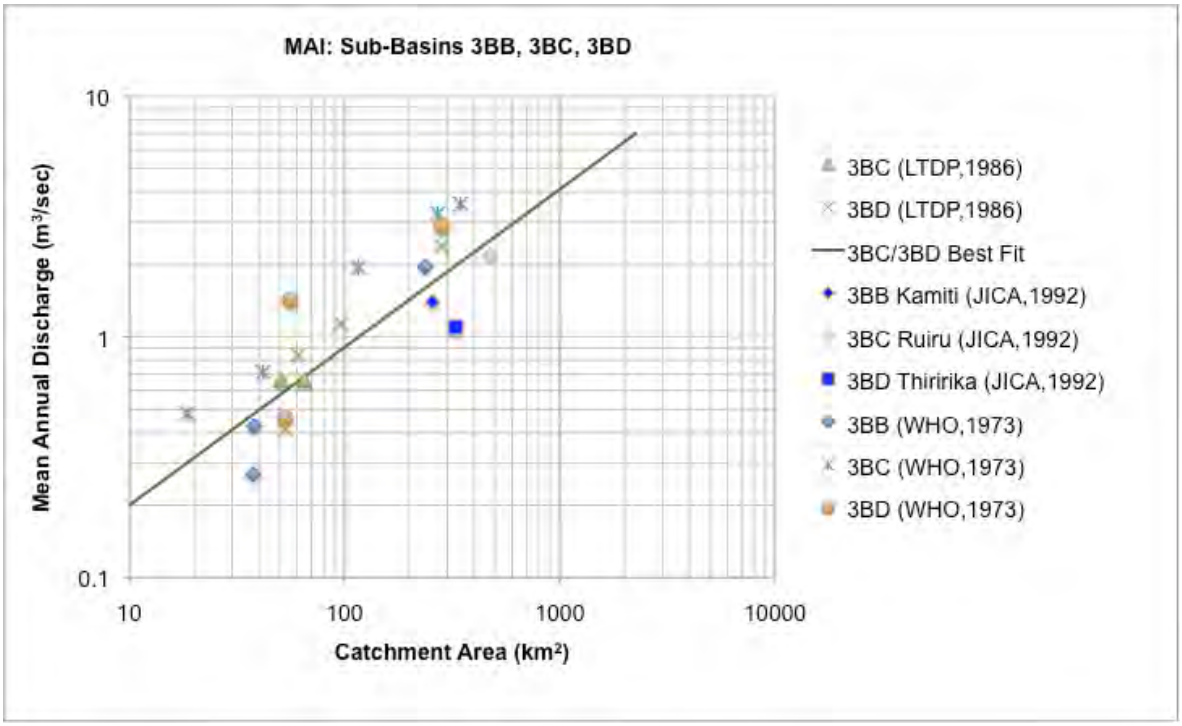


Figure 5.17: Mean Annual Inflow in Sub-Basin 3BB, 3BC and 3BD (various data sources)

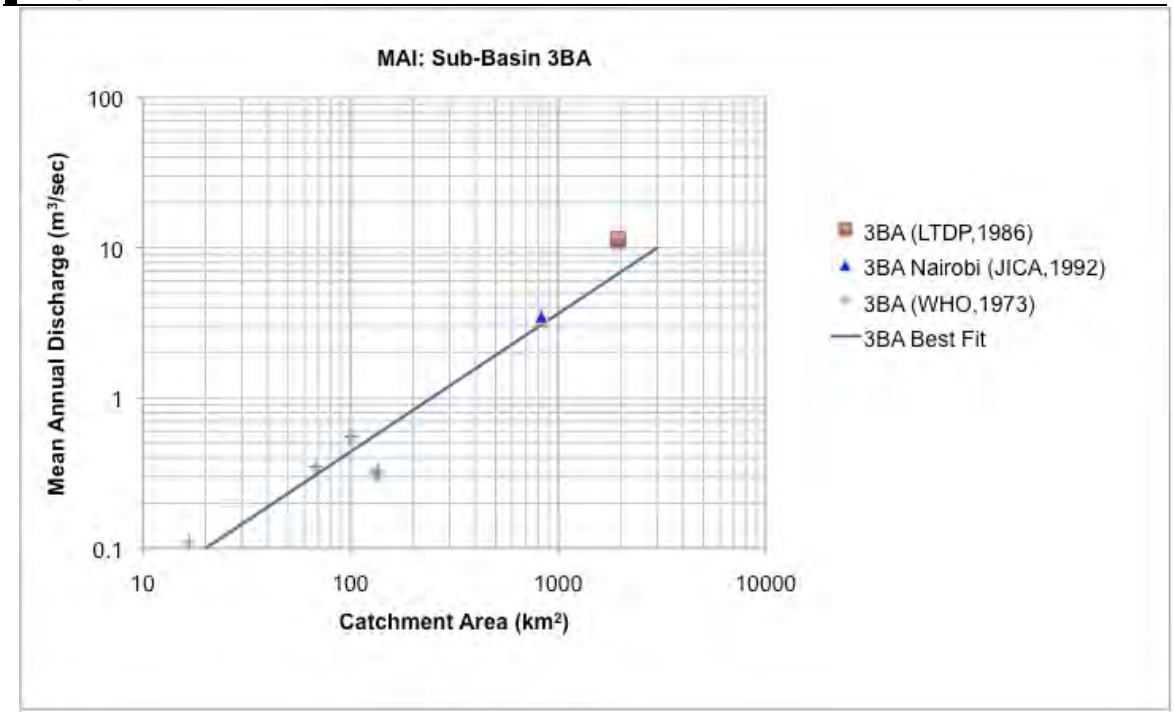


Figure 5-18: Mean Annual Inflow in Sub-Basin 3BA (various data sources)

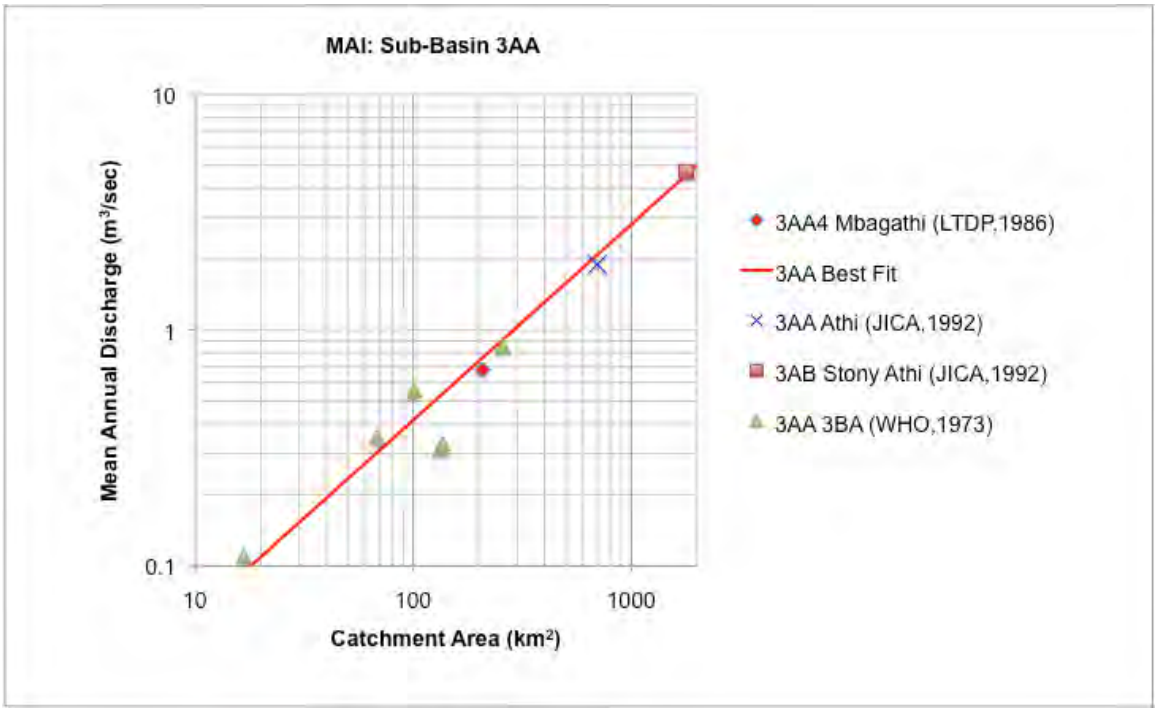


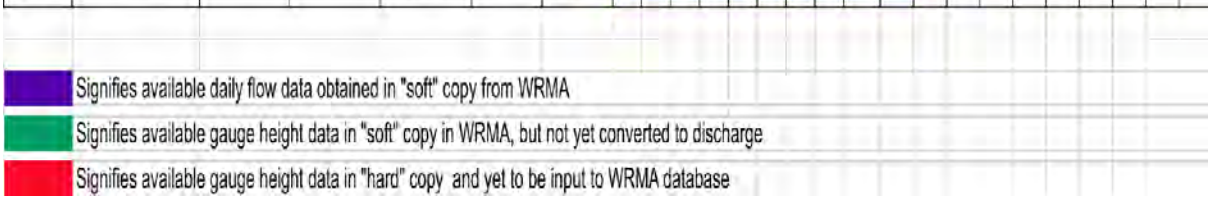
Figure 5-19: Mean Annual Inflow in Sub-Basin 3AA (various data sources)

6.2 River Flow Database

The digitised daily river flow data from WRMA has been entered into the Consultant's HYDATA database.

Table 5-14: Flow Records

Station RGS No	River	Latitude S	Longitude E	Catchment Area km2	Data Begin	Data End
3AA04	Mbagathi	9,846,700	258,800	208.0	1950	1985
3BC09	Bathi	9,886,000	251,300	50.6	1957	1994
3BD08	Thiririka	9,897,500	249,000	60.6	1960	1995
3CB02	Ndarugu	9,890,200	268,200	98.8	1960	2000
3CB05	Ndarugu	9,876,200	296,070	312.0	1956	1994
3DA02	Athi	9,879,200	298,800	5590.0	1956	2000
4AD01	Gura				1951	1996
4BD01	Mathioya	9,921,300	297,600		1948	1963
4BD02	Mathioya				1959	1960
4BD06	South Mathioya	9,925,300	264,500	50.9	1972	2003
4BD07	North Mathioya	9,930,700	272,300	123.3	1976	2009
4BE01	Maragua	9,901,720	296,000	414.0	1946	2000
4BE03	Irati	9,913,200	278,500	102.0	1975	2004
4BE04	Kayahwe			86.1	1975	2004
4BE05	Gatanda			19.5	1977	2004
4BE06	Irati			27.1	1977	1997
4BE08	Gikigie	9,920,300	259,800	14.4	1977	2005
4BE09	Little Maragua	9,921,400	262,400	41.2	1977	2009
4CA02	Chania	9,886,600	284,500		1956	2008
4CA04	Kimakia				1978	2006
4CA15	Kimakia			50.3	1958	2006
4CA23	Karimenu			137.0	1970	2005
4CB04	Thika	9,887,300	288,480	331.0	1975	2010
4CB05	Thika			32.3	1950	2010
4CB07	Thika			20.5	1959	2001



6.3 River Gauging Station Data

As stated earlier, the frequency with which river gauging is conducted is indicative of data quality:

- The expectation that there will be regular visits by the gauging team helps ensure that gauge readers remain motivated and diligent.
- On the occasion of a visit by the current meter gauging team, the gauge height reading is compared with the most recent recording in the gauge reader's book.
- Regular gauging verifies the applicability of the station stage-discharge rating curve, and if there are rating changes, these are identified early. If the reason for the rating change is man-induced, action can be taken to rectify the situation.

Another Consultant was appointed by AWSB (BRLi/Seureca) to examine the Chania Basin's hydrology, as part of a study of the Sasumua / Ngethu system. Their analysis is not duplicated here.

Table 5-15 on page 5-31 tabulates the gauging record on Northern Collector Rivers throughout the stations' history. Of particular interest is the gauging record since 1994:

- Stations RGS 4BE1, 4BE3, 4BE6, 4BE7, 4BE8, 4BD7: No gauging since 1997 until gauging re-commenced in 2010.
- Stations RGS 4BE4, 4BE9, 4BD6: Isolated gauging in years till 2003, none thereafter.

The gauge reader data quality for the period 1994 to 2010 cannot be checked, but based on past reports, and based on the infrequency of visits by gauging teams, it is unlikely to be reliable. The exception will be RGS 4CB5, which is monitored daily by the NCWSC as the gauge is the basis from which inflows to Thika Dam (Ndakaini Dam) are determined. Also, 4CB5 is a measuring weir for which the rating is unlikely to change. Hence particular importance is attached in this report to this record.

The river flow gaugings have re-commenced with frequency at selected stations in 2010. Unfortunately, close inspection of the database shows that most of the gaugings conducted in 2010 were spot measurements only, with no gauge readers in place. Also, many of these readings were in low flow periods.

Individual gauging station stability checks based on the available data are presented in the following sections.

Table 5-15: Gauging record extended from 1994 Onwards

(The number of current meter gaugings in each period or year is indicated)

Station Ref. No	River	Date Opened	Gauging Record To 1984	Gauging Record 1985-94	Gauging Record 1994-2009	Gauging Record Since 2010
4CB5	Thika	1950	14 (1961-82)	11 (1990-94)	1 (1997) 1 (1999) 1 (2000) 1(2009)	13 (2010)
4CB7	Thika	1958	40 (1958-75)	13 (1985-93)		
4BE1	Maragua	1948	8 (1950-53) 11 (1957-63) 41 (1963-71) 23 (1977-84)	10 (1985-94)	2 (1997)	20 (2010) 4 (2011)
4BE3	Irati	1975	43 (1975-84)	14 (1985-94)	1 (1995) 1 (1996) 2 (1997)	20 (2010) 2 (2011)
4BE4			42 (1975-84)	25 (1985-94)	1 (1995) 2 (1996) 6 (1997) 3(1999) 6 (1999) 2 (2000) 1 (2002) 1 (2003)	
4BE5		1977	25 (1977-84)	26 (1985-94)	2 (1996) 2 (1997)	
4BE6			35 (1977-84)	4 (1985) 26 (1985-94)	2 (1995) 3 (1996) 3 (1997)	
4BE5			25 (1977-84)	26 (1985-94)	2 (1996) 2 (1997)	
4BE7			32 (1977-84)	30 (1985-94)	1 (1995) 3 (1996) 4 (1997)	
4BE8	Gikigie	1977	28 (1977-84)	28 (1985-94)	2 (1995) 2 (1996) 1 (1997)	21 (2010) 2 (2011)
4BE9	Maragua	1977	26 (1977-84)	29 (1985-94)	2 (1995) 2 (1996) 1 (1997) 1 (1999) 2 (2000) 2 (2003)	
4BD1	Mathioya	1934	47 (1948-61)	Abandoned	Abandoned	
4BD6	S.Mathioya	1972	56 (1972-84)	18 (1985-92) 8 (1994)	2 (1995) 2 (1996) 1 (1997) 1 (1999) 2 (2000) 2 (2003)	
4BD7	N.Mathioya	1976	33 (1976-84)	20 (1985-94)	3 (1997) 1 (1999) 2 (2000) 3 (2003)	18 (2010) 3 (2011)

6.3.1 Station 4BD6 – South Mathioya River

The rating curves and gaugings dating from 1976 to 2007 are presented in **Figure 5.20**.

The MoWD rating derived from 1972-91 gauging data is almost identical to the modified rating derived through the various studies published in 1986 (LTDP, HH) and 1998 (NCS-FR, HH).

This station has a stable section, and the rating has not changed. No medium to high-flow gaugings have been recorded since the 1985-92 period, but the station rating will be assumed not to have changed.

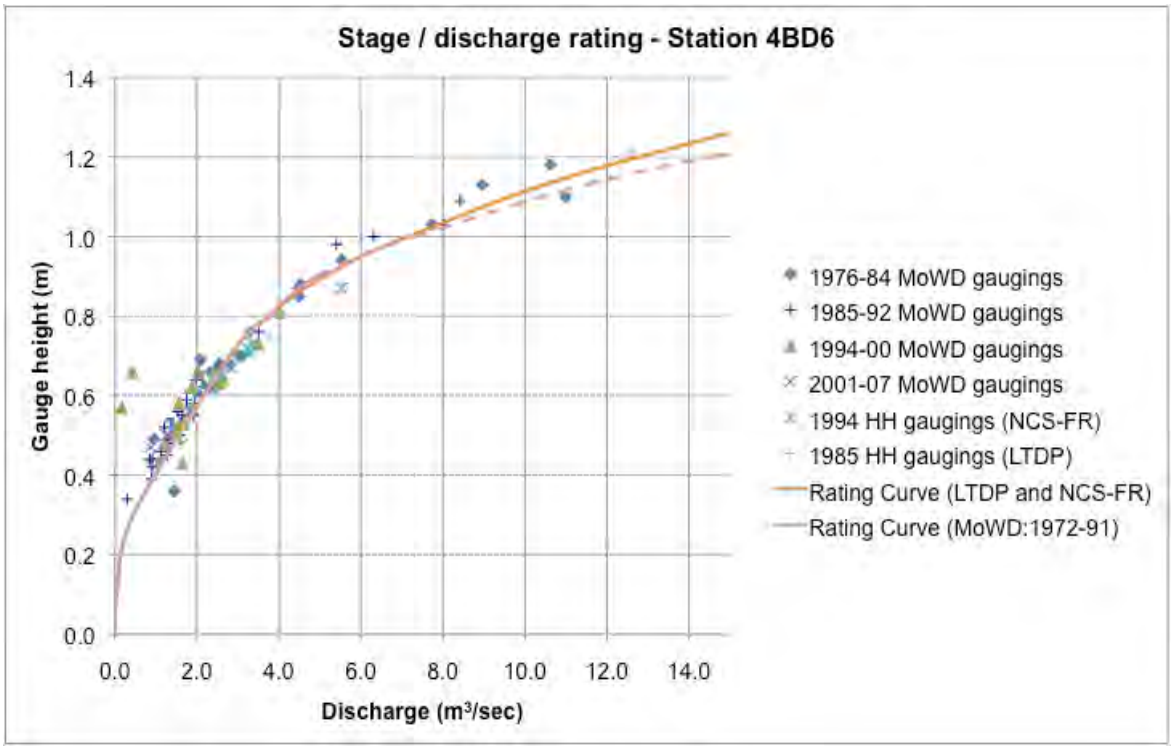


Figure 5.20: Station 4BD6 Rating Check

6.3.2 Station 4BD7 – North Mathioya River

The rating curve and gaugings are presented in **Figure 5-21** on **page 5-33**, dating from 1980 to 2011. The following comments apply:

- The 1976-78 MoWD Rating 1 is identical to the1986 LTDP rating.
- The 1998 NCS-FR (HH) rating shows a downward shift, but at higher flows the extent of the shift is not justified. For Q>5 m^3/s the HH rating will over-estimate flows.
- The 1978-98 MoWD Rating 2 is a good fit.
- The 2010/11 gaugings display a significant downward shift from the 1998 rating which is due to a gauge datum shift. This gauge was re-established in 2010 specifically for a small hydropower study undertaken by Graeme Watson Associates for KTDA. A new staff gauge was fitted by WRMA for that purpose.

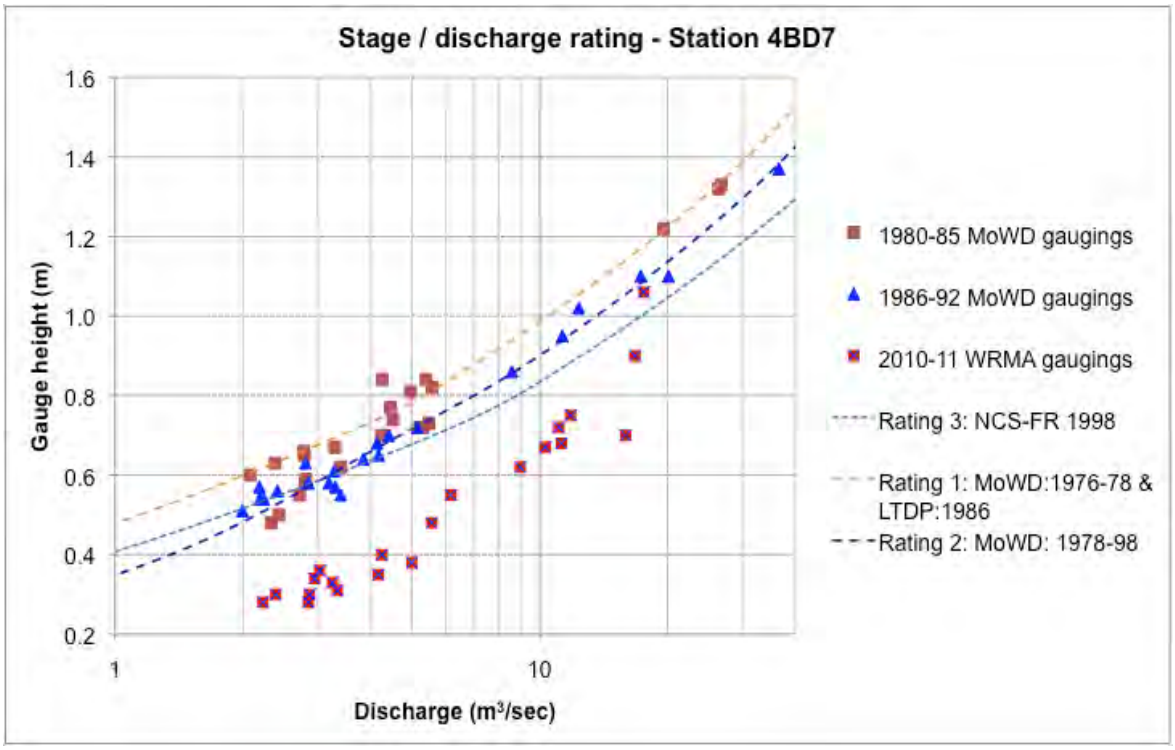


Figure 5-21: Station 4BD7 Rating Check

6.3.3 Station 4BE1 – Maragua River

The WRMA (MoWD) rating curves and associated gaugings are plotted in **Figure 5-22** on **page 5-34**.

"…Throughout the record the station has been poorly rated at moderate to high flows… (above 1.8 metres) (LTDP, Hydrology, 1986)". This was due to insufficient gaugings in this flow range.

"…It is believed that the station has been relatively stable at high flows and past rating changes have been mainly caused by zero changes in the staff gauge… (ibid.)"

The Long Term Development Plan (LTDP) and the Northern Corridor Scheme Feasibility Report (NCS-FR) introduced changes to the WRMA rating curves. The various ratings are compared and discussed as follows:

- **Figure 5-23** on **page 5-34**, 1963-77: The ratings are almost identical.
- **Figure 5-24** on **page 5-35**, 1977-85: The gaugings tend to the left of the MoWD rating. The HH rating proposed a small departure in the high flow range (>1.8 metre river stage).
- **Figure 5-25** on **page 5-35**, 1986-99: The ratings are very close, but the gaugings fit the MoWD rating more closely.
- **Figure 5-26** on **page 5-36**, 2010-11: The stage discharge relationship appears slightly shifted compared to the previous rating curves. The MoWD rating provides a better fit, although a new rating curve is needed.

The absence of gaugings in recent years is a concern, but the station appears to have remained stable, and recent WRMA flow data up to 2000 will be useful.

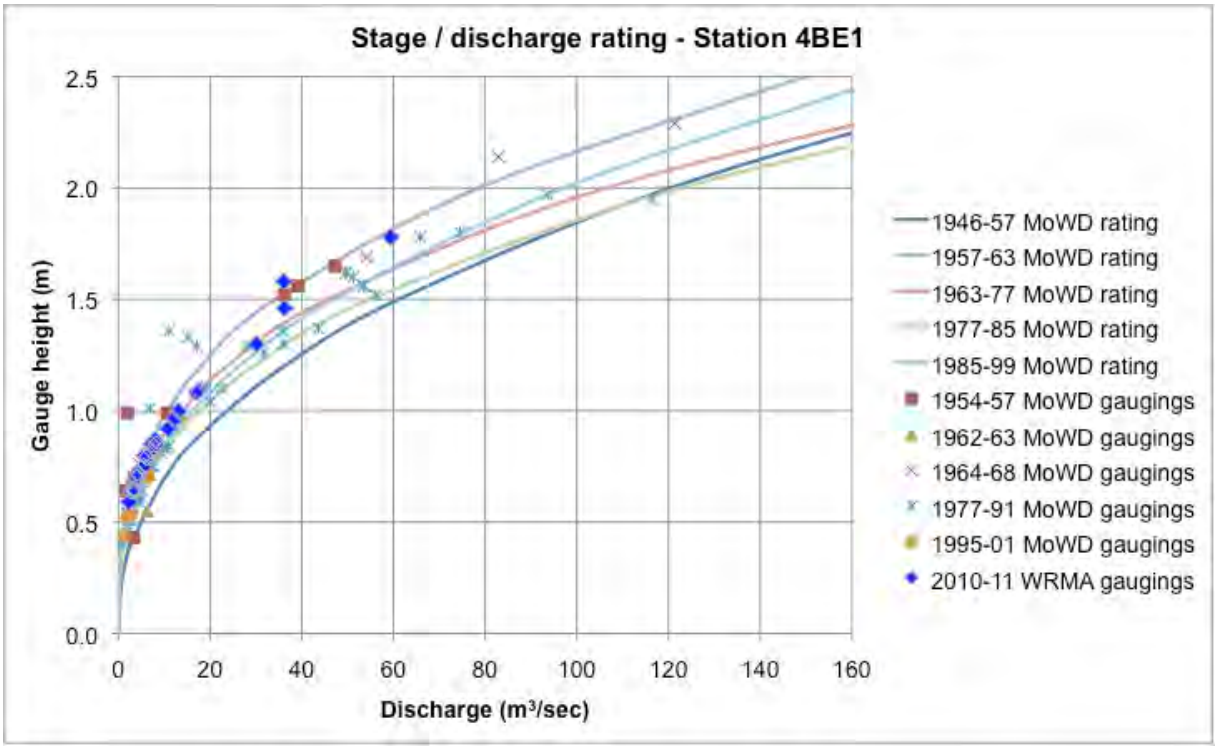


Figure 5-22: Station 4BE1 Rating Check

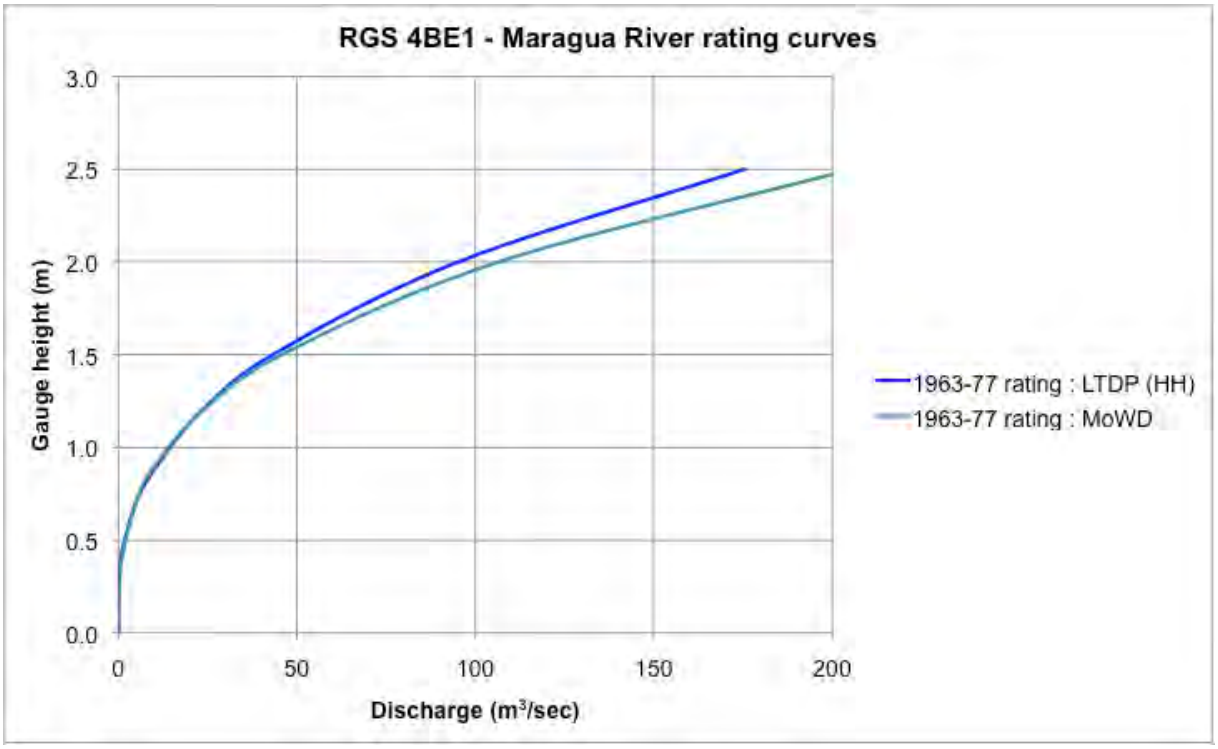


Figure 5-23: Station 4BE1 rating comparison 1963-77

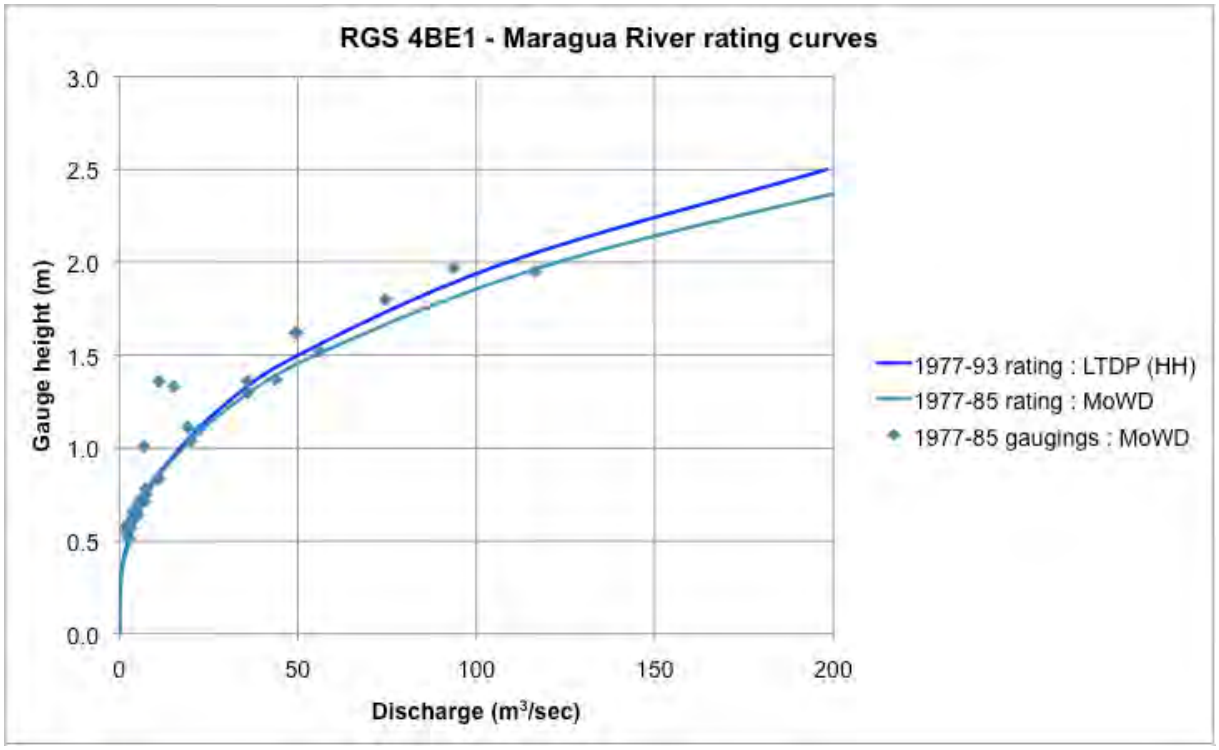


Figure 5-24: Station 4BE1 Gaugings 1977-85

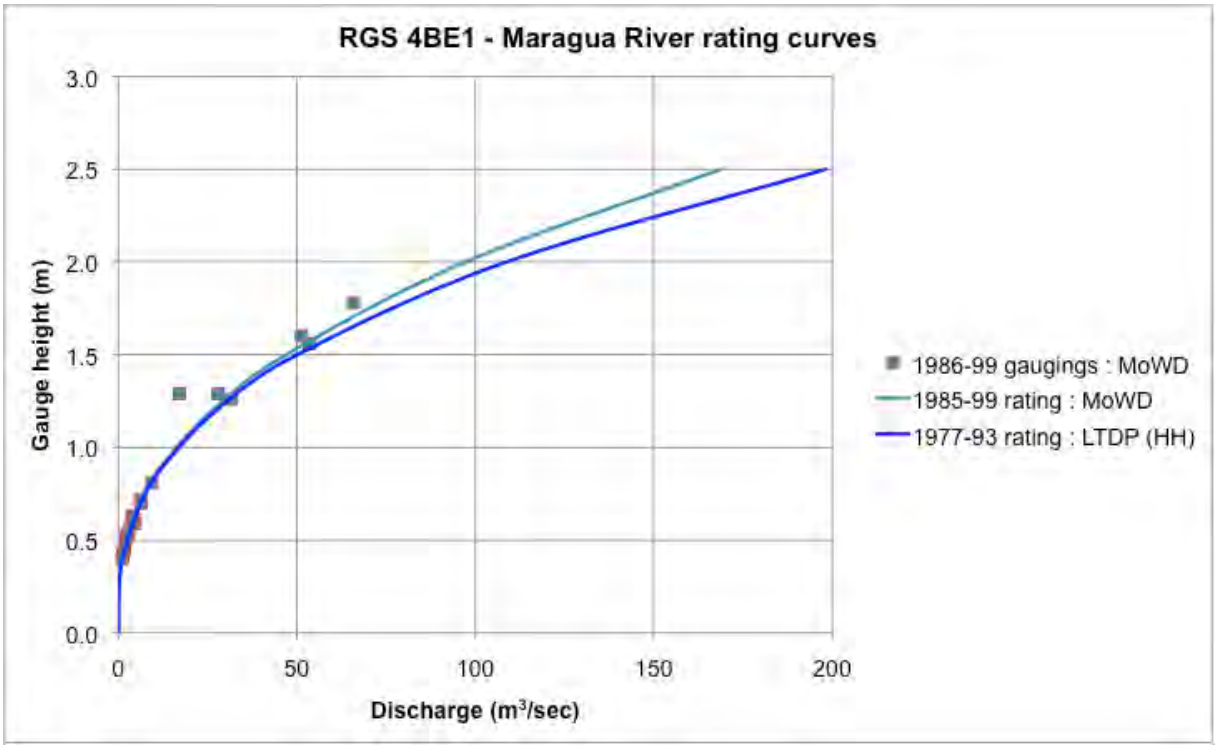


Figure 5-25: Station 4BE1 Gaugings 1986-99

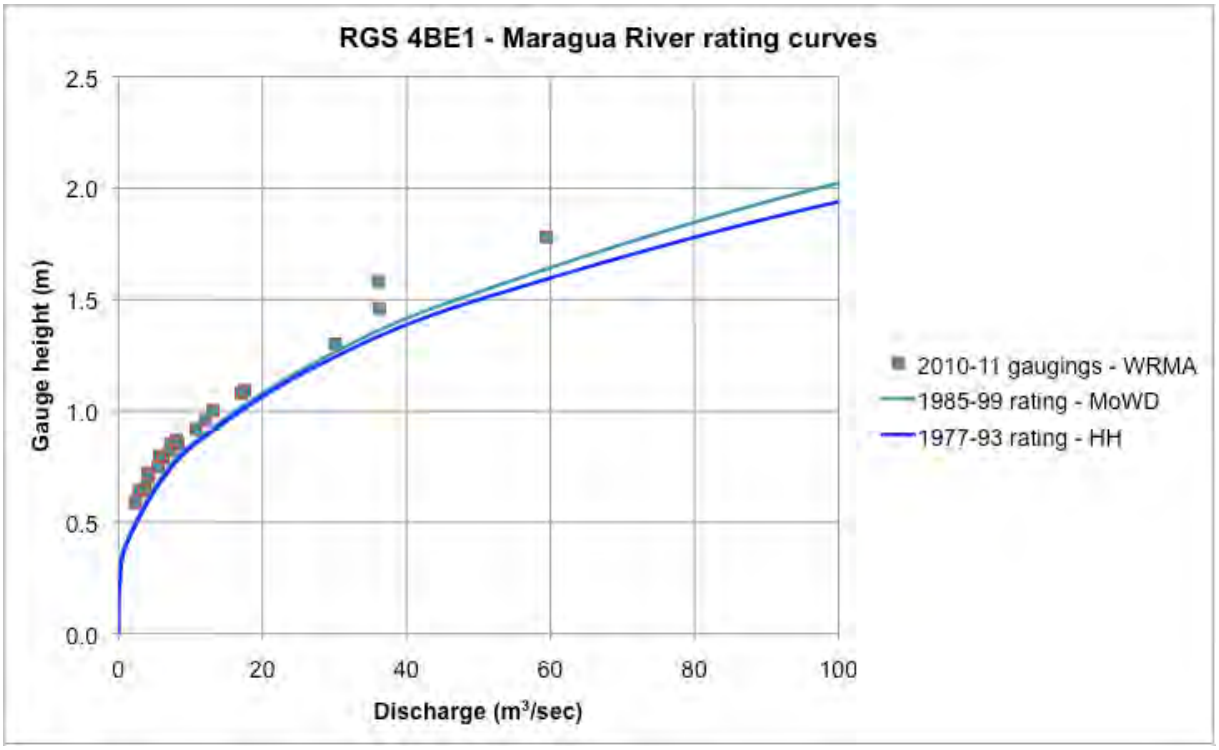


Figure 5-26: Station 4BE1 Gaugings 2010-11

6.3.4 Station 4BE3 – Irati River

The gauging record and rating equations are presented in **Figure 5-27**. The WRMA and HH ratings are very similar. Hence, the WRMA flows will be applicable.

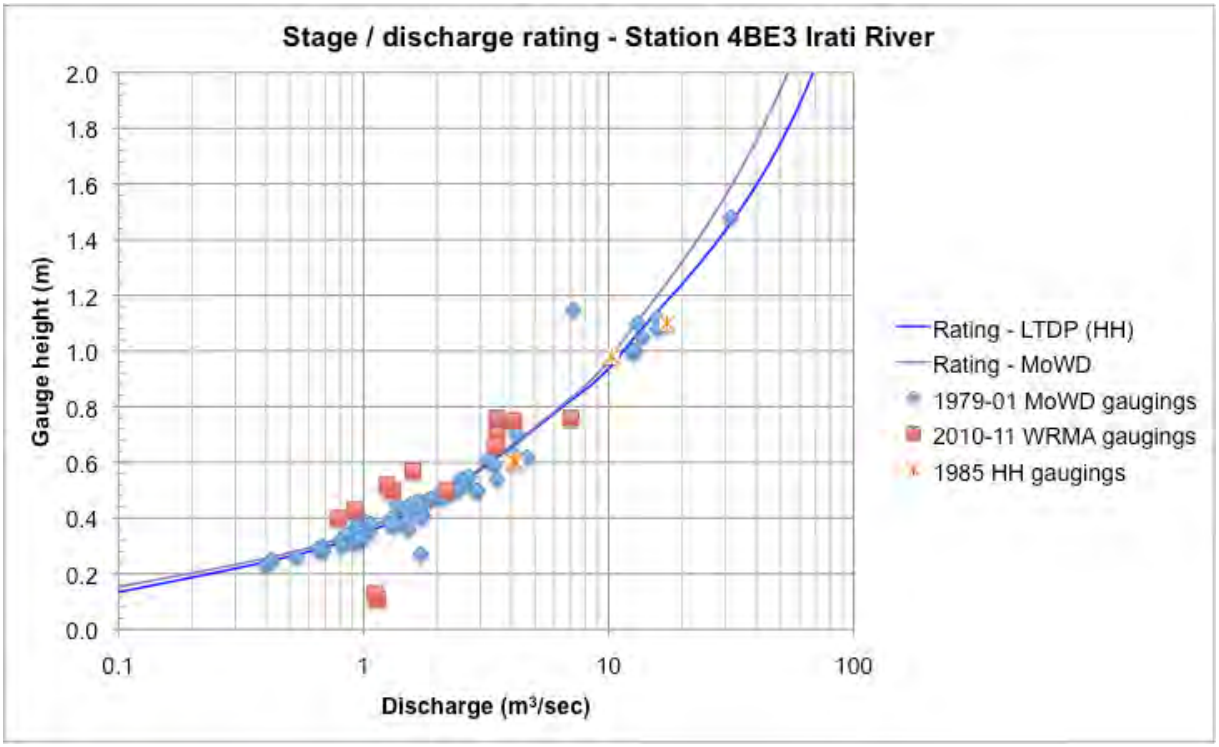


Figure 5-27: Station 4BE3 Rating Check

6.3.5 Station 4BE4 – Kayahwe River

This station is not reviewed in either the Long Term Development Plan or the Northern Corridor Scheme Feasibility Report. Daily flow data was however provided by WRMA.

The available flow gauging data is presented in **Figure 5-28**, from which the following observations can be made:

1. There are five MoWD rating equations dating between 1975 and 1996, suggesting that the station is unstable or that the gauge board is regularly disturbed (MoWD=Ministry of Water Development, the fore-runner of WRMA).
2. Gauging data since 1998 was supplied by WRMA. The earlier data was not provided.
3. Since 1987, the gaugings show a considerable shift for which a revised rating is provided. The extent of the shift suggests that the gauge board was re-positioned.

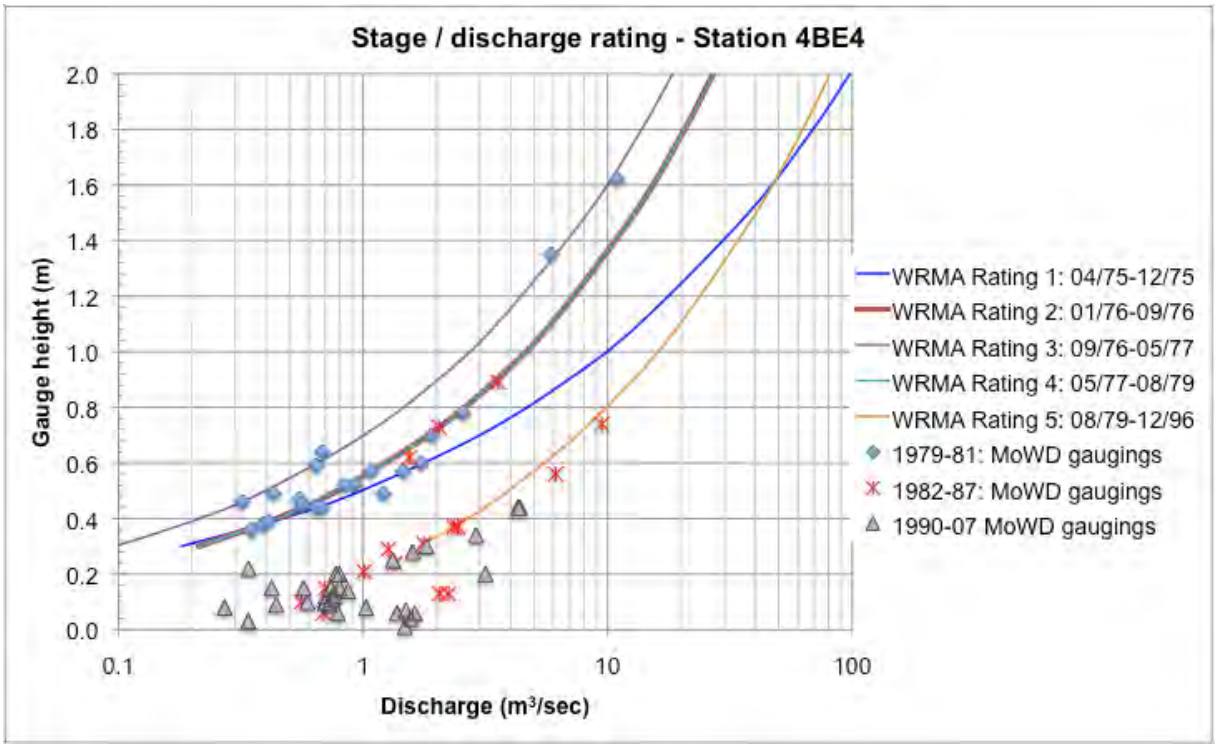


Figure 5-28: Station 4BE4 Rating Check

6.3.6 Station 4BE6 – Irati River

The station was established in 1977. The current meter gauging record after 1980 is presented in **Figure 5-29**.

The following observations are made:

1. Gaugings prior to 1980 were not provided by WRMA.
2. This station's history is not reviewed in the Long Term Development Plan, although project gaugings were reported at this station (LTDP, Hydrology App.B)
3. The station was included in the Northern Corridor Scheme Feasibility Report (NCS-FR), and a number of gaugings done by HH in 1994 were presented.
4. The various HH gaugings fit the NCS-FR rating.
5. The MoWD gaugings show inexplicable scatter.
6. The NCS-FR and MoWD rating equations are almost the same.
7. There are no gaugings since 1992.

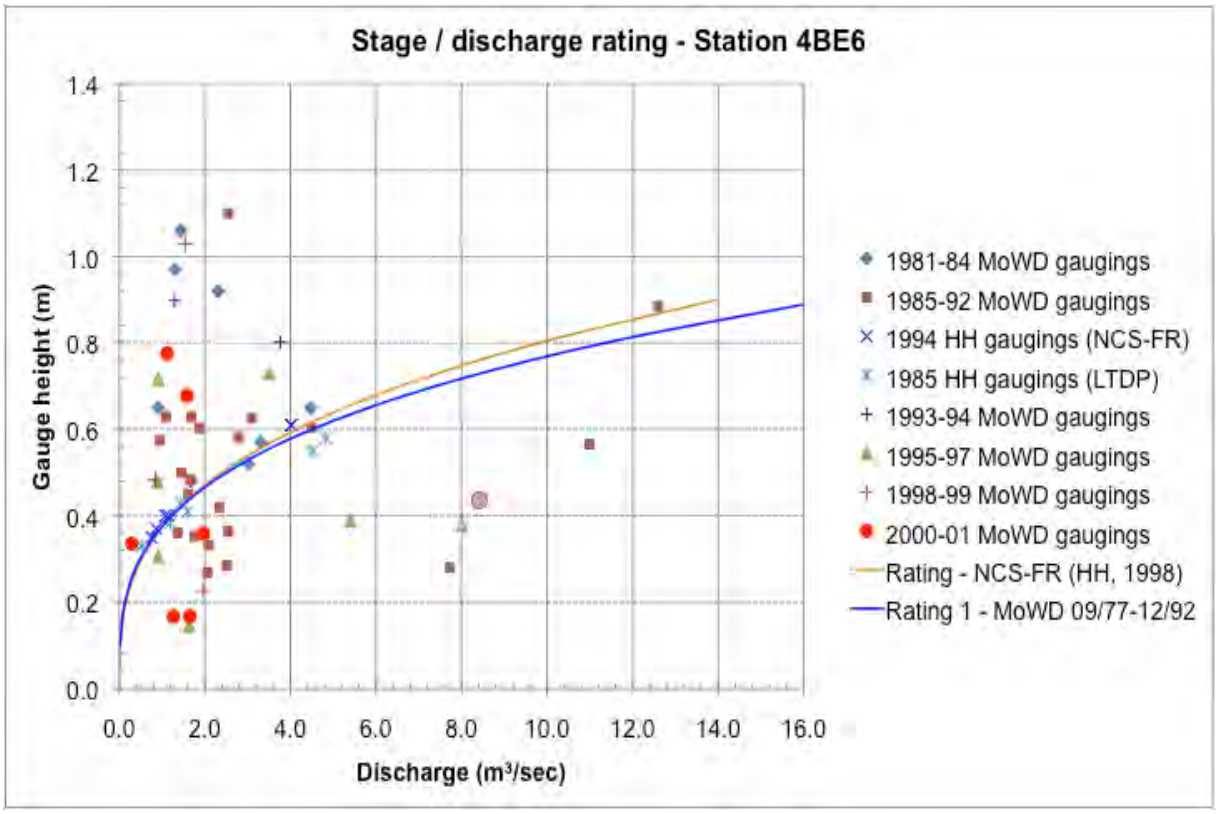


Figure 5-29: Station 4BE6 Rating Check

6.3.7 Station 4BE7 – Gitaigua River

This station was included in the Northern Corridor Scheme Feasibility Report (NCS-FR). The station was opened in 1977.

The available current meter gaugings and ratings are presented in **Figure 5.30**.

The following observations are noted:

1. WRMA did not provide gaugings prior to 1981. There are no gaugings after 1992.
2. The station is stable.
3. The MoWD and HH rating equations are similar, but the HH rating is a better fit for gauge heights exceeding 0.7 metres. WRMA flow data will under-estimate flows beyond this point.

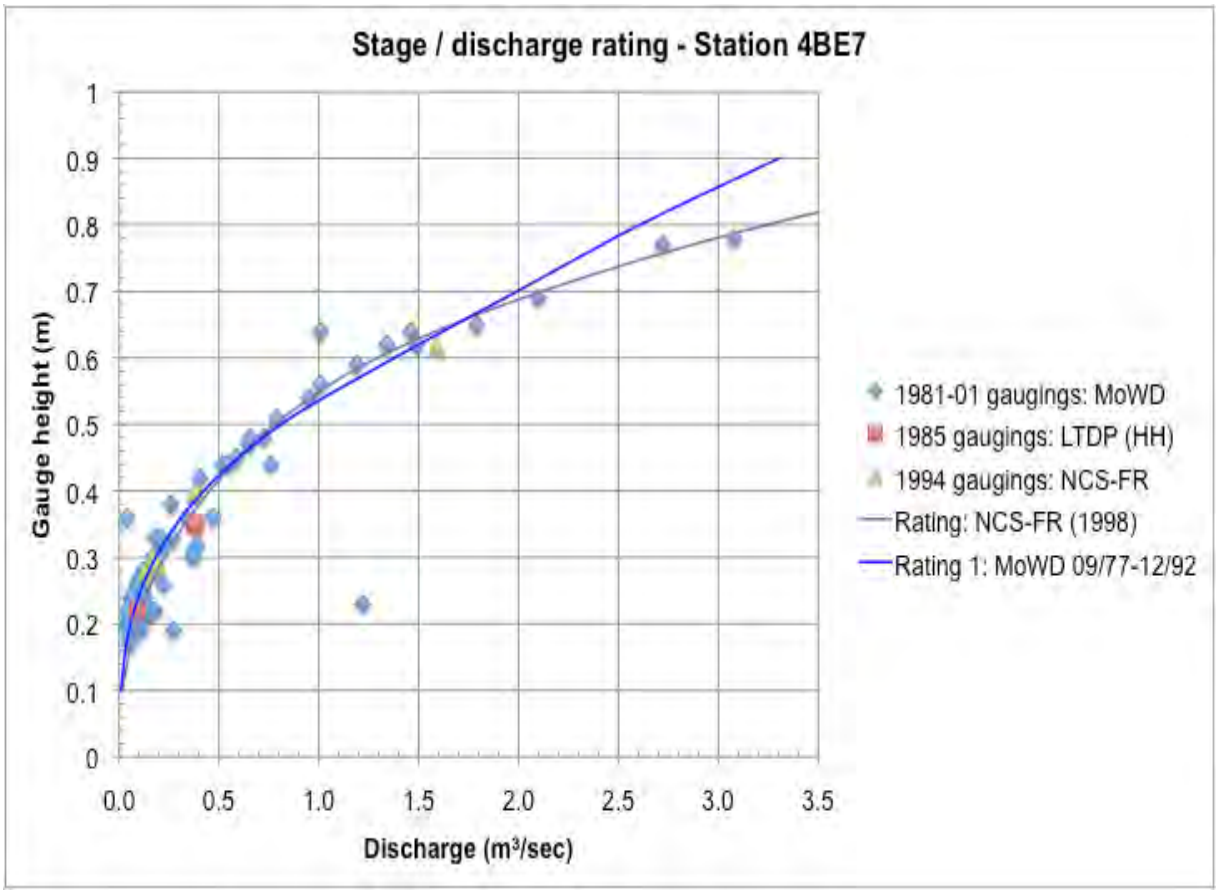


Figure 5.30: Station 4BE8 Rating Check – Gikigie River

6.3.8 Station 4BE8 – Gikigie River

Station 4BE8 was previously reported suffering from "siltation problems at low flows" with "low flow affected by up to 50%" (Northern Corridor Scheme Feasibility Study, Chapter 4-16, 1998). All gauging data collected since the 1998 studies are plotted in **Figure 5-31** together with the station's rating curve. The following observations are made:

1. The MoWD and HH ratings are very similar.
2. 2010/11 gaugings show a significant shift to the left.
3. This is a station for which constant flow gauging and station maintenance is required.
4. In the absence of gauging data between 1997 and 2010, the flow data is unreliable, as the timing of the rating shift is unknown.

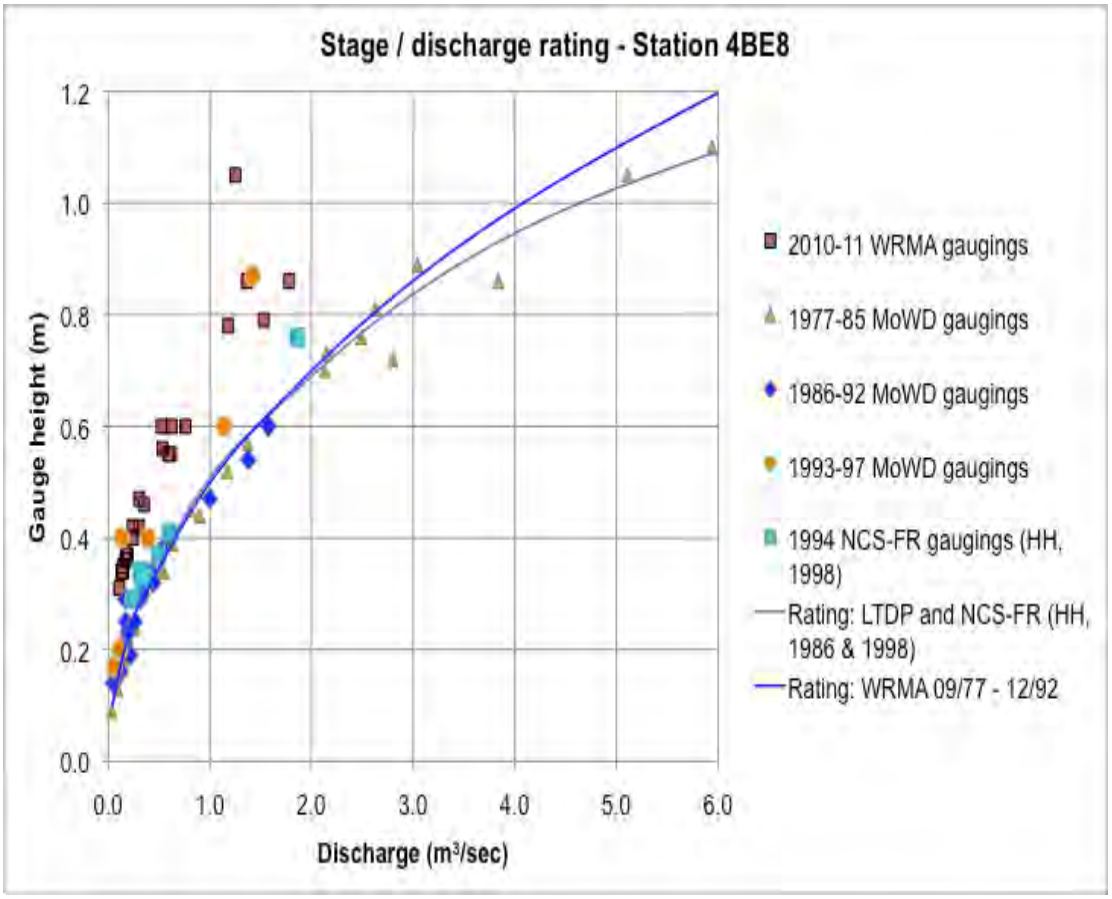


Figure 5-31: Station 4BE8 Rating Check – Gikigie River

6.3.9 Station 4BE9 - Irati River

The station was established in 1977. The MoWD gaugings from 1981-92 are plotted together with the rating curve in **Figure 5-32**. Gaugings prior to 1981 were not provided by WRMA.

Confirmatory gaugings were done in 1985 (LTDP, 1986), and these included a useful flood gauging with which to check the high-flow range of the rating. The MoWD rating curve was "satisfactory (ibid)".

There are no gaugings since 2007.

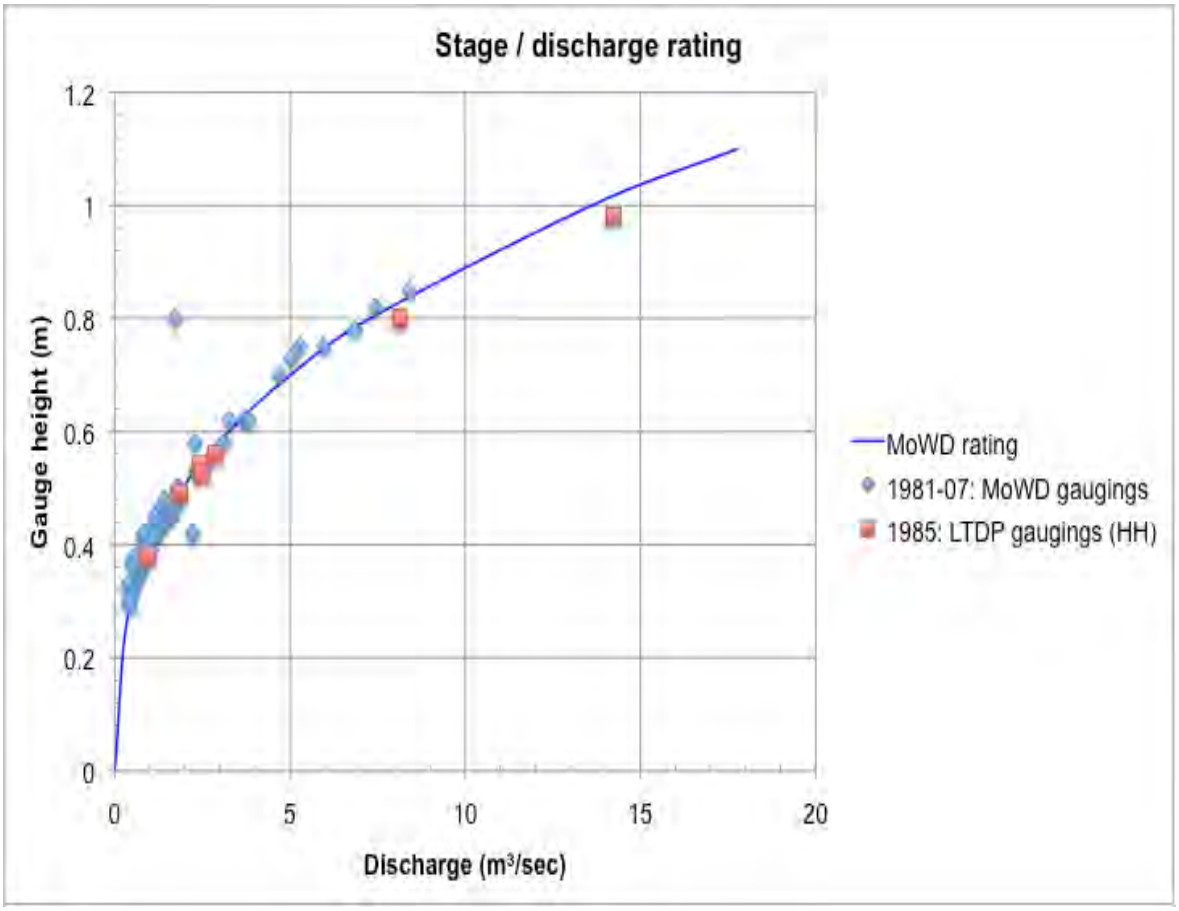


Figure 5-32: Station 4BE9 Rating Check – Irati River

6.3.10 Station 4CB5 – Thika River

Records commenced in 1950 at Station 4CB5 (see Chapter 1-4.11). The measurement structure is a compound sharp and broad-crested weir (Hydrology Review, HH, 1996).

The 1995 Hydrology Review reported that "there are not enough current meter gaugings available to examine the rating (ibid)". Consequently "the MoWD rating curve was accepted as correct (ibid)".

Figure 5-33 presents the MoWD rating curve with the available gaugings. The recent 2010-11 gaugings have shown that the station rating has not changed, and have provided useful gaugings in the higher flow range. The earlier gaugings did not include any gaugings at stages greater than 0.3 metres, so the recent gaugings represent an improvement.

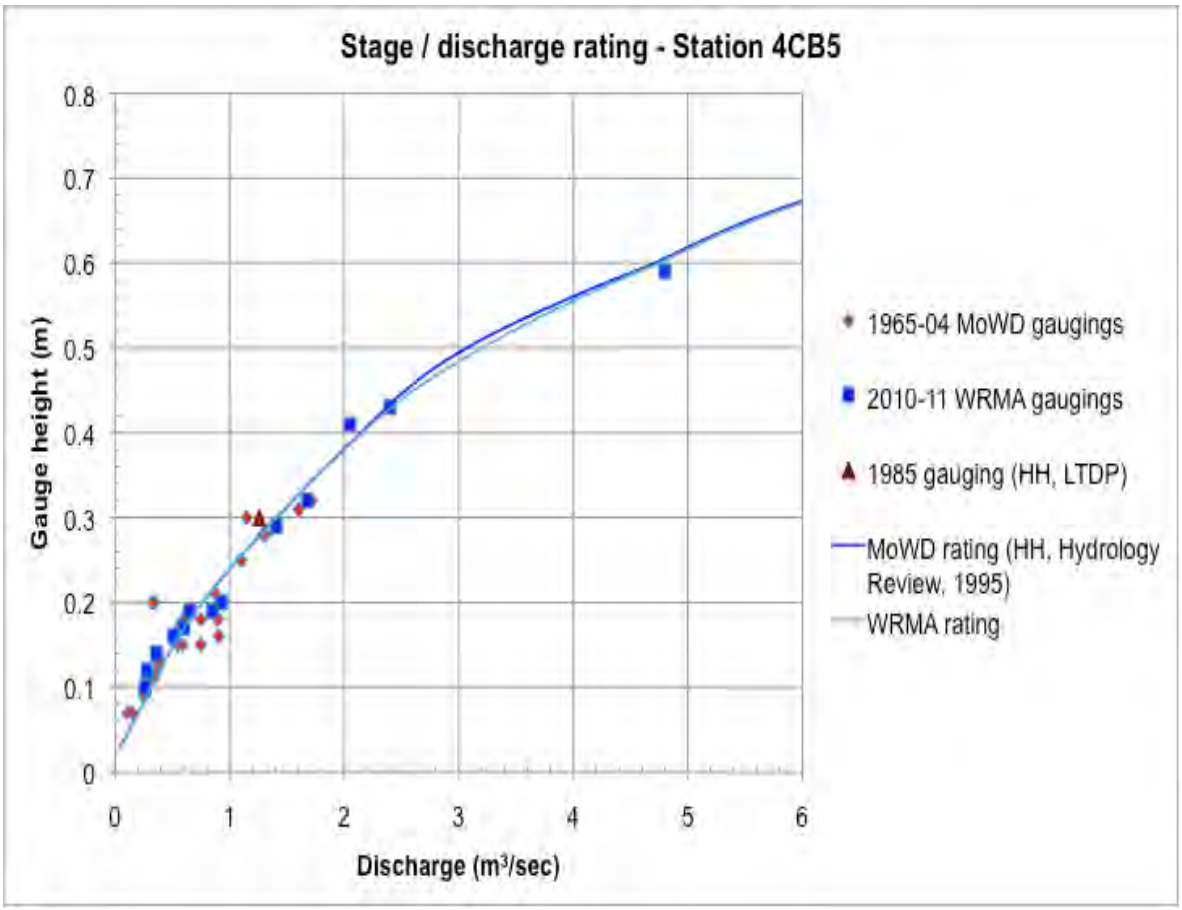


Figure 5-33: Station 4CB5 Rating Check

6.3.11 Station 4CB7– Thika River

This station was opened in 1958 and the control is the natural river section.

Between 1958-77, 34 river gaugings were done (Figure 13.1, Stage 1 Report, Thika Data, 1990). The rating was very stable.

Gaugings from 1962-77 as provided by WRMA are plotted in the **Figure 5-34**. The station rating has not changed. HH proposed a rating almost identical to the MoWD (WRMA) rating.

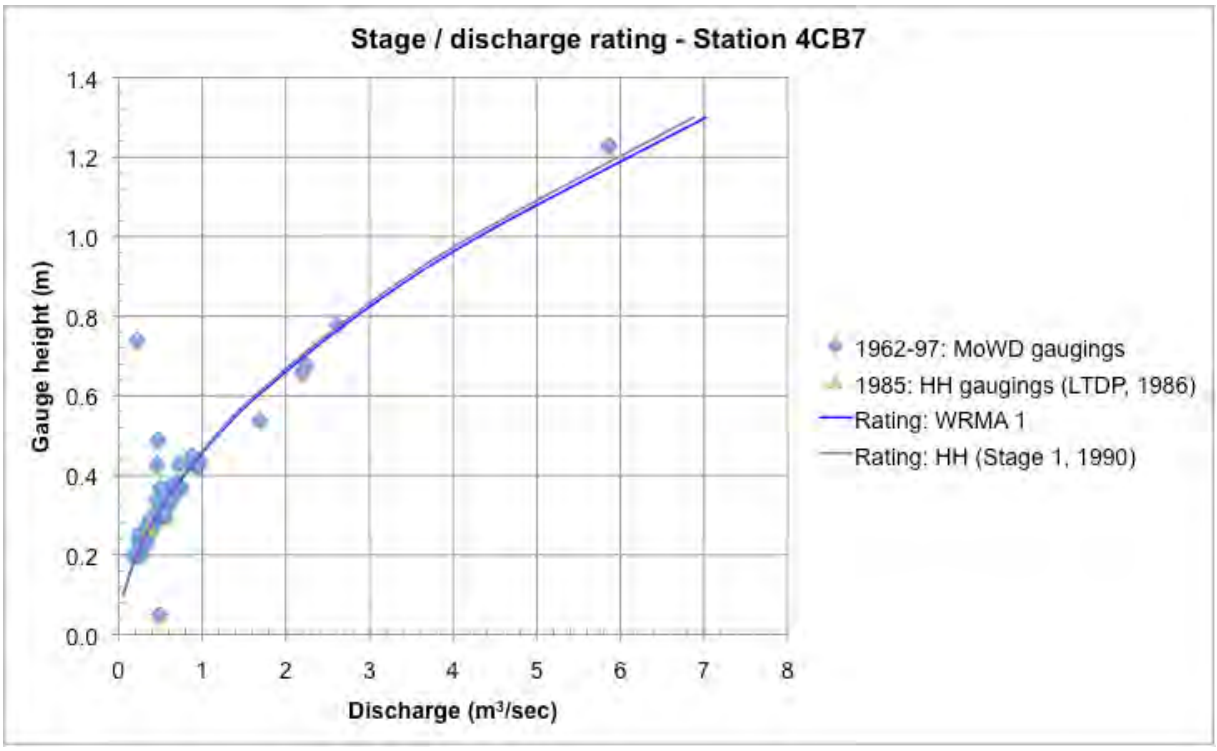


Figure 5-34: Station 4CB7 Rating Check

6.4 Flow Comparisons – Double Mass Curves

Double-mass curves can be used to check for data discontinuities. The cumulative runoff for one station is compared with another within the same hydrological zone. An example is presented in **Figure 5-34**. RGS 4CB5 is an important station as it is the base station upon which inflows to Thika Dam are recorded. There is a large flow discontinuity evident in 1980. The data suggests a massive increase in runoff measured at 4CB5 during this period. As this is improbable, a second comparison was carried out at RGS 4CB7 upstream from RGS 4CB5. The same discontinuity is evident. Inspection of the WRMA flow data for 4CB5 shows an improbable increase in runoff values for the period 15th April to 29th June 1980. The original daily gauge heights need to be inspected to identify the cause.

The Howard Humphreys simulation of "Thika natural inflows" does not have this discontinuity (Feasibility Report, Volume 2, Appendix C). Discrepancies that were identified at that time do not appear to have resulted in corrections to the WRMA database, which is unhelpful.

There are other inexplicable discrepancies, such as the data tabulated in Table 5-16. RGS 4CB5 recorded a very significant flood in August 1979, whereas the gauge a short distance upstream experienced no flow change, and the two rain gauges in the catchment did not have a

single day of rainfall sufficient to cause flood runoff. The effect of removing this event is shown in **Figure 5-37** on page 5-46. Of course, it is possible that this flood event was "missed" at all the other stations, but that seems unlikely.

Spurious high flow data is easier to pick up than spurious low flow data. The high flow data does not affect the run-of-river yield assessments, but does impact on the design of reservoir impoundments, as spurious high flows can lead to higher mean annual runoff than is actually available. Equally, where gauge readers miss flood events, the water resource can be under-estimated.

There are likely to be numerous other discrepancies, and it takes considerable time to go through the entire database to complete this checking / infill exercise to a satisfactory level. Visual checks have been done based on plotting the series and identifying obvious outliers.

As WRMA routinely provide this flow data for design purposes, it is recommended that a thorough quality review be undertaken by WRMA, so that only consistent data is provided.

Table 5-16: Flow and Rainfall Comparisons

Date	RGS 4CB5 m^3/sec	RGS 4CB7 m^3/sec	Rain Gauge 9036233 mm	Rain Gauge 9036259 mm
Av daily past 21 days			1.7	1.1
30 Jul 1979	0.765	1.056	0.5	0.0
31 Jul 1979	0.709	0.895	0.0	0.0
01 Aug 1979	68.562	0.838	3.5	0.0
02 Aug 1979	68.562	0.838	2.4	2.2
03 Aug 1979	66.816	0.819	0.0	0.0
04 Aug 1979	66.816	0.801	0.0	1.0
05 Aug 1979	45.060	0.782	4.2	7.4
06 Aug 1979	44.374	0.838	16.2	3.2
07 Aug 1979	44.374	0.895	0.5	4.2
08 Aug 1979	26.540	0.895	0.4	0.0
09 Aug 1979	26.035	0.876	0.0	0.0
10 Aug 1979	25.535	0.857	1.2	3.6
11 Aug 1979	13.757	0.857	2.0	8.4
12 Aug 1979	13.412	0.857	1.5	9.8
13 Aug 1979	13.412	0.838	3.7	11.4
14 Aug 1979	13.073	0.782	3.6	8.4
15 Aug 1979	12.738	0.711	1.8	7.4
16 Aug 1979	5.310	0.677	1.5	8.8
17 Aug 1979	5.120	0.677	0.0	2.2
18 Aug 1979	1.546	0.694	4.0	12.2
19 Aug 1979	1.546	0.711	0.0	8.4
20 Aug 1979	1.546		0.0	0.0

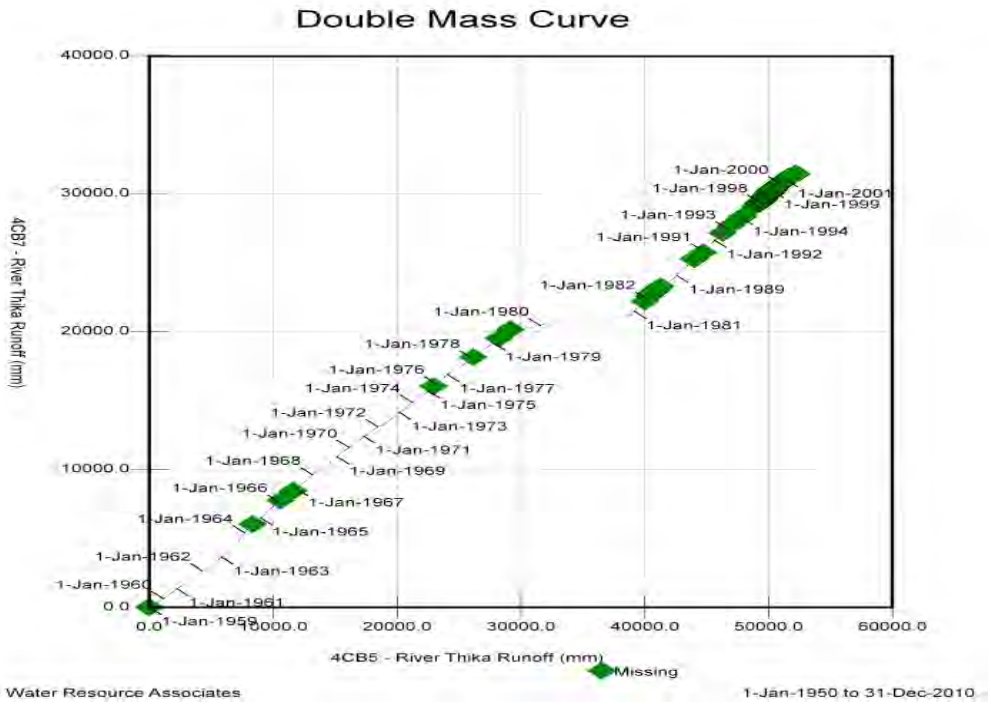


Figure 5-35: Double Mass Curve – Checking RGS 4CB5 Data with RGS 4BE1

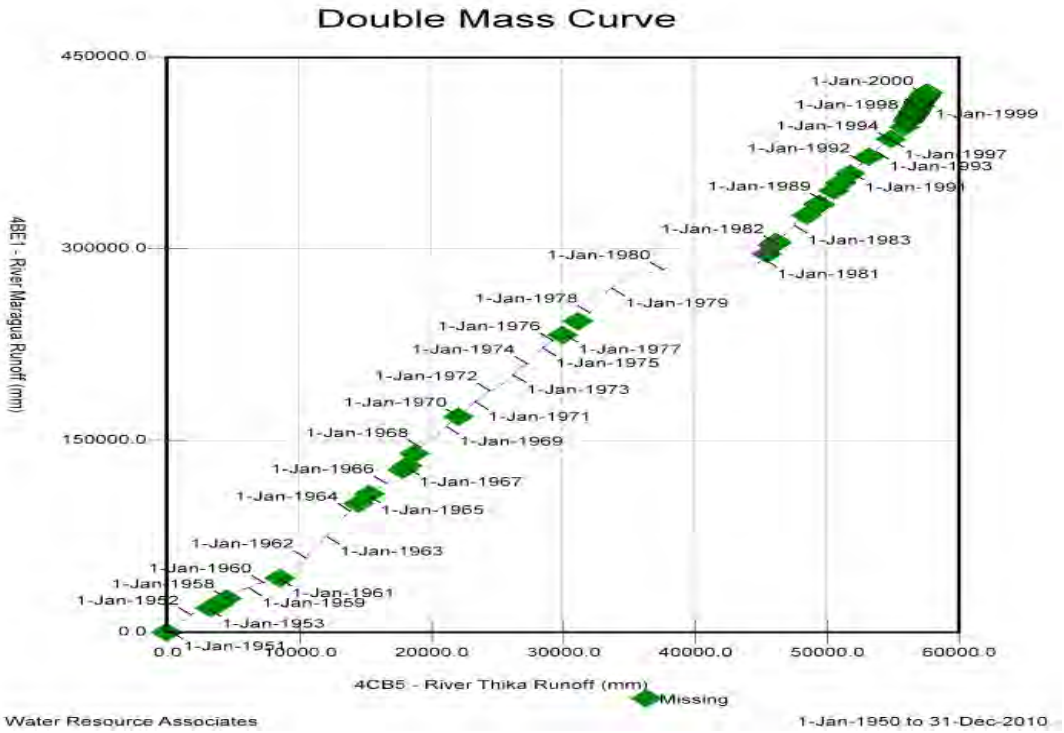


Figure 5-36: Double Mass Curve – Checking RGS 4CB5 data with RGS 4CB7

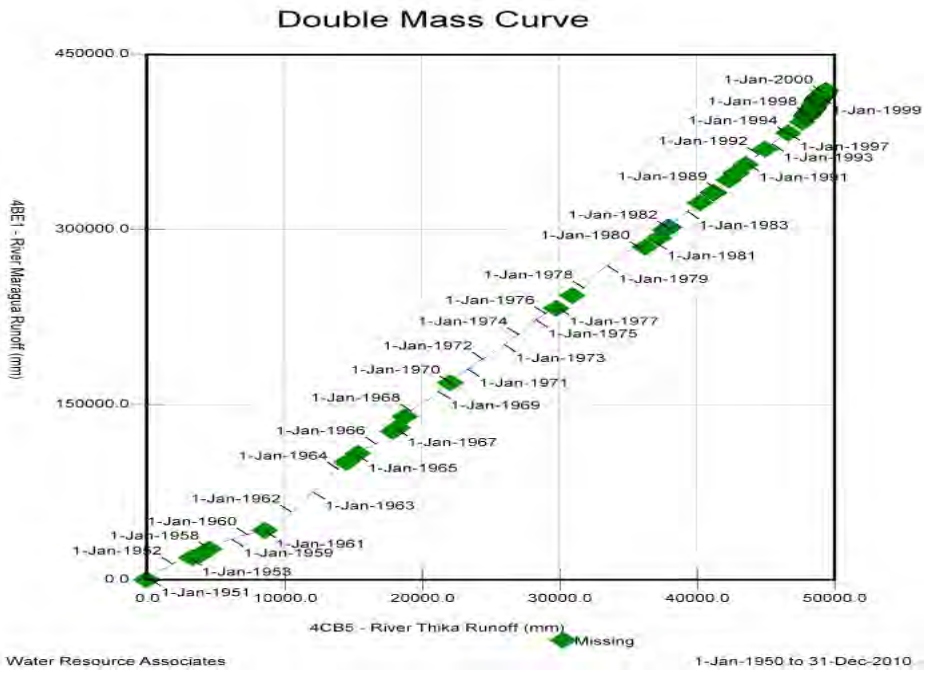


Figure 5-37: Comparison RGS 4BE1 / 4CB5 with later spurious 4CB5 data deleted

6.5 Flow Data Infill and Extension

The WRMA database is fragmented with many gaps, plus many of the stations have not been recorded in recent years – see Table 5-14. For the Northern Collector Rivers, RGS 4BE1 and 4CB5 are key stations for which long term data is available. If good correlation can be established with other stations, these records can form the basis for flow extension and infilling.

6.5.1 RGS 4CB5 Record Extension - Thika River

RGS 4CB7 is located about 10 km upriver from 4CB5. Hence the daily flow patterns at 4CB7 will be experienced a few hours later at 4CB5. The flows at 4CB7 are reportedly not affected by upstream abstractions. The flow correlation between these two stations is very useful for the purpose of infilling missing data at either station.

The early studies proposed the following flow correlation

Equation 1: Q(4CB7) = 0.63 x Q(4CB5) + 0.07
(Source: Equation 71, Stage 1 Report, Part 2B, HH, 1979)

The following figures graphically present the correlation of the coincident measured flows at the two stations:

- Figure 5-38 on page 5-47 for the data period 1972-82**;**
- Figure 5-39 on page 5-47 for the fragmented data period 1990-01.

There is no change in the correlation in later years. Unfortunately there are no gauge height records as RGS 4CB7 after the year 2001.

The above equation is almost identical to the catchment area ratio for the two stations, as follows:

Equation 2: Area (4CB7) = 0.68 x Area (4CB5)

The stations are located not far apart; hence the flow and area correlations are consistent with each other, with a slight unit runoff reduction downstream, as would be expected.

This correlation equation (Equation 1) is acceptable for the purpose of data infilling and record extension between these two stations.

The WRMA RGS 4CB5 database has thus been infilled and extended. The annual runoff series is compared with previous published data in Table 5.17 on page 5-48. The annual rainfall for the nearby Gatare Forest Station is also included. The following comments are noted:

1. The WRMA data was amended for the years 1963/64 to correct data errors highlighted in an earlier report (Stage 1, Part 2B, 1979)
2. The average annual runoff of the extended 1959-09 sequence is the same as the average for the earlier 1959-77 sequence, although there is a 10% reduction in the annual rainfall average over the period.

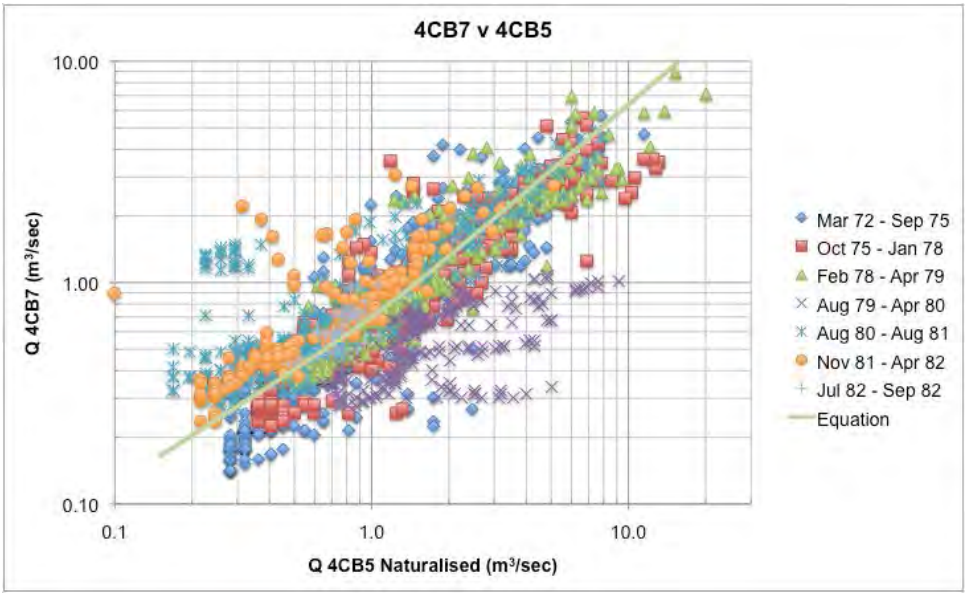


Figure 5-38: Correlation of 4CB5 Naturalised and 4CB7 Flows, 1972-82 Data

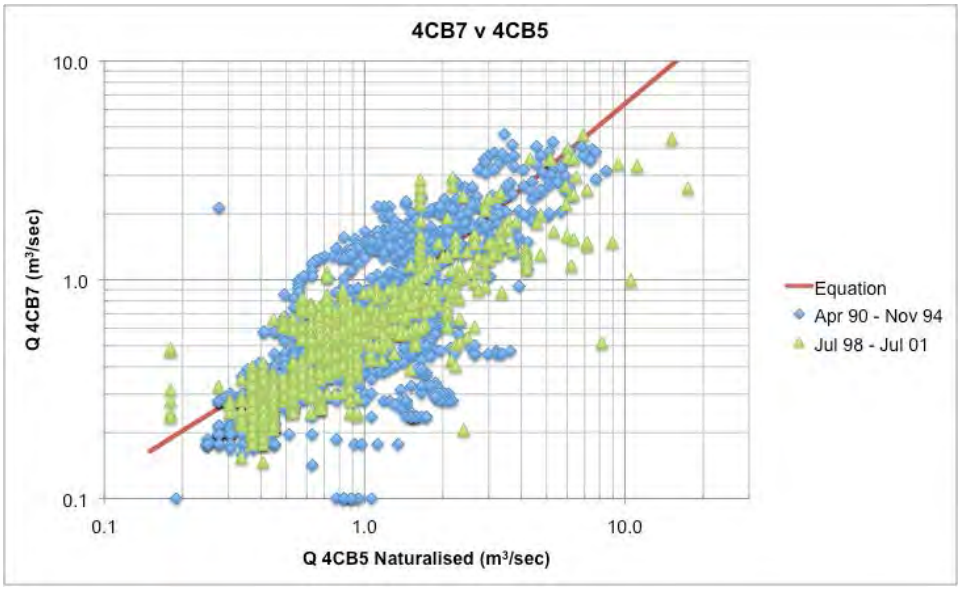


Figure 5-39: Correlation of 4CB5 Naturalised and 4CB7 Flows, 1990-01 Data

Table 5.17: RGS 4CB5 – Extended WRMA data compared with previous studies

Year	STAGE 1 1979 (m^3/s)	Short Term Plan 1986 (m^3/s)	Hydrol Review 1995 (m^3/s)	WRMA 4CB5 Infilled Extended (m^3/s)	Gatare Rainfall 9036259 Infilled (mm)
1959	1.11		1.10	0.90	
1960	1.20		1.18	1.11	
1961	2.04		1.88	1.97	3913.2
1962	1.59		1.52	1.56	2827.9
1963	1.83		1.70	1.92	3135.4
1964	1.80		1.71	1.81	3254.4
1965	1.42		1.37	1.76	2568.4
1966	1.60		1.52	1.66	2627.4
1967	1.32		1.31	1.49	2720.9
1968	2.01		1.90	2.00	3409.8
1969	0.94		0.91	0.96	2037.3
1970	1.27		1.23	1.21	2398.7
1971	1.07		1.03	1.02	2046.0
1972	1.58		1.51	1.65	2618.8
1973	1.07		1.06	1.08	1828.3
1974	1.34		1.31	1.36	2443.7
1975	0.75		0.75	0.76	1661.7
1976	0.99	0.99	0.98	1.00	1978.6
1977	2.04	2.04	1.90	2.05	3213.8
1978		1.80	1.69	1.81	3226.8
1979		1.99	1.88	2.50	3060.1
1980		1.53	1.47	1.67	2567.9
1981		1.20	1.17	1.25	2584.9
1982		1.73	1.65	1.73	2778.9
1983		1.23	1.20	1.29	2459.1
1984		1.00	1.00	1.01	1916.7
1985			1.22	1.40	2293.4
1986			1.11	1.15	2372.6
1987			0.95	1.13	1792.1
1988			1.43	1.59	2779.7
1989			1.56	1.58	2785.7
1990			1.53	1.86	2530.7
1991			1.03	1.05	1531.5
1992			1.24	1.26	2148.4
1993				1.33	2104.5
1994				1.93	2671.2
1995				1.73	1730.0
1996				1.27	2224.1
1997				1.77	3116.0
1998				1.66	2779.6
1999				1.10	2187.6
2000				0.63	1531.0

Year	STAGE 1 1979 (m^3/s)	Short Term Plan 1986 (m^3/s)	Hydrol Review 1995 (m^3/s)	WRMA 4CB5 Infilled Extended (m^3/s)	Gatare Rainfall 9036259 Infilled (mm)
2001				1.43	2580.9
2002				1.51	2686.5
2003				1.46	2366.1
2004				1.23	1778.0
2005				1.08	1334.5
2006				1.07	978.6
2007				1.51	2831.8
2008				1.35	1923.1
2009				1.37	
2010					
Mean annual					
1959-1977	1.42			1.44	2628.5
1959-92			1.35	1.46	2547.3
1959-2009				1.43	2423.7

6.5.2 RGS 4BE1 Record Extension – Maragua River

The daily flow data from WRMA extends to the year 2000 only. However data extends back to 1950, which is potentially useful for back-extending shorter records at other gauging stations in the area.

RGS 4BE1 was the key base station used by previous studies. Many of the key Northern Collector River records correlate well with this station's record.

The correlation of RGS 4BE1 with other stations is reviewed in the various report sections that follow.

An extended flow sequence has been derived for RGS 4BE1, based on the actual WRMA flow database and some infilling. The resultant cumulative sequence is compared in Figure 5.40 with cumulative rainfall at Kimakia Forest Station. This present study was unable to obtain daily rainfall data from KMD for the 1950s. Hence the rainfall series that is used in Figure 5.40 is taken from the monthly series published in the Northern Corridor Scheme Feasibility Report. The RGS 4BE1 river flow sequence is also compared in the figure with the flow sequence derived for the same river gauge in the Northern Collector Scheme Feasibility Report.

The Gatare Forest Station rainfall data would have been preferred, as this gauge is geographically located within the catchment, but earlier data from the 1950s was not available. The Kimakia Forest Station gauge is however not far away, and the two gauges correlate well.

Figure 5.40 on page 5-51 shows a change of slope of the runoff curve occurring after 1960, with another smaller slope change in 1967. Previous studies have stated that gauge readings in the 1960s were inaccurate (HH, LTDP, Hydrology Appendices, 1986). This may be the case, but this was a period of land usage change in these catchments, and the change in runoff slope can also be attributed to changing catchment conditions and the associated change in runoff characteristics.

The Northern Corridor Scheme Feasibility Report (NCS-FR) used hydrological modelling to derive its design flow sequences. This modelling process can be used to "smooth out" the data.

This "smoothing" effect can be seen in Figure 5.40 where the NCS-FR generated flow sequence is compared with the "actual" data sequence developed for this study from the WRMA data. Although the NCS-FR curve is smoother, there is still a change in slope in 1960, and the total cumulative runoff of the smoothed sequence is not greatly different from the actual WRMA infilled sequence in **Figure 5.40** on page 5-51.

This study prefers to retain the actual flow sequences, as there is no data to do otherwise. It might however be prudent to exclude the very early years from analysis, as the runoff in those early days is not representative of conditions in the later years, as land usage was different, as it preceded the small-holder tea development. Further evidence of these changes is to be found in the flow duration curves produced by this and other studies. Further discussion is included in Section 5.6 on other studies, and **Figure 5-54** on page 5-53 shows the change in flow duration characteristics.

The extended data from 1992 to 2008 is also presented in Figure 5.40. The "data" after 2000 is created through correlation with the available record at RGS 4CB5.

There is no specific data available to this study on catchment changes insofar as they affect runoff. The following is useful historical information indicative of the documented land use changes that took place in the forest catchment of the Maragua and Thika Rivers in the 1950s:

- The Aberdare National Park was created in 1950.
- "Kimakia Forest Station was opened in 1956, with the object of replacing 2,025 ha of indigenous bamboo forest with uniform plantations of exotic coniferous trees between 1957 and 1958 (Dyson, 1979)…"
- "Gatare Forest Station was opened simultaneously with a similar tree planting programme (ibid)…"
- "The decision to open up two new forest stations in the South-East Aberdare Forest Reserve was made on social and economic grounds (ibid)…"
- "In 1956, the adjacent Kikuyu lands were overcrowded with landless, unemployed families, who had been compulsorily returned to Kikuyu-land from the large settler farms west of the Rift Valley during the Mau Mau Emergency…(ibid)"
- "The forest villages, originally established to settle landless people, have now developed into thriving permanent communities, and land which in 1956 was uninhabited has been converted into a valuable productive area….(ibid, P.154)"
- "Tea was planted as early as 1958….(KTDA website, Kanyenyaini Tea Factory"
- "CDC was involved at independence in the beginnings of its most successful venture in Kenya, the development of small-holder tea-growing which, from 1954, had been developed to 1,600 acres and one tea factory…….In 1960 CDC committed further funds……to develop small-holder tea growing and six tea factories….A second KTDA scheme increased the number of factories to seventeen by the end of 1970….. and a third KTDA scheme increased the acreage to 64,500 acres by the end of 1972…..In 1973 CDC agreed to support three more factories....the Fourth KTDA plan to expand acreage by a further 36,000 acres and the construction of a further twenty-two factories….. (Holthamy and Hazlewood)"

It is of interest to note that the commercial forestry development at Kimakia has since ceased, and the community has been removed from the forest, and the forest has since been left undisturbed to recover. Ongoing debates continue within Government with regard to the question of commercial forestry in this area (Pers.Comm, Rhino Ark).

Although catchment studies were done in the Kimakia Forest Station area at the time, there was no baseline data of the hydrology prior to the forestry interventions. Hence the precise change in runoff characteristics was not measured by those studies (Dyson, Blackie, et al 1979).

In conclusion:

1. The smallholder tea-growing was developed in the period from mid-1950 to the early 1970s, and this was also the period when commercial forestry in areas of Kimakia and Gatare Forest Stations was being explored. These are significant land use changes.
2. The WRMA flow data at RGS 4BE1 in Figure 5.40 shows that the steepest part of the cumulative runoff occurred between 1960 and 1967, which coincides with the period during which the small-holder tea growing was being developed, and commercial forestry was being explored and developed. The runoff pattern changes conveyed in the RGS 4BE1 record are consistent with land usage changes. This assumes that the rainfall record is accurate.
3. The subsequent post-1967 period reflects the period after which the tea plantation has been established in the catchment areas adjoining the forest. This was also a period during which there was increased abstraction from the river, although the abstraction is not believed to have continued to increase since that time. The available flow record at RGS 4BE1 from 1967 to 2010 reflects this, as the cumulative runoff curve is of uniform slope indicating no change in runoff relative to rainfall. The recent extended record suggests a steepening of the runoff curve, indicative of the increasing proportional runoff conveyed by the RGS 4CB5 record. This increase would be compatible with farming intensification, and in particular the interference with the riparian zone reported elsewhere in this Chapter (see Section 9.3).

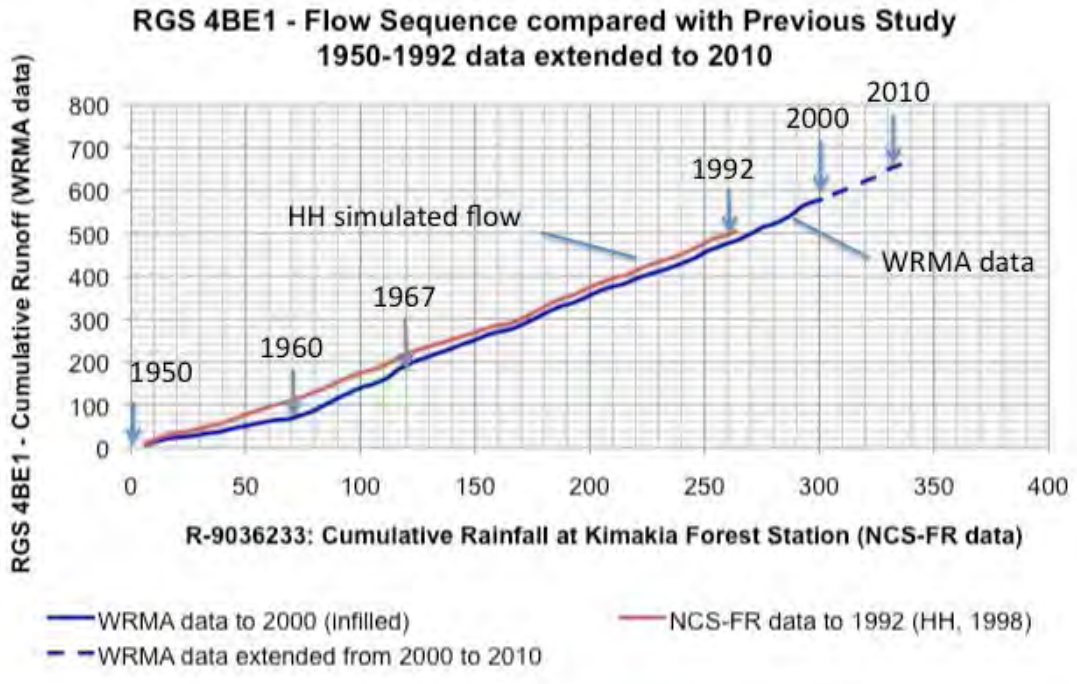


Figure 5.40: Cumulative Runoff at RGS 4BE1 – Comparison With Previous Studies and with Period Extended

6.5.3 RGS 4BD6 Record Extension – South Mathioya River

Previous studies developed the following flow correlation equations using RGS 4BE1 as the base station:

Equation 3: 1946-74: $Q(4BE1) < \text{Median } Q(4BE1)$: $Q(4BD6) = 0.870 \times Q(4BE1)^{0.527}$
$Q(4BE1) > \text{Median } Q(4BE1)$: $Q(4BD6) = 0.377 \times Q(4BE1)^{0.864}$

Equation 4: 1972-79: $Q(4BE1) < 11.8\ m^3/s$: $Q(4BD6) = 0.826 \times Q(4BE1)^{0.5200}$
$Q(4BE1) > 11.8\ m^3/s$: $Q(4BD6) = 0.450 \times Q(4BE1)^{0.7664}$

Equation 5: 1980-84: $Q(4BE1) < 17.4\ m^3/s$: $Q(4BD6) = 0.750 \times Q(4BE1)^{0.592}$
$Q(4BE1) > 17.4\ m^3/s$: $Q(4BD6) = 0.493 \times Q(4BE1)^{0.7391}$

(Source of Equations: Tables 3.3 and 5.8, Long Term Development Plan, HH, 1986)

The equations are compared in **Figure 5-41** on **page 5-53**. Also plotted is the catchment area ratio curve, which forms the expected lower limit of the regression.

The following figures graphically present the correlation of the coincident measured flows at the two stations using the 1980-84 equation 5 for comparison:

- Figure 5-42 on page 5-53 for the data period 1972 to 1985;
- Figure 5-43 on page 5-54 for the period 1986 to 1992;
- Figure 5-45 on page 5-55 for the period 1993 to 2000.

There is no obvious departure of the later data from the previously established regression. There is more data scatter in the recent years. An attempt was made to establish whether there has been any increase in abstractions upstream of 4BD6. This would tend to increase the number of points falling below the regression, as in Figure 5-45 on page 5-55. On the other hand data quality has diminished in recent years, and this can also contribute to the scatter.

There is no data beyond the year 2000 at either 4BE1 or 4BD6. Hence these records can only be extended by correlation with a gauge with record to 2010. RGS 4CB5 is the only station in the area that fulfils this requirement.

The infilled WRMA RGS 4CB5 database has been discussed above in Section 6.5.1 above.

The correlation of RGS 4BD6 and 4CB5 is displayed in **Figure 5-45** along with the derived equation as follows:

Equation 6: $Q(4BD6) = 2.1735 \times Q(4CB5)$

The data sequence has been infilled and extended using the various correlation equations. The infilled sequence cumulative runoff from 1972-92 is compared with the sequence presented in the Northern Collector Feasibility Report.

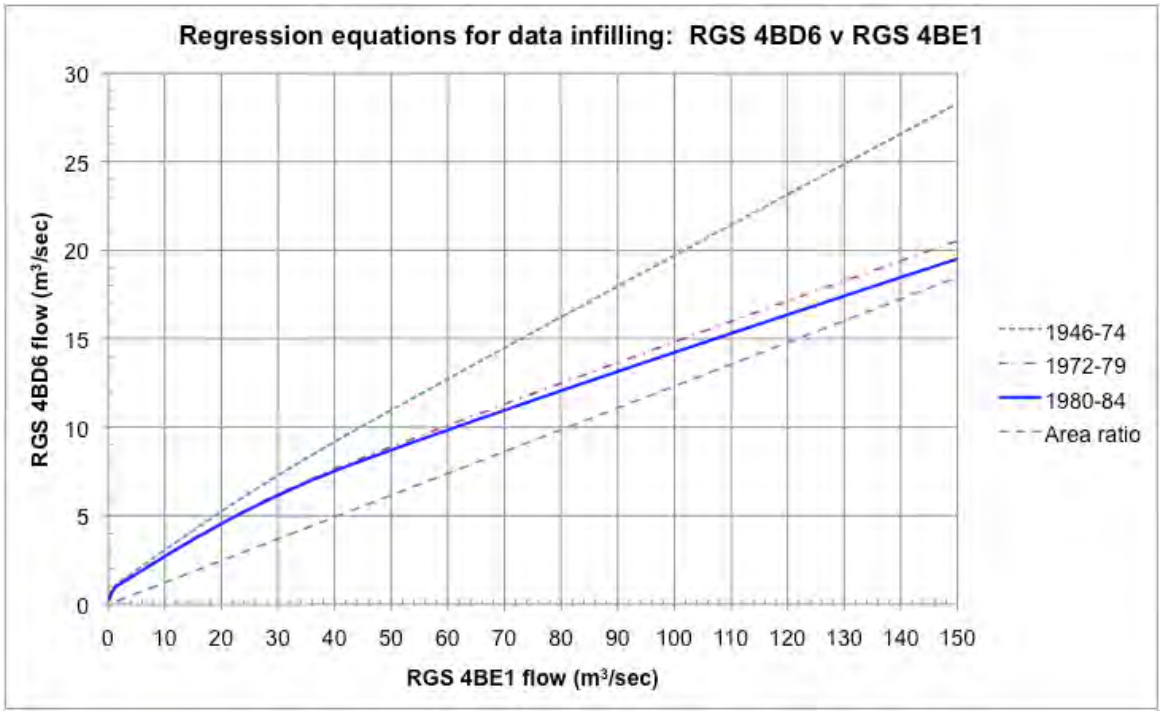


Figure 5-41: Regression equations for data infilling – RGS 4BD6 v 4BE1

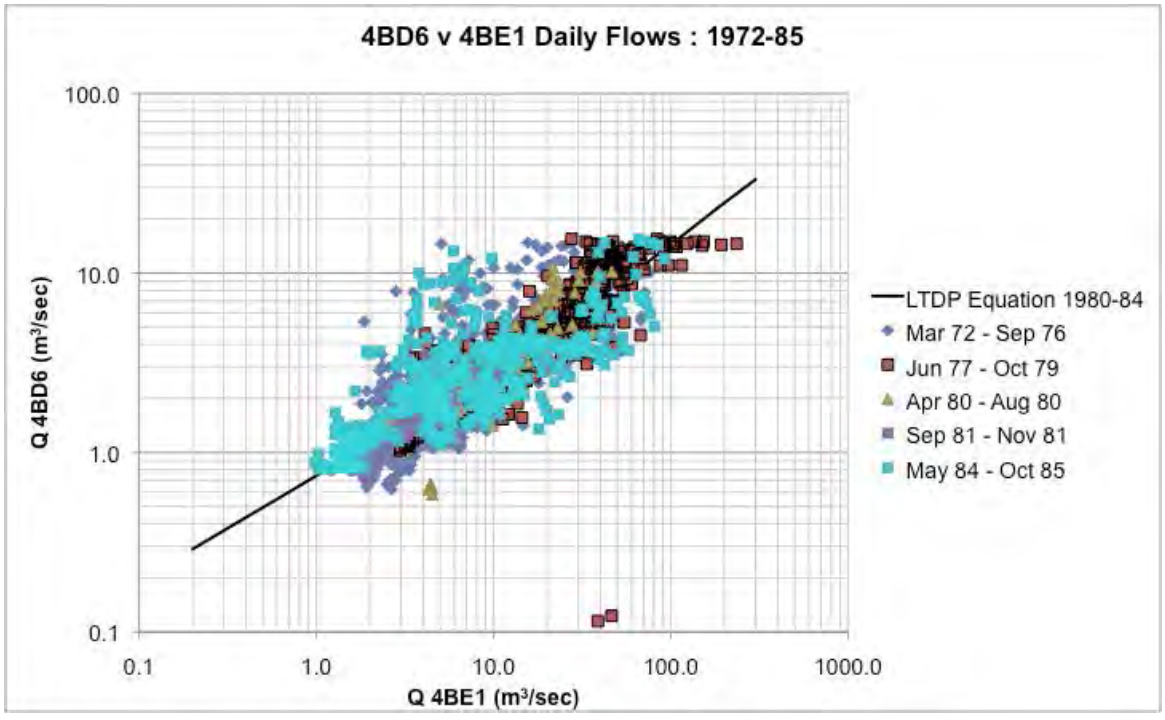


Figure 5-42: RGS 4BD6 v 4BE1 – 1972 to 1985 flow correlation

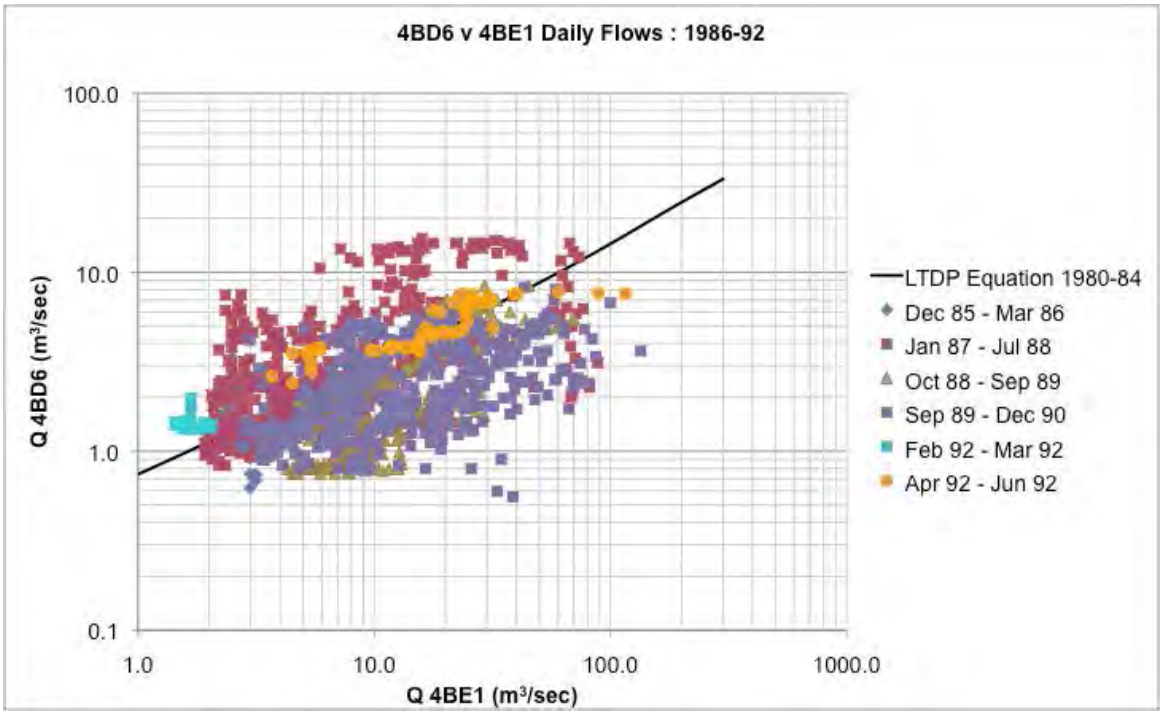


Figure 5-43: RGS 4BD6 v 4BE1 – 1986 to 1992 flow correlation

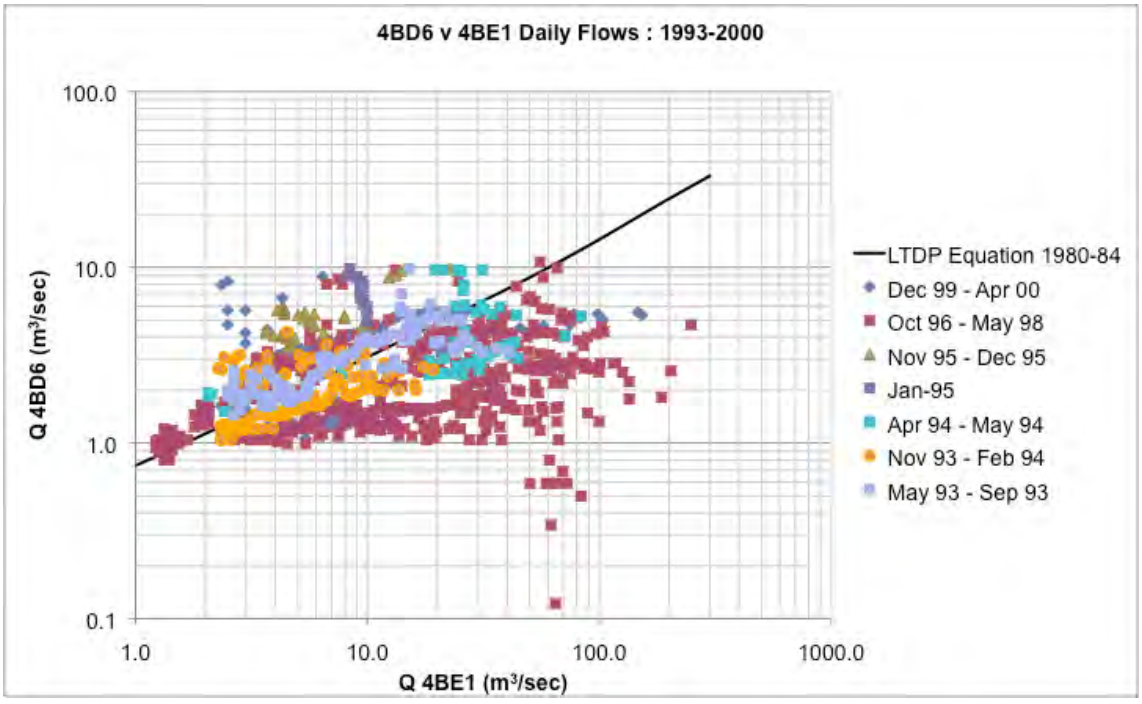


Figure 5-44: RGS 4BD6 v 4BE1 – 1993 to 2000 flow correlation

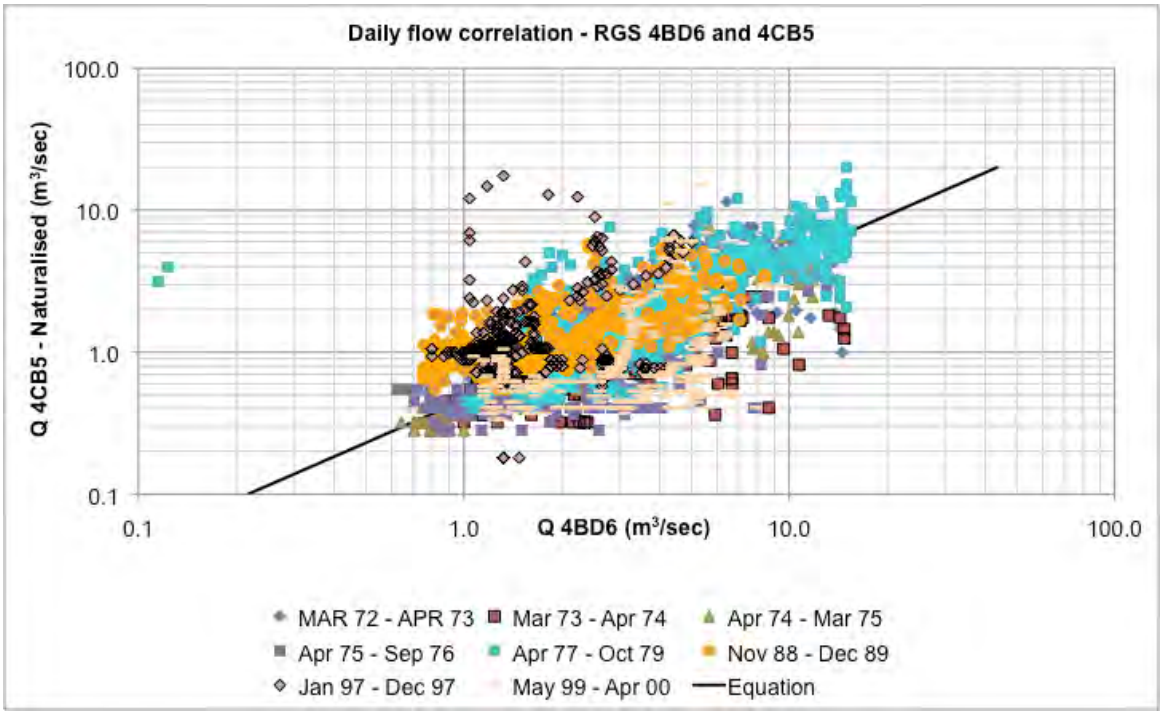


Figure 5-45: RGS 4BD6 v 4CB5 – Correlation with Adopted Equation

6.5.4 RGS 4BD7 Record Extension – North Mathioya River

Previous studies developed the following flow correlation equations using RGS 4BE1 as the base station:

Equation 7: 1975-79: $Q(4BE1)<14\ m^3/sec$, $Q(4BD7) = 2.006 \times Q(4BE1)^{0.5583}$
$Q(4BE1)>14\ m^3/sec$, $Q(4BD7) = 1.839 \times Q(4BE1)^{0.5925}$

Equation 8: 1980-84: $Q(4BE1)<28\ m^3/s$: $Q(4BD7) = 1.822 \times Q(4BE1)^{0.5872}$
$Q(4BE1)>28\ m^3/s$: $Q(4BD7) = 1.071 \times Q(4BE1)^{0.7473}$

(Source of Equations: Tables 3.3 and 5.8, Long Term Development Plan, HH, 1986)

The equations are compared in **Figure 5-46** on page 5-56. Also plotted is the catchment area ratio curve, which forms the expected lower limit of the regression.

Figure 5-47 on **page 5-56** graphically presents the good correlation of the coincident measured flows at 4BE1 and 4BD7, and the 1980-84 Equation 8 is included for comparison. There is no obvious departure in correlation in more recent years from the previously established regression.

There is no data beyond the year 2000 at either 4BE1 or 4BD7. Hence these records can only be extended by correlation with a gauge with record to 2010. RGS 4CB5 is the only station in the area that fulfils this requirement.

The infilled WRMA RGS 4CB5 database has been discussed above in Section 6.5.1 above.

The correlation of RGS 4BD7 & 4CB5 is displayed in **Figure 5-49** on page 5-57 along with the derived Equation 9:

Equation 9: $Q(4BD7) = 5.2950 \times Q(4CB5)$

The correlation of RGS 4BD7 and 4BD6 is shown in **Figure 5-48** on page 5-57. These are adjacent catchments with similar unit runoff, and hence the correlation equation is the same as the catchment area ratio.

Equation 10: Q(4BD7) = 2.4361 x Q(4BD6)
Equation 11: Q(4BD6) = 0.4105 x Q(4BD7)

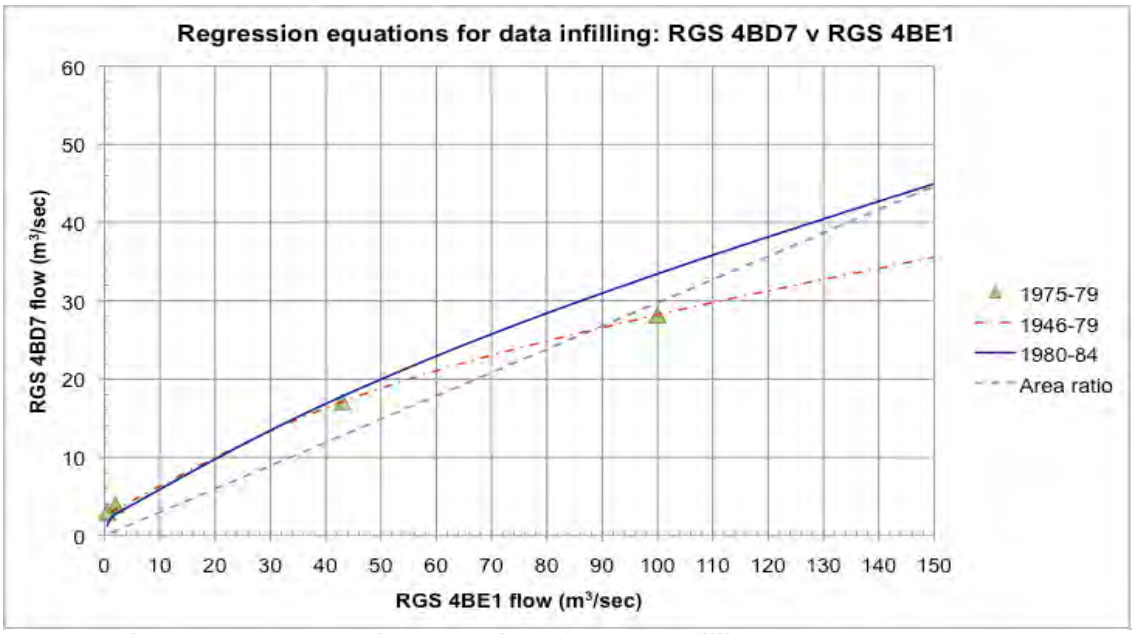


Figure 5-46: Regression Equations for Data Infilling – RGS 4BD7 v 4BE1

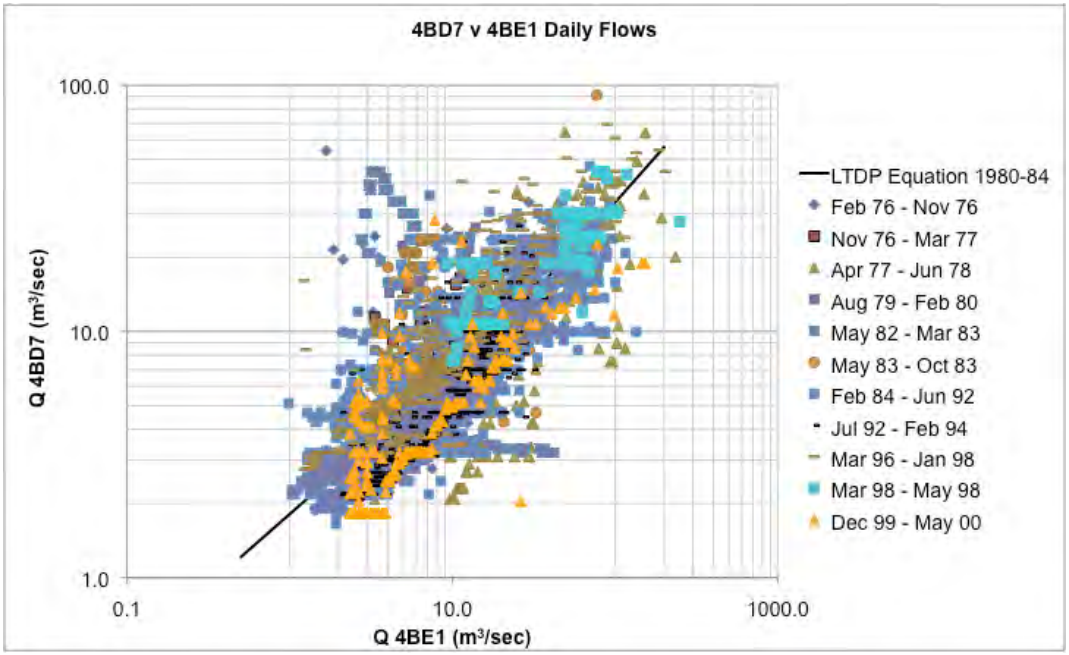


Figure 5-47: RGS 4BD7 v 4BE1 – Daily Flow Correlation

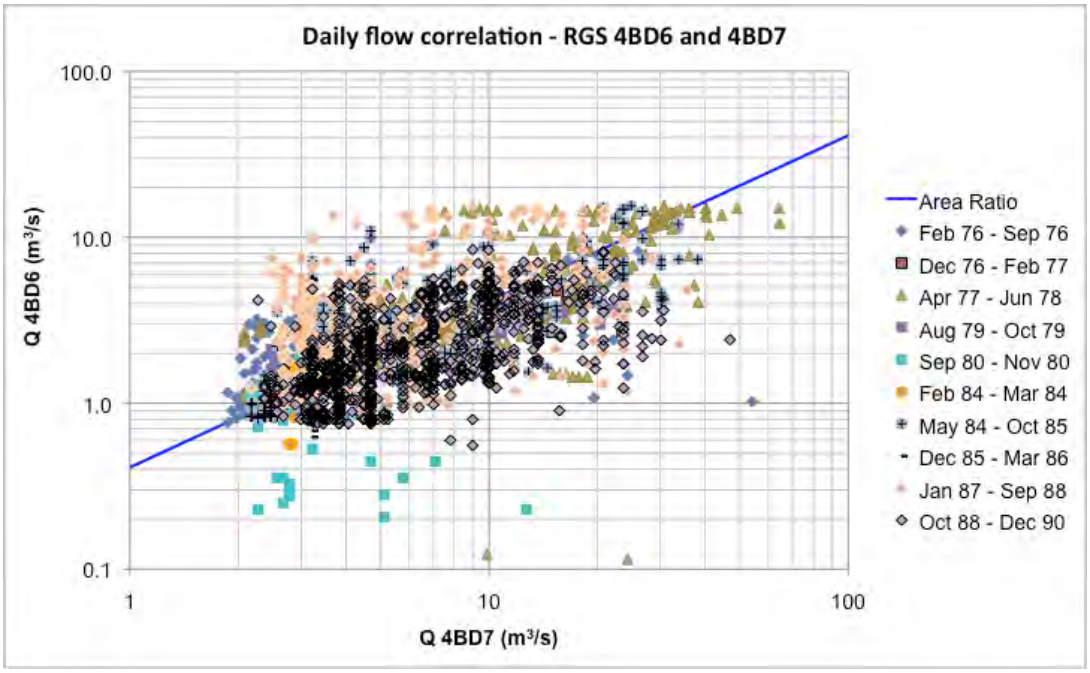


Figure 5-48: RGS 4BD6 v 4BD7 – Daily Flow correlation

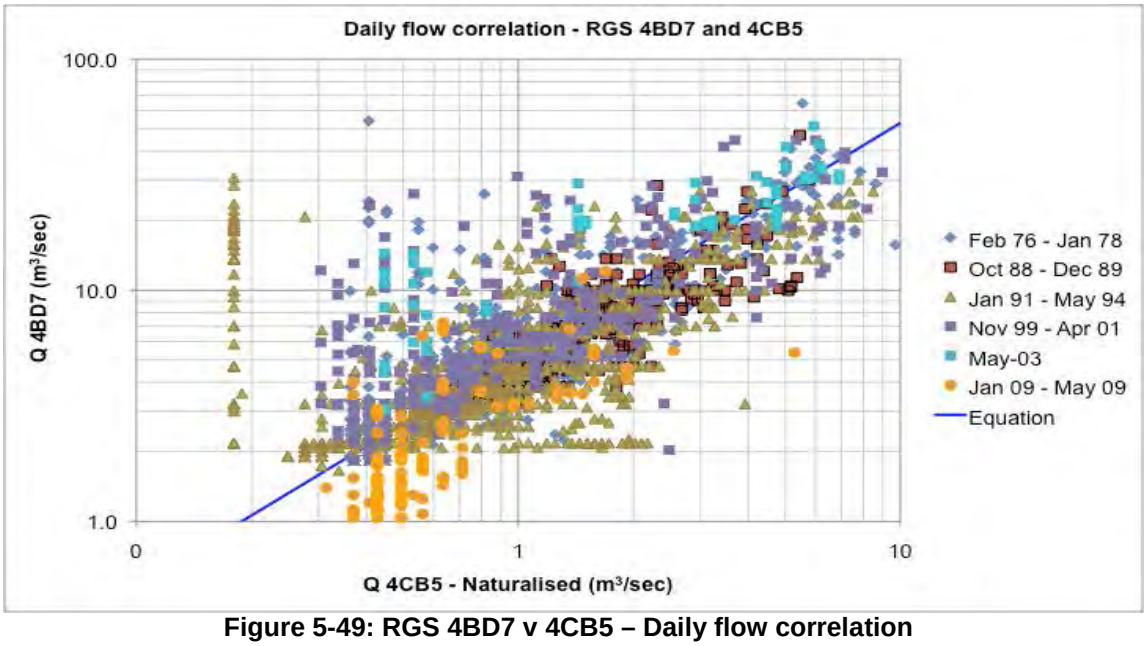


Figure 5-49: RGS 4BD7 v 4CB5 – Daily flow correlation

6.5.5 RGS 4BE6 Record Extension – Irati River

Previous studies did not present any correlation equations for this station, although flow sequences were derived in the Northern Collector Scheme Feasibility Report (HH, 1998).

Figure 5-50 below presents the available data together with the following correlation Equation 12 which fits the data:

Equation 12: $Q(4BE6) = 0.1 \times Q(4BE1)^{0.95}$

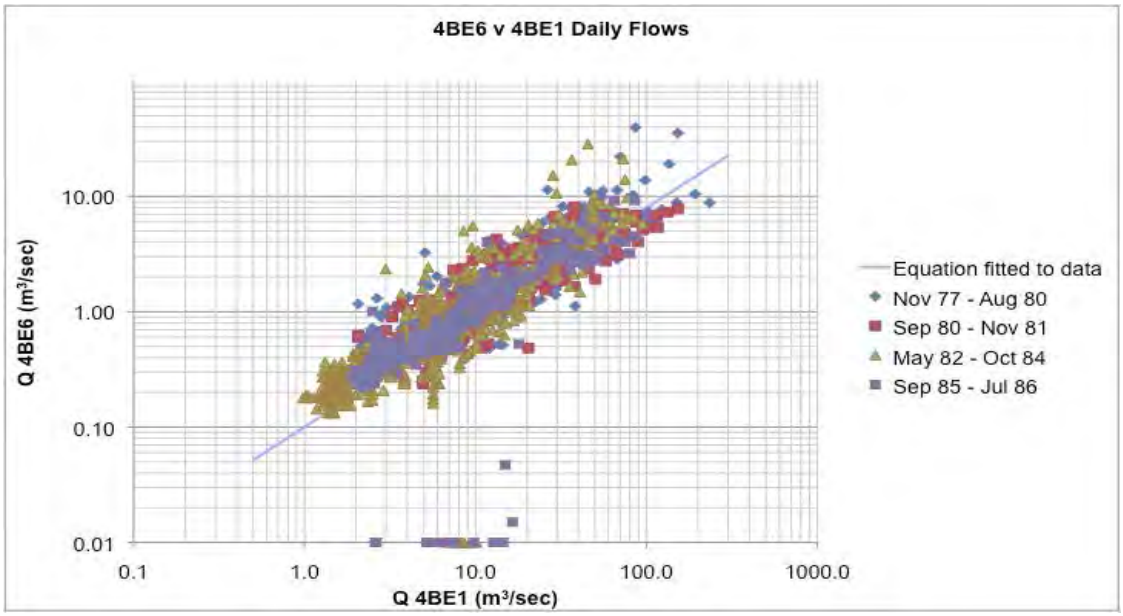


Figure 5-50: RGS 4BE6 v 4BE1 – Daily flow correlation

6.5.6 RGS 4BE8 Record Extension – Gikigie River

Previous studies developed the following flow correlation equations using RGS 4BE1 as the base station:

Equation 13: 1975-79: $Q(4BE1)<6\ m^3/sec$, $Q(4BE8) = 0.0769 \times Q(4BE1)^{0.7127}$
$Q(4BE1)>6\ m^3/sec$, $Q(4BE8) = 0.0406 \times Q(4BE1)^{1.0685}$

Equation 14: 1980-84: $Q(4BE1)<2\ m^3/sec$, $Q(4BE8) = 0.0312 \times Q(4BE1)^{1.2086}$
$Q(4BE1)>2\ m^3/sec$, $Q(4BE8) = 0.0330 \times Q(4BE1)^{1.1629}$

(Source: Table 3.3, Long Term Development Plan, HH, 1986)

The following comparisons are presented:

- Figure 5-51**:** Data from 1977-84 showing the good correlation with Equation 14**.**
- Figure 5-52 on page 5-59: Data from 1990-97 showing that there is no change to the correlation, and the original equation remains applicable.

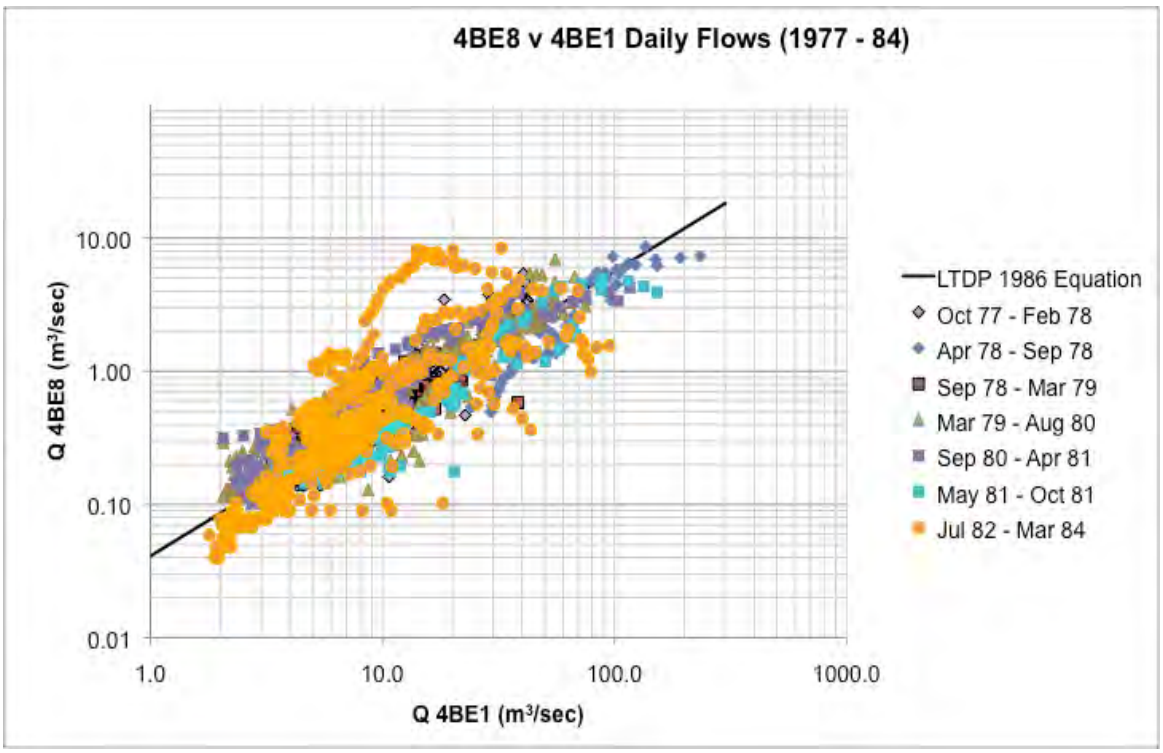


Figure 5-51: RGS 4BE6 v 4BE1 – Daily Flow Correlation (1977-84)

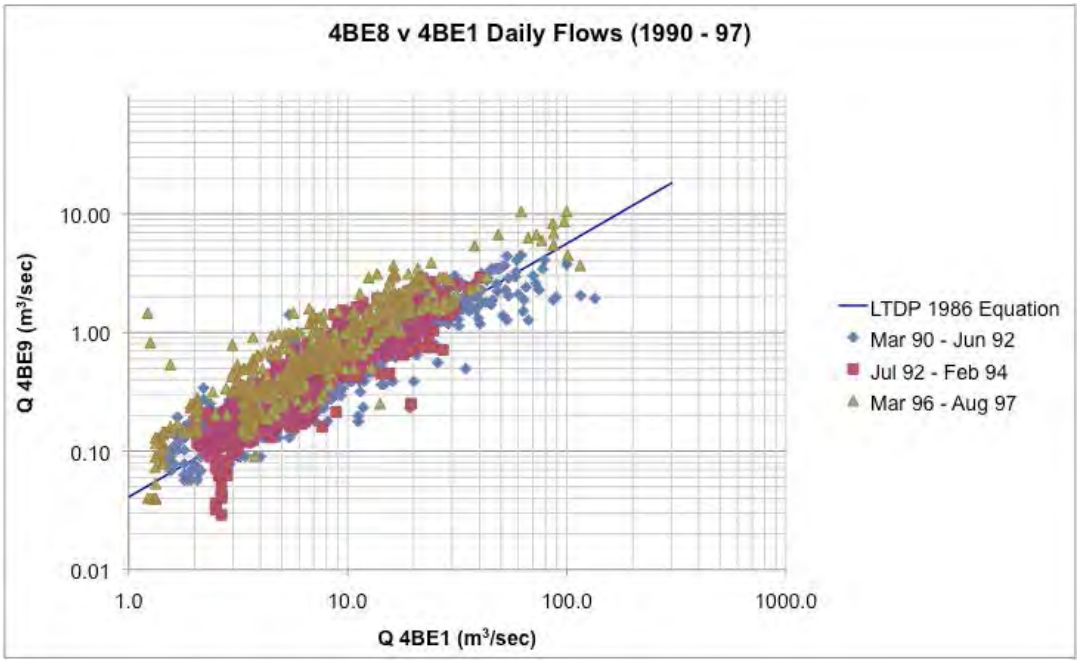


Figure 5-52: RGS 4BE8 v 4BE1 – Daily Flow Correlation (1990-97)

6.5.7 RGS 4BE9 Record Extension – Maragua River

Previous studies developed the following flow correlation equation using RGS 4BE1 as the base station:

Equation 15: 1975-84, $Q(4BE9) = 0.4130 \times Q(4BE1)^{0.7281}$
(Source: Table 3.3, Long Term Development Plan, HH, 1986)

Figure 5-53 presents data from 1977 to 2000 showing the correlation with Equation 15 throughout the period.

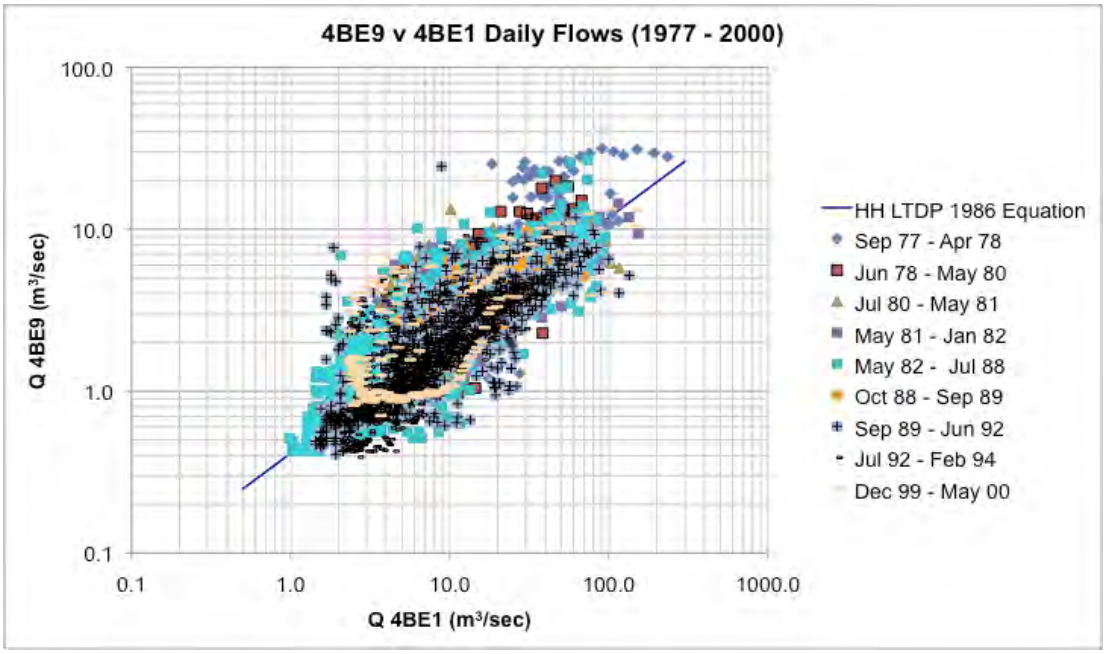


Figure 5-53: RGS 4BE9 v 4BE1 – Daily flow correlation (1977-00)

6.6 Flow Indices - Flow Duration

Flow duration analysis provides the relationship between any given discharge and the percentage of the time that the discharge is exceeded. If the curves are standardised by expressing all discharges as a proportion of the Average Daily Flow (ADF), direct comparison between catchments is enabled. This is a test for catchment homogeneity.

The focus of this assessment was to determine whether the previous hydrological assessments remain applicable today.

The WRMA daily flows were entered into the Consultant's HYDATA database and this enables various analyses.

The digital database is almost complete, albeit with large gaps, although in the case of at least one station, the extended data is still in manuscript form.

The following are compared in **Figure 5-54** on page 5-64:

- The WRMA database from 1950-1992 for RGS 4BE1, infilled and extended;
- The Howard Humphreys NCS-FR (1998) analysis using data from 1950-92;
- The observed database from 1970-2010, infilled and extended.
- Results from a recent Howard Humphreys study of the Bulk Water Supply for Muranga (HH, 2010).

The WRMA 1950-92 curve draws down at low flows compared to the 1970-2010 sequence. The reasons for this were advanced earlier, namely land usage changes arising from smallholder tea development between the mid 1950s and early 1970s – see Section 6.5.2 earlier. The recent Muranga North and South Bulk Water Supply Hydrological Assessment Study (HH, 2010) produced virtually identical curves to the curves derived by this study, which is not surprising as the source database is the same. However the conclusions are interesting. The Muranga Study stated, "there are very few differences" between the periods 1949-1980 and 1981-2000, although noting, "the 1981-2000 data shows increased low flows". The Muranga Study adopted a mean curve for design. In view of the land use change, this study recommends disregarding the record period that preceded the land use changes.

The following are compared in **Figure 5-55** on page 5-64:

- The WRMA database from 1950-1992 for RGS 4BD7, infilled and extended;
- The Howard Humphreys NCS-FR analysis using data from 1950-92;
- The observed database from 1970-2010, infilled and extended.

The following are compared in **Figure 5-56** on page 5-65:

- The observed database from 1950-1992 for RGS 4BD6, infilled and extended;
- The Howard Humphreys NCS-FR analysis using data from 1950-92;
- The observed database from 1970-2010, infilled and extended.

The infilled and extended WRMA data and the Howard Humphreys simulations are very similar. The "drawdown" of the flow duration curve at low flows noted with 4BE1 is also evident at 4BD6 and 4BD7 with the data sequence from 1950, but to a much lesser extent than at 4BE1, as only a much smaller proportion of the catchments are within tea zones.

Figure 5-57 on page 5-65 presents the daily flow duration analysis of the WRMA database of all Northern Collector Rivers. RGS 4CB5 is included to see if the hydrology is similar in character.

Figure 5-58 on **page 5-66** presents the same WRMA data, but "standardised" through division of each flow value by the station average daily flow (ADF). Homogeneous catchments will display similar standardised flow duration curves. The following is apparent:

- Rivers South and North Mathioya have almost identical standardised flow curves. RGS 4BE8 also tallies with these two rivers.
- The "4BE" rivers have very similar standardised flow curves.
- The "4BE" rivers have standardised curves very similar compared to RGS 4CB5.

In Table 5-18, the HYDATA analysis of the WRMA data is compared with the results published in previous reports. No consistent trend emerges, but the values are similar.

The flow duration expressed as unit catchment runoff in Litre/sec/km^2 is presented in

Figure 5-59 on page 5-66 with the Q95 values tabulated in Table 5-18 on page 5-62 overleaf. The very much higher unit runoff of the northern catchments is well illustrated. The unit runoff diminishes progressively to the south from the North Mathioya River, with the nearby southern catchments in cases yielding half or less per unit of catchment area. This reduction is a function of diminishing catchment rainfall to the south.

Figure 5-60 on page 5-67 presents the relationship between average daily flow and catchment area. This relationship was presented earlier in this report based on historic data for all rivers in the project area.

Also included in Figure 5-60 is the relationship between Q95 and catchment area. General trend lines are included for both ADF and Q95. The similarity of the 4BE Rivers and 4CB (4CB5) is illustrated, as is the significantly higher unit runoff of the 4BD Rivers when compared to 4BE & 4CB (4CB5). These updated results are entirely consistent with the historic analysis presented earlier.

RGS 4CB5 has the best available and recent record for comparative analysis. Three columns of data are compared in Table 5-19 on page 5-63. The average daily flow computed by this study is higher, but the Q95 flow is similar. The flow pattern in the extended period 1992-10 is the same as the preceding period of data. This study does not show any significant change with the recent data to 2010.

The updated flow duration analysis of the infilled flow series for the period 1970-2010 is included in Figure 5-57. These results can be combined with transposition equations selected from Table 5-6 on page 5-9 and Table 5-7 on page 5-10 to derive the flow duration at the diversion points, subject to checking on, and making adjustments for, upstream abstractions.

Table 5.18: Comparison of Flows With Previous Estimates

	Units	4BD6	4BD7	4BE1	4BE6	4BE7	4BE8	4BE9	4CB5
Area	Km^2	51.0	123.2	414.0	28.3	8.3	15.0	42.9	32.3
ADF (WRMA 1950-2010)	M^3/sec	2.890	7.058	11.591	1.347	0.364	0.657	2.304	1.459
ADF (WRMA 1970-2010)	M^3/sec	3.004	7.457	12.132	1.358	0.384	0.693	2.467	1.433
ADF (Table 5.10, LTDP 1986)	M^3/sec	2.970	6.850	11.300	-	-	0.590	2.440	-
ADF (Table 4.10, 1950-92, NCS-FR 1998)	M^3/sec	3.173	7.782	11.715	1.375	0.398	0.769	2.491	-
ADF UNIT RUNOFF 1970-2010	$l/s/km^2$	58.9	60.5	29.3	13.3	46.3	35.5	87.2	44.4
FLOW DURATION Q95 WRMA 1950-2010	M^3/sec	0.841	2.055	1.505	0.299	0.028	0.051	0.533	0.345
Q95 WRMA 1970-2010	M^3/sec	0.910	2.250	2.417	0.279	0.055	0.101	0.704	0.345
Q95 (LTDP 1986)	M^3/sec	1.110	2.700	1.950	0.301	-	0.111	0.640	0.447
Q95 (NC-FR 1998)	M^3/sec	0.900	2.000	1.800	0.280	0.058	0.100	0.550	-
Q95 UNIT RUNOFF 1970-2010	$L/s/km^2$	18.4	18.5	5.8	10.2	6.7	6.7	16.1	10.8
Q95 STANDARDISED 1970-2010	Q_{95}/ADF	31%	31%	20%	21%	14%	14%	29%	24%

Notes:
LTDP=Long Term Development Plan, 1986. NCS-FR=Northern Collector Scheme Feasibility Report, 1998. ADF=average daily flow. Q_{95}=95% percentile flow from flow duration analysis.

Table 5.19: RGS 4CB5 – Flow duration for Different Periods Analysed

RGS 4CB5	Previous Studies	1970-1992 [2]	1992-2010 [2]
Area km^2	32.3	32.3	32.3
Average daily flow m^3/sec	1.313 [3] 1.346 [4] 1.291 [5]	1.457	1.453
95 percentile flow m^3/sec	0.447 [1]	0.306	0.404
90 percentile flow m^3/sec		0.373	0.436
75 percentile flow m^3/sec		0.562	0.610
50 percentile flow m^3/sec		0.886	0.917
25 percentile flow m^3/sec		1.637	1.640
10 percentile flow m^3/sec		3.322	3.095
5 percentile flow m^3/sec		4.804	4.358

Notes:

1. *Table 4.3, Hydrology, Long Term Development Plan, HH, 1946-1984 data*
2. *Analysis carried out by EBI/MIBP JV*
3. *Chania-Thika Study, Stage 1 Report, Part 2B, 1979, HH, 1946-77 data*
4. *Short Term Plan to 1995, Hydrology Appendix C, HH, 1946-84 data*
5. *Appendix A.7, Hydrology Review, HH, 1995, 1946-92 data*

Table 5.20: Flow Duration Results

(Flows in m^3/sec)

	Station 4BD6	Station 4BD7	Station 4BE1	Station 4BE6	Station 4BE7	Station 4BE8	Station 4BE9	Station 4CB5
ADF	3.004	7.457	12.132	1.358	0.384	0.693	2.467	1.433
Q95	0.91	2.25	2.417	0.279	0.055	0.101	0.704	0.345
Q90	1.081	2.643	3.015	0.347	0.072	0.131	0.852	0.406
Q75	1.444	3.471	4.409	0.498	0.109	0.198	1.16	0.587
Q50	2.117	4.955	7.03	0.777	0.187	0.338	1.719	0.914
Q25	3.49	8.627	13.099	1.447	0.4	0.722	2.899	1.638
Q10	6.191	15.969	27.58	3.174	0.922	1.664	5.063	3.206
Q5	8.606	21.896	40.716	4.751	1.46	2.642	7.057	4.581

Note: Record period analysed 1970-2010

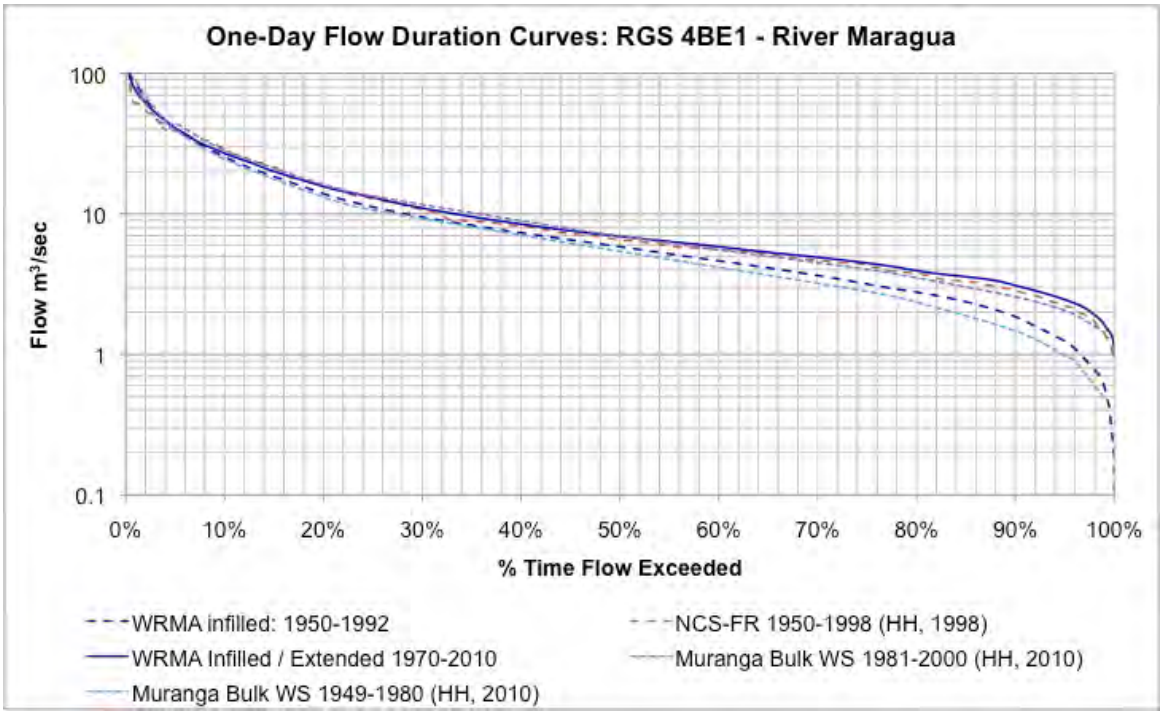


Figure 5-54: Station 4BE1: One-Day Flow Duration Curve Comparisons

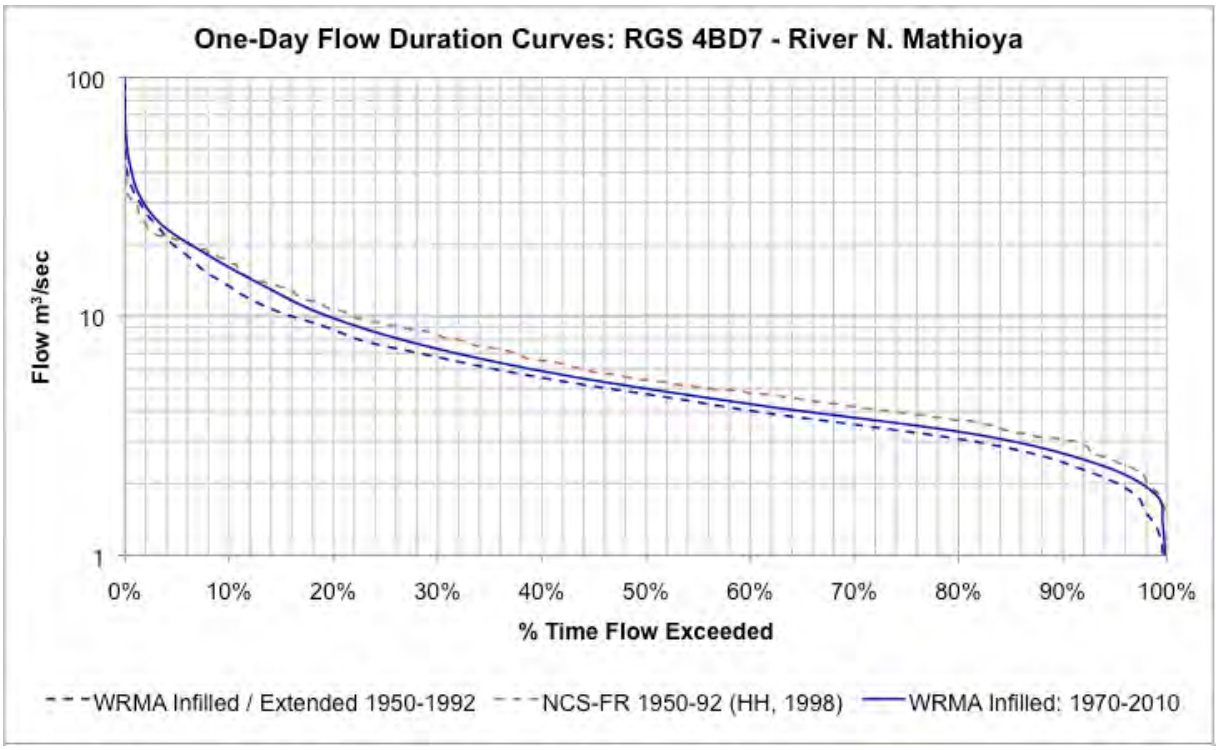


Figure 5-55: Station 4BD7: One-Day Flow Duration Curve Comparisons

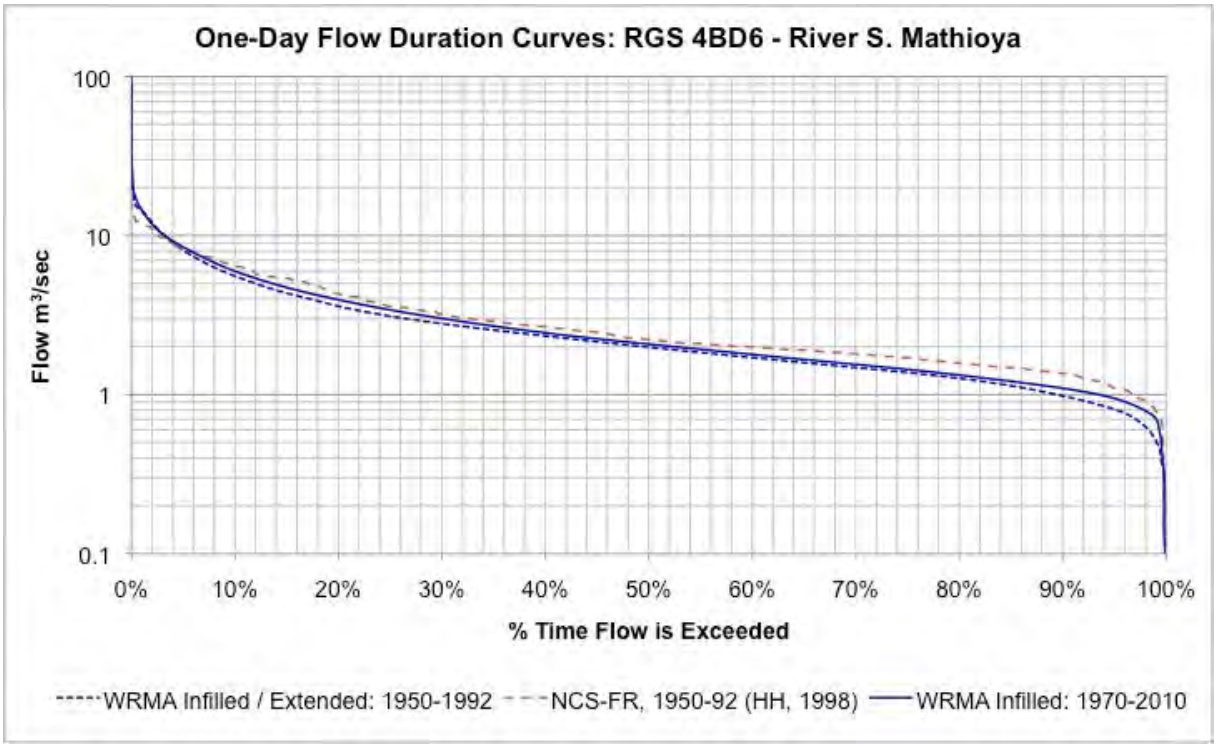


Figure 5-56: Station 4BD6: One-Day Flow Duration Curve Comparisons

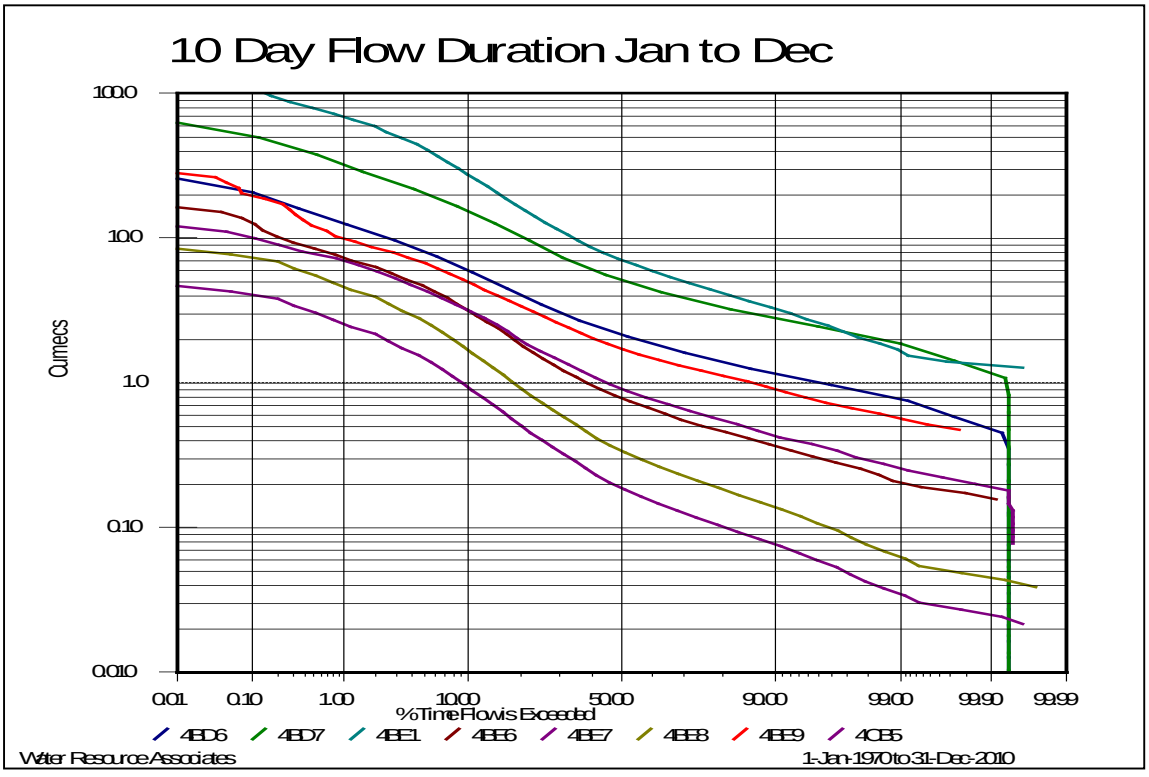


Figure 5-57: 10-Day Flow duration – All N. Collector Rivers (cumec)

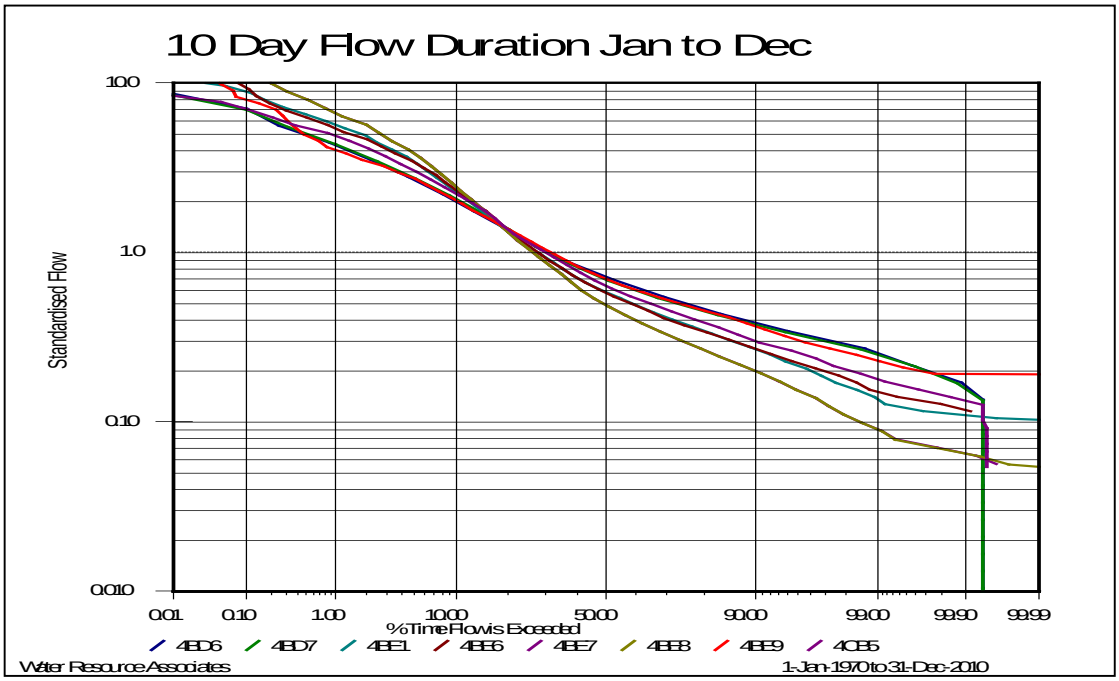


Figure 5-58: 10-Day Standardised Flow Duration – All N. Collector Rivers (Q/ADF)

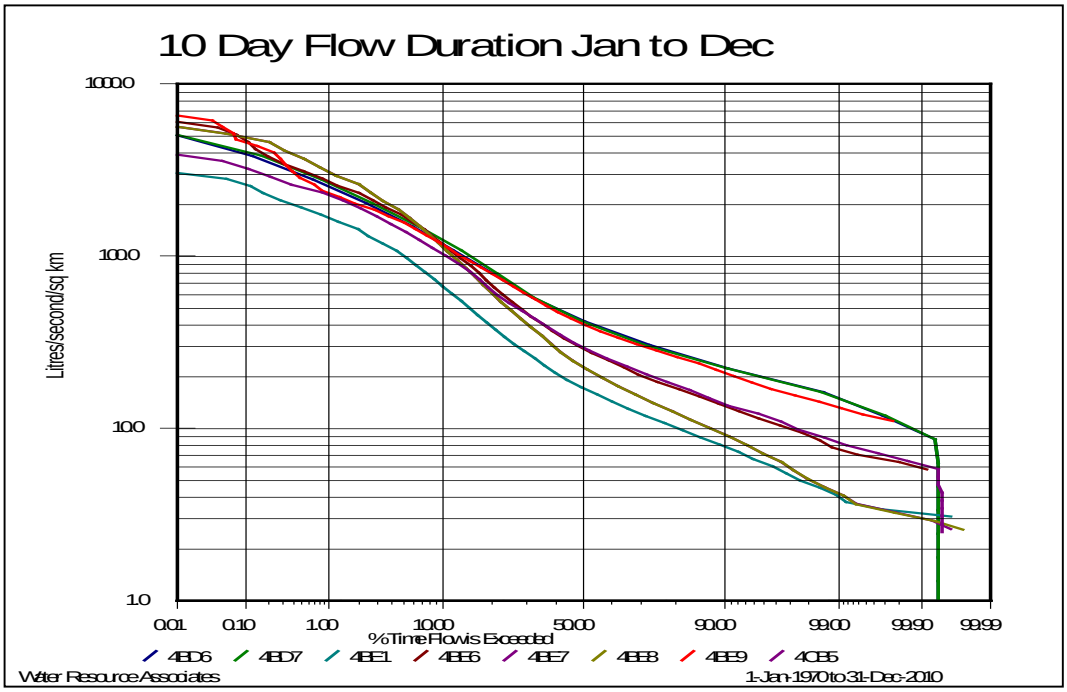


Figure 5-59: 10-Day Flow Duration – All N. Collector Rivers Unit Runoff (L/s/km^2)

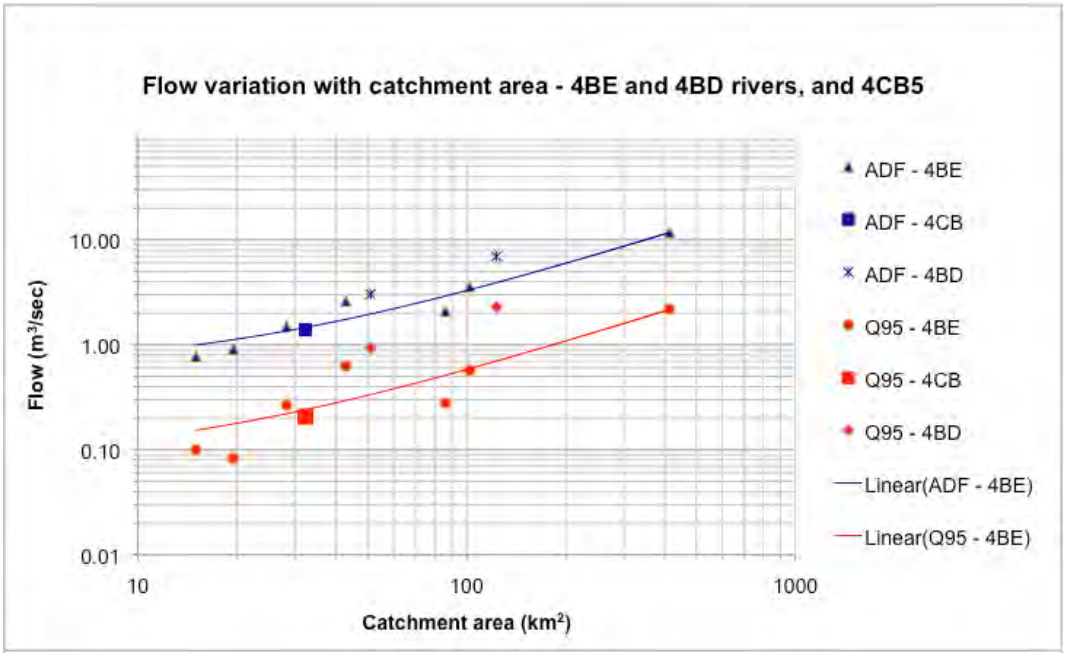


Figure 5-60: Flow / Catchment Area Relationship (1970-2010 data)

As explained in earlier report (Egis/MIBP, Version 02 Water Sources, August 2011), the Rivers close to Nairobi were not analysed in detail as this was beyond the scope of this study. These rivers have much lower annual runoff and were not contributing to the Northern Collector system. For the purposes of master planning for potential water sources for satellite towns, historic 95% exceedence data is presented in the following graphs:

- **Figure 5-61:** Q95 Variation **with** Catchment Area in Sub-Basins 3BA & 3A
- **Figure 5-62: Q95 Variation with** Catchment **Area** in Sub-Basins 3BC & 3BD & 3BB
- **Figure 5-63: Q95 Variation** with Catchment **Area** in Sub-Basins 4CA & 3CB

In some cases, data was scarce, but there is sufficient data to assess appropriate values of MAI for master planning purposes.

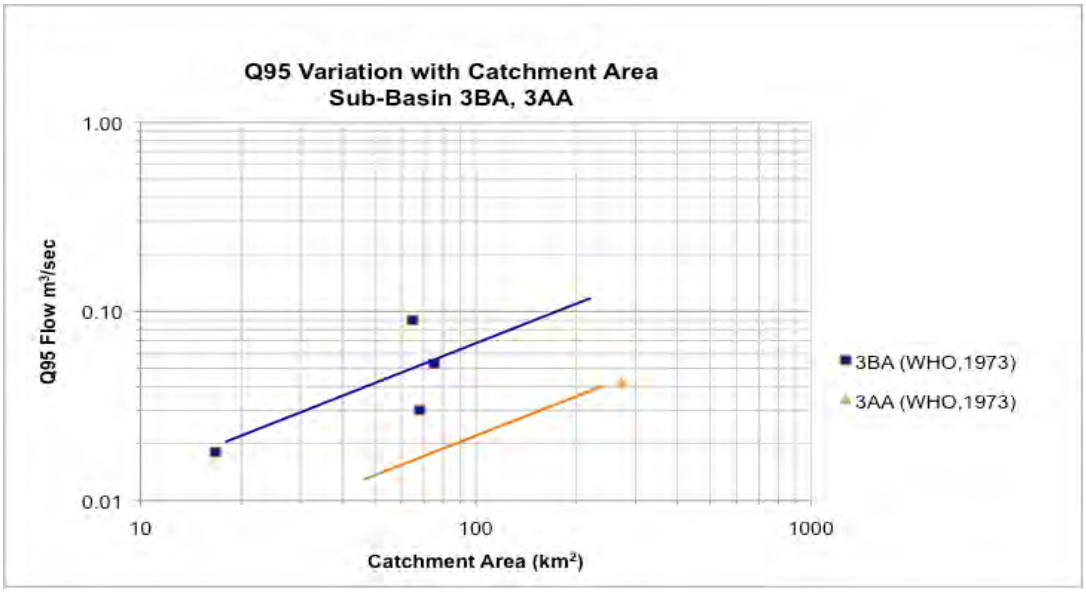


Figure 5-61: Q95 Variation with Catchment Area in Sub-Basins 3BA & 3AA

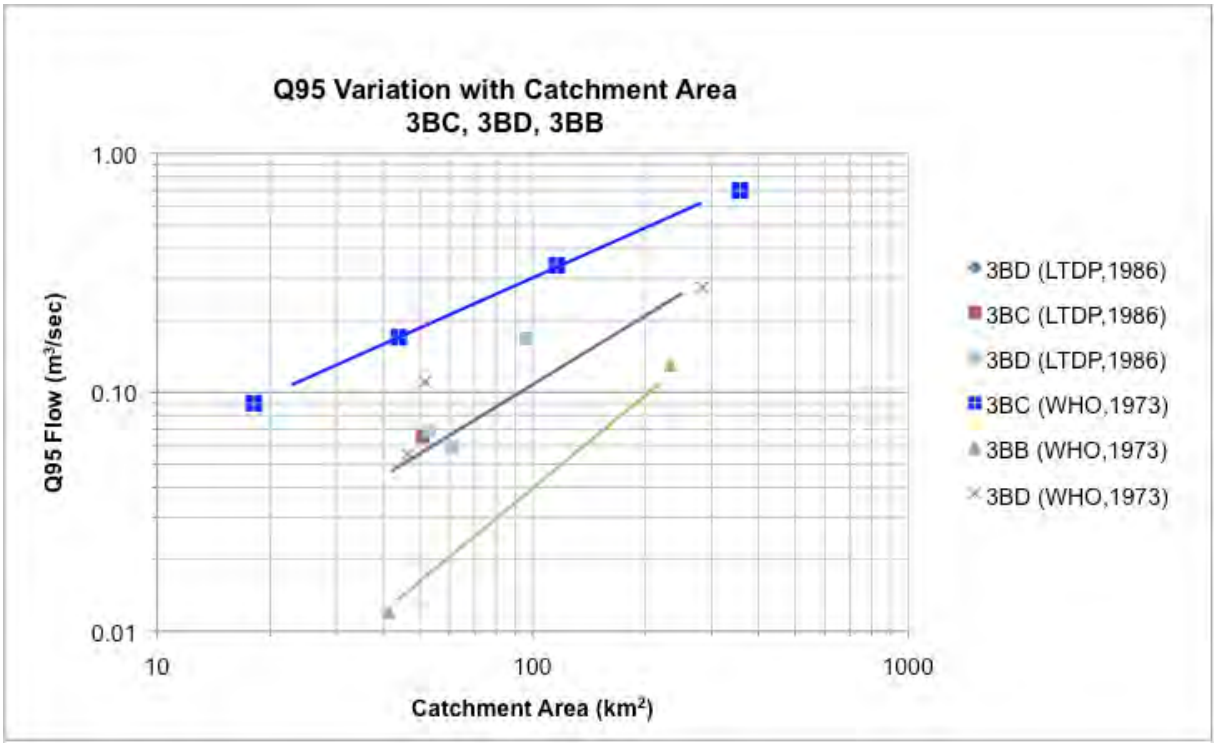


Figure 5-62: Q95 Variation with Catchment Area in Sub-Basins 3BC & 3BD & 3BB

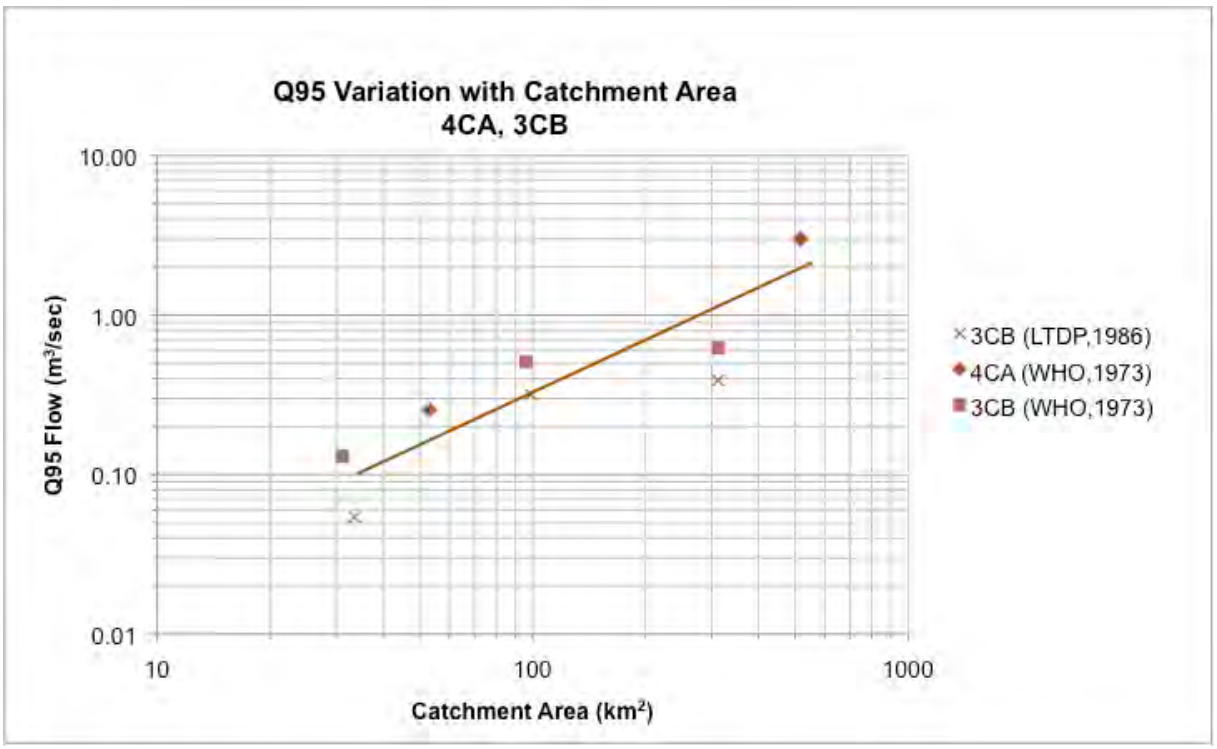


Figure 5-63: Q95 Variation with Catchment Area in Sub-Basins 4CA & 3CB

7 Water Abstraction Permits

7.1 Introduction

As mentioned earlier, the individual abstraction permits, in most cases, are not geo-referenced. Hence it has not possible to distribute the points of abstraction throughout the basins, nor is it possible to determine where the abstraction points are in relation to any proposed diversion points.

7.2 Review of Abstraction Permits

The water abstraction permit database provided by WRMA is summarised in Table 5-21 on page 5-70. The water demand from surface water resources has been presented in Working Paper No.3 (Egis BCEOM / MIBP, 2011). In recent years significant increases in water abstraction permits have been recorded in some basins, and many abstractions are not licensed. The following examples illustrate this point:

1. Studies in Mount Kenya region revealed 300% increase in permit numbers over 12 years (HH, August 2010, referring to Thomas, 2009). The same studies revealed large numbers of illegal abstractions, a common issue throughout the country. 60% of abstractors were without documentation, and 64% of total abstraction volume was not supported by valid permits (HH, August 2010).
2. The recently published 2009/2010 Lake Naivasha catchment abstraction survey revealed 924 abstraction points, 71% of which were not licensed (LANAWRUA / WRMA / WWF).

Hence, an updated survey for the project area is essential. This exercise by WRMA is believed to be ongoing.

Studies by others in the Mathioya basin revealed inexplicable discrepancies in numbers of permits, which were referred back to WRMA (HH 2010 referring to ADEC 2010). In the absence of the quality of data needed, other studies have concluded that the only way to obtain naturalised flow sequences is by using flow sequences up to 1980. This would be acceptable provided it could be established that the hydrological characteristics of those catchments have not changed. It has been demonstrated elsewhere in this report that in the case of RGS 4BE1, there were significant land use changes between the mid 1950s and early 1970s that affected runoff characteristics in this catchment.

Compensation flow releases downstream of proposed intakes will require a water demand and source inventory for downstream users. The effects have been explored earlier through the WEAP Model (v1) described in Working Paper No.4 (Egis BCEOM / MIBP, 2011), and in this report through the WEAP Model (v2) results, reported elsewhere.

Table 5-21: Abstraction permits from WRMA

River	Number of Permits Issued	Permit from Normal Flow m^3/sec	Permit from Flood Flow m^3/sec
Mathioya	21	2.952	0.038
Maragua	57	2.036	0.064
Irati	11	0.251	0.002
Karimenu	19	0.003	0.123
Kayahwe	19	0.027	0.005
Kimakia	8	0.569	0.004
Thika	60	6.914	1.310
Chathanda	2	0.003	0.003
Chania	40	3.446	0.311

8 Reservoir Hydrology

8.1 Probability of Reservoir Failure and Reliability

The probability of failure of a storage reservoir created by an impoundment structure can be defined as the sum of the time units during which the reservoir is empty expressed as a proportion of the total number of time units analysed (McMahon and Mein, 1978).

Hence:

Equation 16: $Pe = P/N$

Equation 17: $Re = 1 - Pe$

where Pe = Probability of failure
Re = Reliability
P = The number of time units during which the storage is empty
N = The total sequence of time units in the streamflow sequence

The Terms of Reference do not specify the required project design reliability, nor the basis for its computation.

In the WEAP Model documentation (see Chapter 9 Version 02 Water Sources Options Report, Egis/MIBP, August 2011), reliability is defined as "the percent of time steps in which a demand site's demand was fully satisfied". This is identical to the McMahon and Mein definition above.

The "reliability" criterion adopted in the previous Howard Humphreys studies is quite different. "90% reliability" was defined as meaning that "in 9 out of every 10 years on average, full supply could be maintained without interruption, whereas in 1 year out of every 10 years, on average, there would be periods when insufficient water is available to enable the full design yield to be supplied (Short Term Plan to 1995, HH, 1986)". Under this definition, in a year of failure, the "periods" of failure could range from one single day to 365 days in a year, and yet the failure rate would be unchanged. In other words, irrespective of the number of days failing to supply within that year, that year would still count as "1 in 10 year" failure.

It will be demonstrated elsewhere in this report that the definition adopted in earlier reports based on an annual time step for analysis leads to a higher reliability when compared to reliability computed on actual time steps of failure. For instance, the 90% reliable yield of the annual time step methodology equates to 98% reliable yield calculated by the WEAP methodology using actual time steps. The difference in definitions of reliability needs to be

borne in mind throughout this report, and it is very important to define which definition is adopted.

Yield results were presented in earlier working papers on the basis of WEAP water balance modelling using the definition described above and in the WEAP software manual. Following review of the Working Papers with the AWSB and the World Bank, 90% reliable yield was adopted as the design basis, and the reliability was computed using the annual time step based definition of the earlier Howard Humphreys reports.

8.2 Reservoir Yields from Previous Studies

Eighteen storage reservoir sites were studied during the Chania – Thika Study. Seven of these were on the Thika River, four were on the Chania River, and others were on the Kiama, Karimenu, Samuru, Ngenya, Kimakia, and Kabuku Rivers. These earlier investigations were reported in the "Dams, Stage 2 and 3 Report", Volume 4, dated 1980. Various yield storage curves were presented, and these are reproduced in **Figure 5-64** to **Figure 5-66** on pages pages 5-72 – 5-73 respectively.

In addition, eight sites were investigated on the "Northern Rivers", which included the Gura, N.Mathioya, Zuti, Maragua 4, S.Mathioya, Irati, Maragua 7 and Maragua 8. The scheme costs were reported in the Supplement to Volume 4 of the Stage 2 & 3 Report (1980), the Supplement being dated September 1984. The "Supplement" did not present any hydrology for these reservoirs. Hence there are no yield storage curves to refer to.

Following consideration of all the above sites and transfer options, the Stage 2 & 3 Report recommended the construction of the Thika 6 dam. This scheme was implemented, and is operational today.

At the same time as Thika 6 was being developed, the Long Term Development Plan was presented, and submitted various impoundment possibilities, and various yield permutations were presented based on various cross catchment transfer tunnels. The main reservoir sites were Thika 6, Ruiru 2, Ndarugu 1 and 2, Maragua 4 and 8. Area / storage curves were developed (reproduced in Figure 5-70), and the direct supply yields are reproduced in Figure 5-67 and Figure 5-68 on the following sheets.

The next stage of water supply development that was proposed was the Northern Collector Scheme, described in the Northern Collector Scheme Feasibility Report (NCS-FR, dated 1998. This scheme would intercept several northern rivers, and divert a portion of their flows through tunnels to supplement inflow to Thika Dam. The proposed Northern Collector Phases I and II were based on the diversion of run-of-river flows under gravity, without any storage provision. However, the following storage considerations were mentioned:

1. *Supplemental Storage to Thika Dam:* The diversion of flows to supplement the Thika dam inflows would lead to substantial spill, which could be harnessed through construction of additional storage downstream of Thika Dam. The potential to increase storage to as much as 250 M.m^3 was mentioned (Section 4.9.2, Feasibility Report, Chapter 4-77). The existing dam is at capacity, and cannot be raised, so the additional storage provision was envisaged downstream.
2. *Storage reservoir at river diversion points (*Figure 5-69*):* The Feasibility Report stated, "In principle, storage could be provided at any or all of the diversion points (Feasibility Report, Section 4.9.4)". The site on the N.Mathioya was the largest by far, and the possibility of using this reservoir in conjunction with Thika Dam was mentioned, although not studied, as such a study required "more sophisticated analysis inappropriate to the purposes" of the Feasibility Report. These storage reservoirs would increase the yield,

and would be “useful for mitigating the impacts of the project upon the downstream environment and infrastructure (Feasibility Report, Section 1.5)”.

3. *Independent Storage Reservoirs (*Figure 5-69*)*: These were on the Northern Collector Rivers, but would have no connection to the Northern Collector, hence would be independent.

4. *Larger reservoir on Maragua River (*Figure 5-68*):* This reservoir was envisaged to regulate the Phase II flows to the Northern Collector.

Figure 5-64 to Figure 5-66 present the 98% reliable yield / storage data for various reservoirs considered under the Chania – Thika Study dated 1980. These yields are the “net yield” available for Nairobi after allowing for the local water supply and irrigation needs, based on the Howard Humphreys annual time step definition of reliability. The “direct supply” yields are self explanatory, and the “regulated” yield is the added net yield provided at Mwagu through regulated release from the reservoir under consideration. If two reservoirs are built on the same river, the yields are of course not additive.

Figure 5-67 and **Figure 5-68** on page 5-74 present 90% reliable yields for various potential storage sites reported in the Long Term Development Plan dated 1986. These include the combined Ruiru Dams (existing dam plus extra site downstream), Ndarugu Dams 1 and 2, and Maragua Dams 4 and 8, and they are compared with Thika 6 (the existing Thika Dam).

Figure 5-69 on page 5-75 presents 90% reliable gross yields for individual reservoirs at each of the Northern Corridor diversion points. These results were reported in the Northern Collector Feasibility Report (HH, NCS-FR, 1998).

As discussed earlier, the earliest studies adopted the 98% reliability criterion, whereas later studies adopted the less severe 90% reliability. For comparison purposes, the 98% reliable yields are approximately 80% of the 90% reliable yields, although the ratio does vary. It should also be remembered that the previous yield reliability criterion definition may differ from that adopted in other studies, for instance as proposed in the WEAP Model documentation. It is important to define reliability to ensure validity of comparisons.

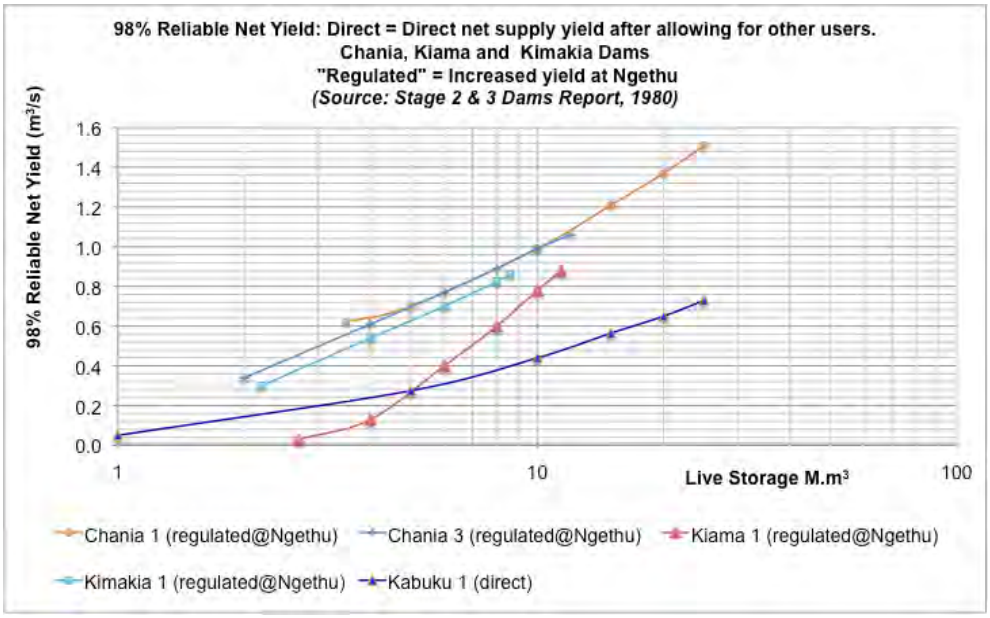


Figure 5-64: Various reservoir sites – Chania, Kiama and Kimakia
Source: Chania-Thika Study, Dams, Stage 2 & 3 Report, Volume 4, 1980

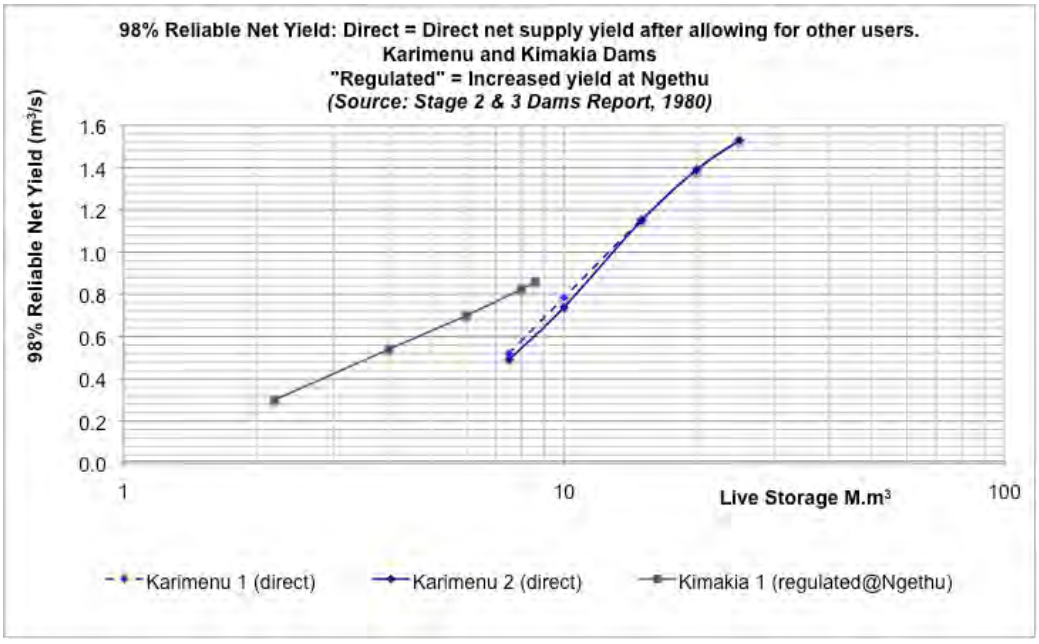


Figure 5-65: Various Potential Reservoir Sites – Karimenu and Kimakia Compared
Source: Chania-Thika Study, Dams, Stage 2 & 3 Report, Volume 4, 1980

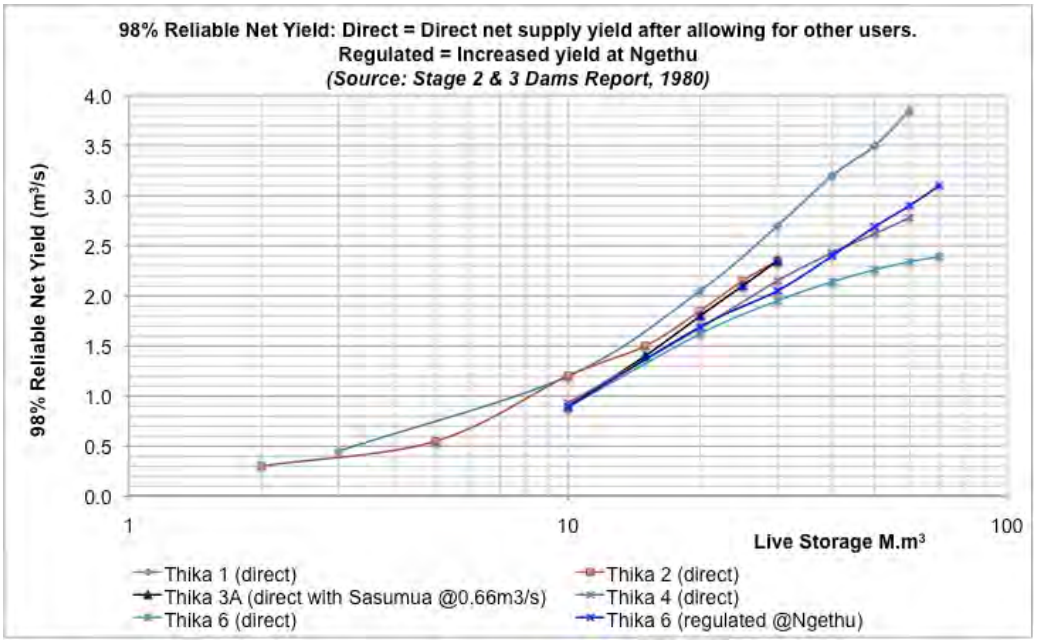


Figure 5-66: Various Potential Reservoir Sites on Thika River
Source: Chania-Thika Study, Dams, Stage 2 & 3 Report, Volume 4, 1980

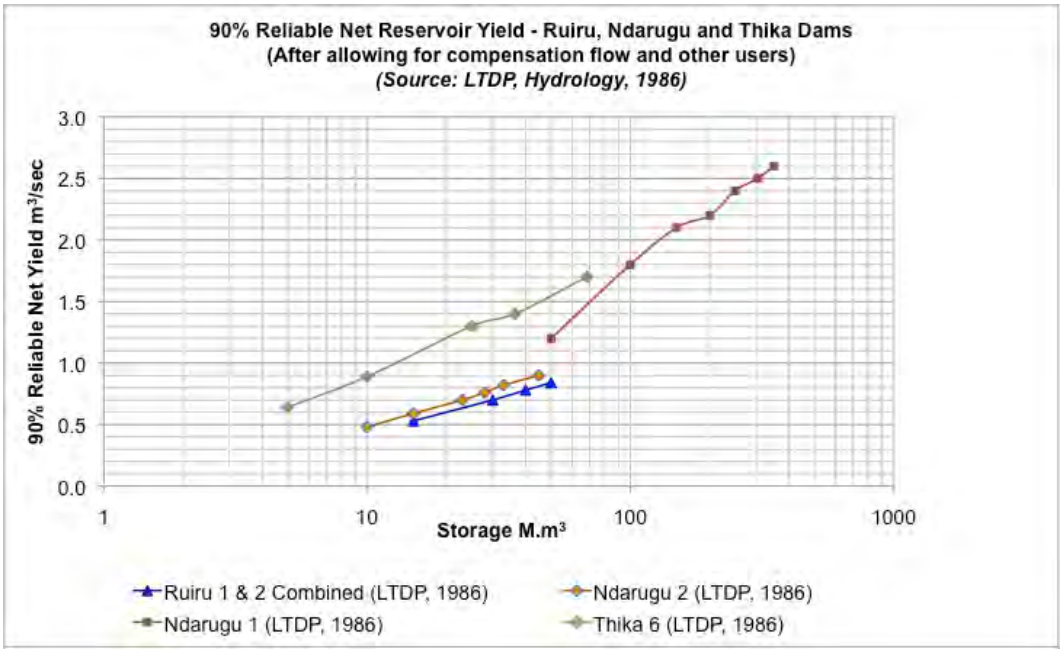


Figure 5-67: Potential Ndarugu, Ruiru potential reservoir yields compared with Thika 6
Source: Long Term Development Plan, Hydrology, 1986

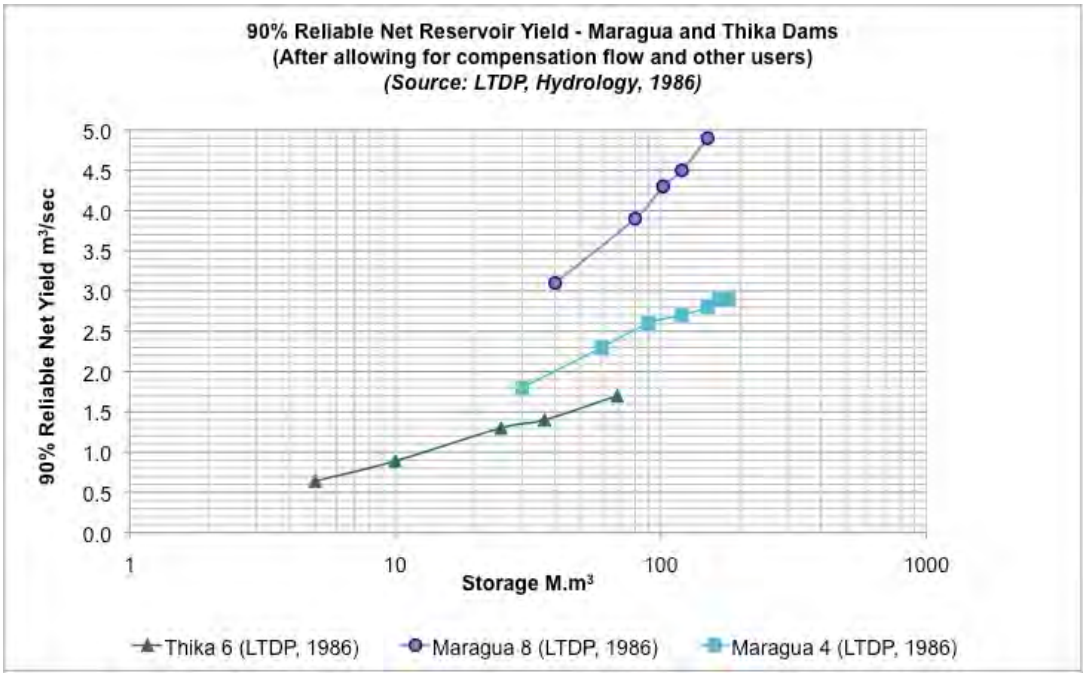


Figure 5-68: Potential Maragua Reservoir Yields Compared with Thika 6
Source: Long Term Development Plan, Hydrology, 1986

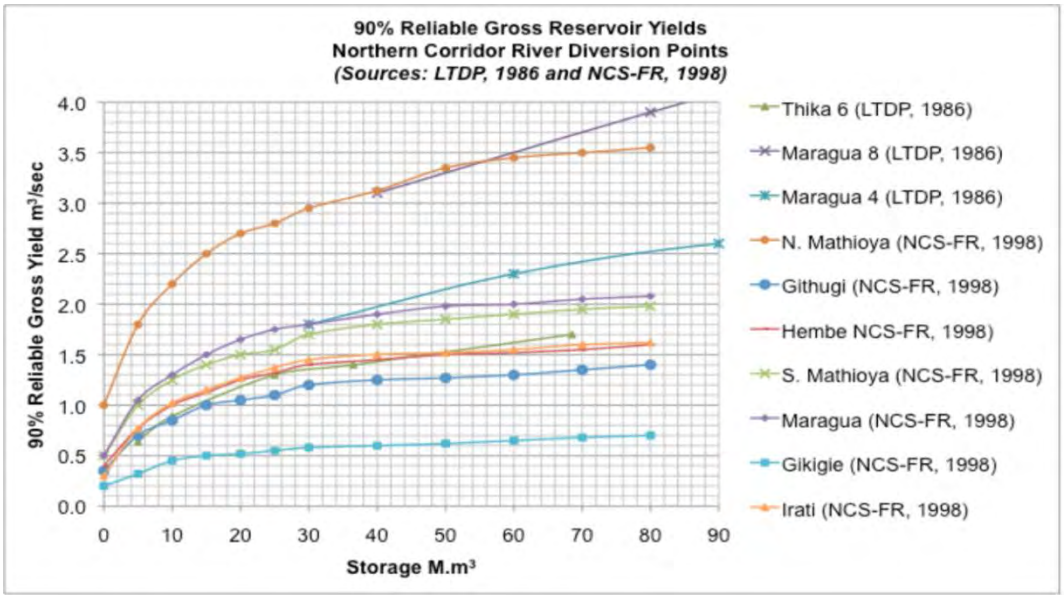


Figure 5-69: Potential Reservoir Yields at Northern Corridor Diversion Points Compared with Thika 6 and Potential Maragua Yields

Sources: Northern Corridor Feasibility Report, 1998, and Long Term Development Plan, Hydrology, 1986

8.3 Reservoir Area / Storage Relationships for Major Reservoirs (from Previous Studies)

Figure 5-70 presents reservoir storage/ area data for the existing Sasumua and Thika reservoirs, contrasted with large reservoirs proposed by earlier studies at Ruiru 2, Maragua and Ndarugu.

Sasumua is small in storage capacity, and the potential site at Ndarugu 1 is conspicuously larger in storage potential than all the other sites plotted.

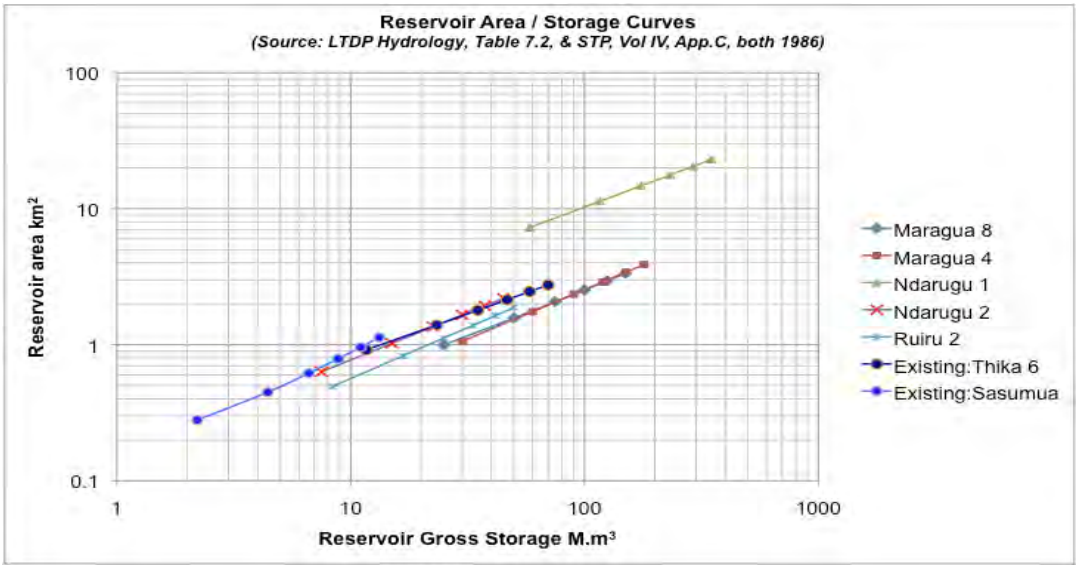


Figure 5-70: Reservoir Area / Storage Curves

Source: Long Term Development Plan, Hydrology, Table 7.2, 1986

8.4 Reservoir Net Evaporation from previous studies

Open water evaporation data is presented in **Figure 5-71** on **page 5-77** from the following sources:

1. *Long Term Development Plan, HH, 1986:*Annual open water evaporation data at the following locations were presented (LTDP Hydrology, Table 7.2):
    a. Sasumua Dam: 1154 mm/yr @ altitude 2499 m
    b. Kimakia Forest Station: 1529 mm/yr @ altitude 2439 m
    c. Ruiru Coffee Research Station: 1621 mm/yr @ altitude 1621 m
    d. Thika Horticulture Research Station: 1776 mm/yr @ altitude 1621 m
    e. Mwea Irrigation Scheme: 2082 mm/yr @ altitude 1621 m
    f. Marimanti (Meru): 2024 mm/yr @ altitude 1621 m

2. Ministry of Water Development publication *"Evapotranspiration in Kenya"* (Kalders, 1988)*:*
    a. E_t = 2523.414 – 0.4408 x ALTITUDE
    (E_t = Annual evapotranspiration mm/year)
    b. Nairobi Kabete Observatory: Et=1845.6 mm/yr @ altitude 1820 m
    c. S. Kinangop Forest Station: Et=1181.2 mm/yr @ altitude 2591 m
    d. Ruiru Coffee Research Station: Et=1690.3 mm/yr @ altitude 1608 m
    e. Thika Horticulture Research Station: Et=1659.1 mm/yr @ altitude 1549 m
    f. Nyeri Met Station: Et=1196.3 mm/yr @ altitude 1815 m
3. *Third Nairobi Water Supply Project, Hydrology Review, 1995*: The results are reproduced in Table 5-22. The "net" evaporation is the loss after taking into account rainfall on the water surface. A sensitivity analysis showed that the supply to Nairobi is not sensitive to the evaporation loss assumed.

The E_t values in Figure 5-71 for S. Kinangop, Nyeri and Thika Dam are the same, irrespective of altitude differences. Hence for the project area reservoirs, adopting the Thika Dam "net" data in Table 5-22 will be conservative.

Table 5-22: Mean Monthly Reservoir Evaporation Estimates at Thika Dam

Month	1986 Study Mean (mm)	1994 Study Mean (mm)	1994 Study "Net" (mm)
January	114	119	100
February	121	124	139
March	125	135	120
April	113	110	0
May	88	91	0
June	71	61	0
July	59	48	41
August	55	52	53
September	92	86	94
October	109	110	93
November	95	83	0
December	112	105	107
TOTAL	**1154**	**1123**	**761**

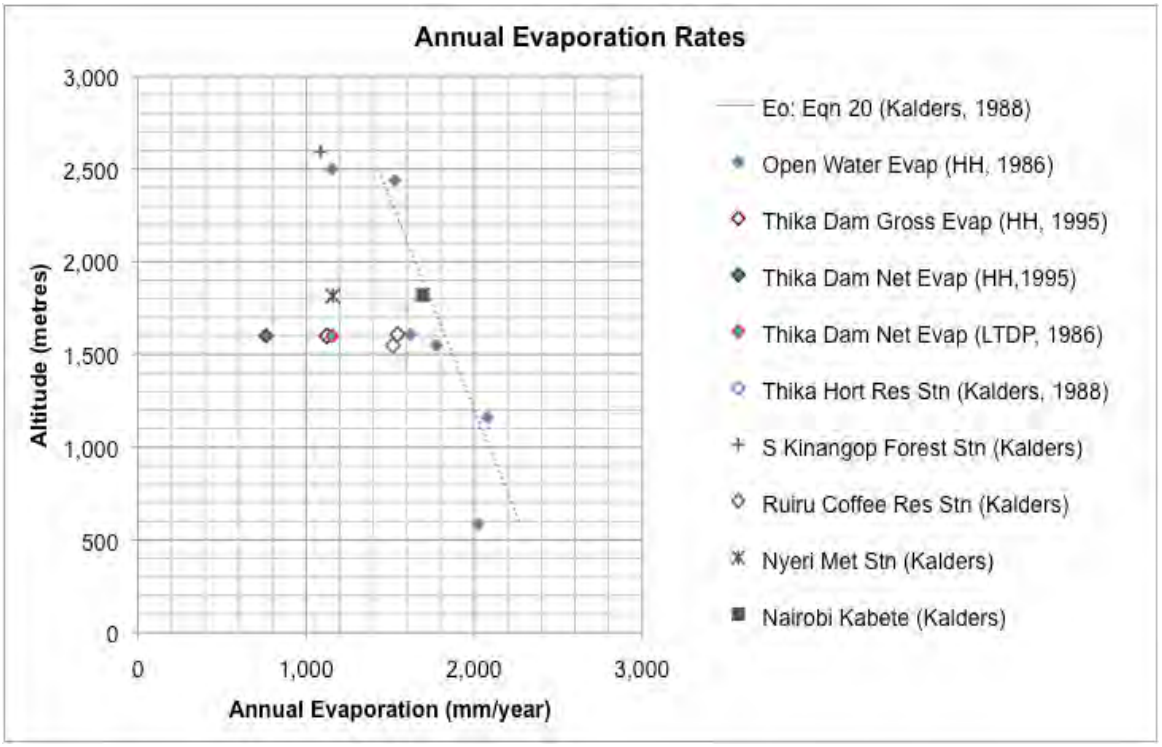


Figure 5-71: Evaporation Data

8.5 Thika Dam Hydrology

8.5.1 Summary of Previous Hydrological Assessment

Thika Dam provides a performance benchmark for the hydrological assessments previously undertaken under the Third Nairobi Water Supply Project. The Thika Dam reservoir was designed on the same basis as the various studies being referenced for this study, and the reservoir has since been in operation several years, with operation records collected. These records were obtained from NCWSC.

The original hydrology comprised a simulated sequence of flows based on river flow measured by RGS 4CB5 upstream of the Thika dam, plus the flow contribution between the gauge and dam, this contribution being estimated as 22% of the flow reaching RGS 4CB4 downstream of the dam (HH, Short Term Plan, Vol.IV, App.C, Table C.7). The flows were naturalised, and the simulation equation was:

Q(Thika 6) = Q(4CB4) + (0.22 x Thika direct flow)

A naturalised flow sequence from 1976-84 was thereby derived (ibid, App.C.12.1). A gauging station was established at the dam site and measurements taken from 1980-82 (Station RGS 4CB8). Good correlation with the simulated sequence was reported (ibid., Figure C.10).

A longer simulated flow sequence was presented in 1986 in the Long Term Development Plan. This was later extended in 1998 in the Northern Collector Feasibility Report. A summary of findings is presented below.

8.5.2 Updated Assessment of Thika Dam inflows

There are four streams feeding into the Thika Dam, one of which can be ignored, as the flows are negligible (Pers. Comm. NCWSC). Three streams were initially measured after the dam was constructed, but due to gauge maintenance challenges, all stations have been abandoned apart from RGS 4CB5, which is today observed daily by operational staff from the dam. This gauge is reported by NCWSC to capture 50% of the dam's total inflow. The data is provided to WRMA. Data for RGS 4CB5 is current.

Figure 5.72 on page 5-79 shows the excellent correlation that was previously established between the RGS 4CB5 flow and the dam inflows measured not far downstream at RGS 4CB8. This was to be expected.

Figure 5.73 on page 5-79 is a plot of coincident daily flows at RDGS 4CB8 and 4CB5, together with the following straight-line relationship adopted by the dam's operational staff:

Q Thika 6 = Q (4CB8) = 2 x Q (4CB5)

Hence the dam inflows are assumed to be double the flow measured at RGS 4CB5.

The 4CB5 data since 1997 is plotted in **Figure 5-75** on page 5-80. The average daily flow of this sequence calculated to be 2.42 m^3/sec. This is identical to the value presented in the 1998 Northern Collector Feasibility Report, and is very close to the value derived by the 2011 BRLi/Seureca study.

The Kandara Water Supply abstraction upstream of RGS 4CB5 (0.40 m^3/sec) has been taken into account in Table 5.23, based on assumed rather than measured abstraction. The measured runoff into the dam in Figure 5-75 has fluctuated about the period mean, with no visually apparent deviation, which tends to confirm that upstream abstractions remained the same.

Table 5.23: Thika Dam Mean Annual Inflow (MAI)

Period	Naturalised MAI[6] m^3/sec	Upstream Abstraction[5] m^3/sec	Net MAI [6] m^3/sec	Source of flow data
1946-77	2.62 [1]	0.40	2.22	HH, Stage 1 Report, 1979
1946-84	2.46 [3]	0.40	2.06	HH, Long Term Plan, 1986, Table 7.11& Appendix E
1950-92	2.82	0.40	2.42[2]	HH, N. Collector Feasibility Report, vol.2, Appendices, 1998
1977-10	2.82	0.40	2.42	NWSC / WRMA data, based on RGS 4CB5. Data analysis by EBI/MIBP JV
1997-10 1946-10	(2.80) [4] (3.09) [4]		2.40 2.69	BRLi/Seureca Hydrological Study, 2011, Table 24: • Operation data 1997-2010 • Simulation 1946-2010

Notes:
1. *Assume MAI=2.11x4CB5*
2. *Thika natural inflows (less Kandara Water Supply abstractions)=76.33 MCM = 2.42 m^3/s*
3. *Appendix E, LTDP, Hydrology Appendices*
4. *Value naturalised by this study*
5. *Kandara Water Supply (dates from the 1980s)*
6. *MAI-Mean Annual Inflow*
7. *HH=Howard Humphreys*

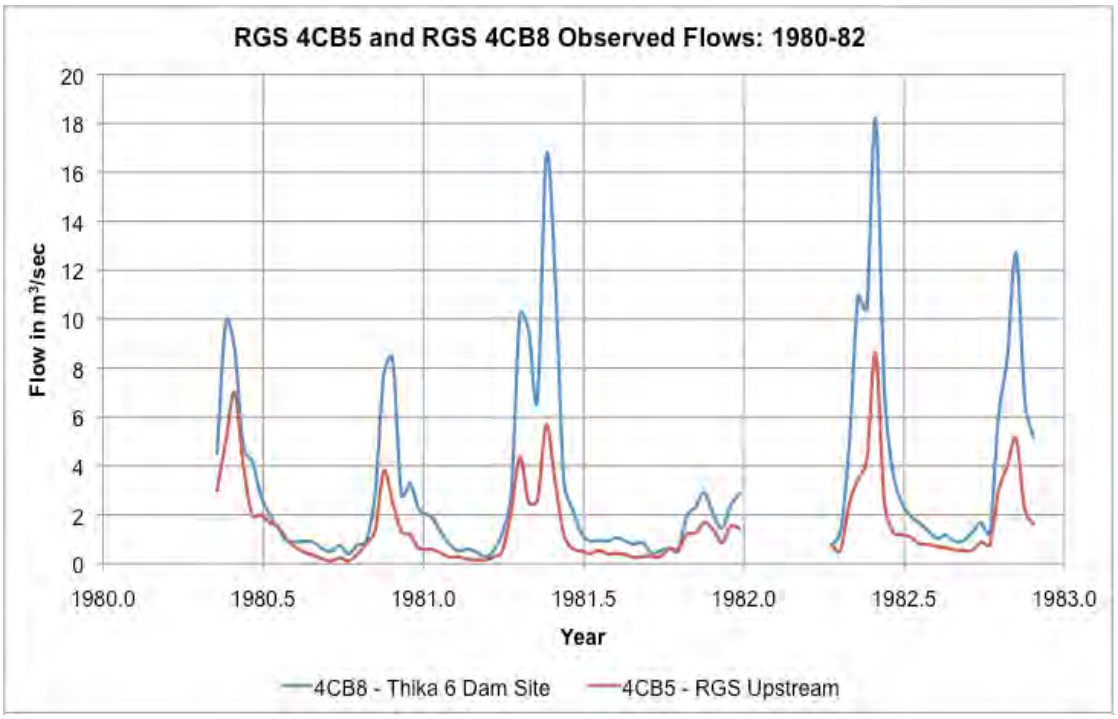


Figure 5.72: Correlation between RGS 4CB5 flows and Thika dam inflows

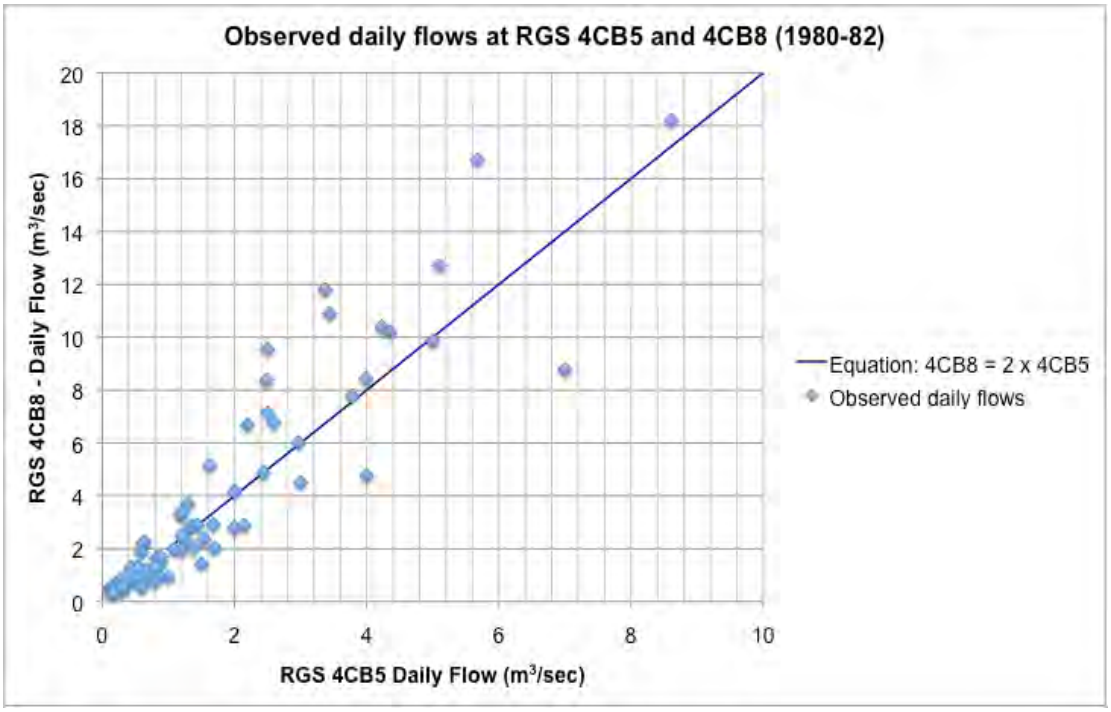


Figure 5.73: Observed Daily Flow Correlation – RGS 4CB5 and RGS 4CB8

8.5.3 Thika Dam Inflows

Inflow data for Thika Dam was obtained from the Nairobi City Water & Sewerage Company (NCWSC). In **Figure 5-74** the inflows are plotted as a ratio of the simultaneous RGS 4CB5 flow. There are many spurious readings. Based on earlier analysis, the expectation was that the ratio would be '2' throughout, which is not the case. Also, the inflow and outflow data does not balance, with outflow total exceeding inflow. To remove obvious anomalies, consistency has been achieved by applying the factor '2' throughout the sequence. The corrected inflow sequence is presented in **Figure 5-75**.

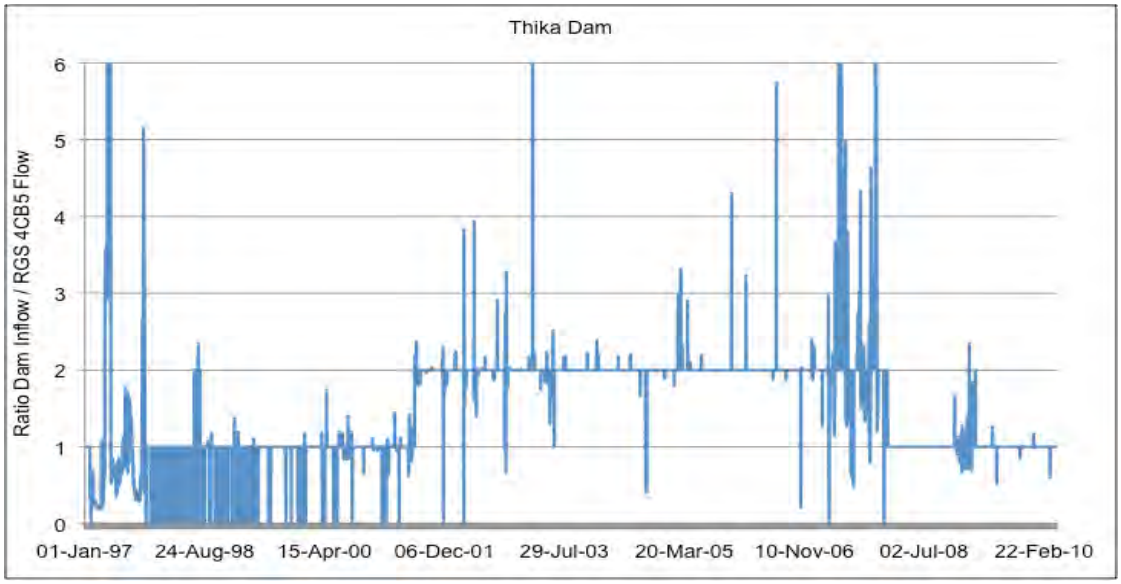


Figure 5-74: Thika Dam – NCWSC Inflow as Proportion of RGS 4CB5 Flow

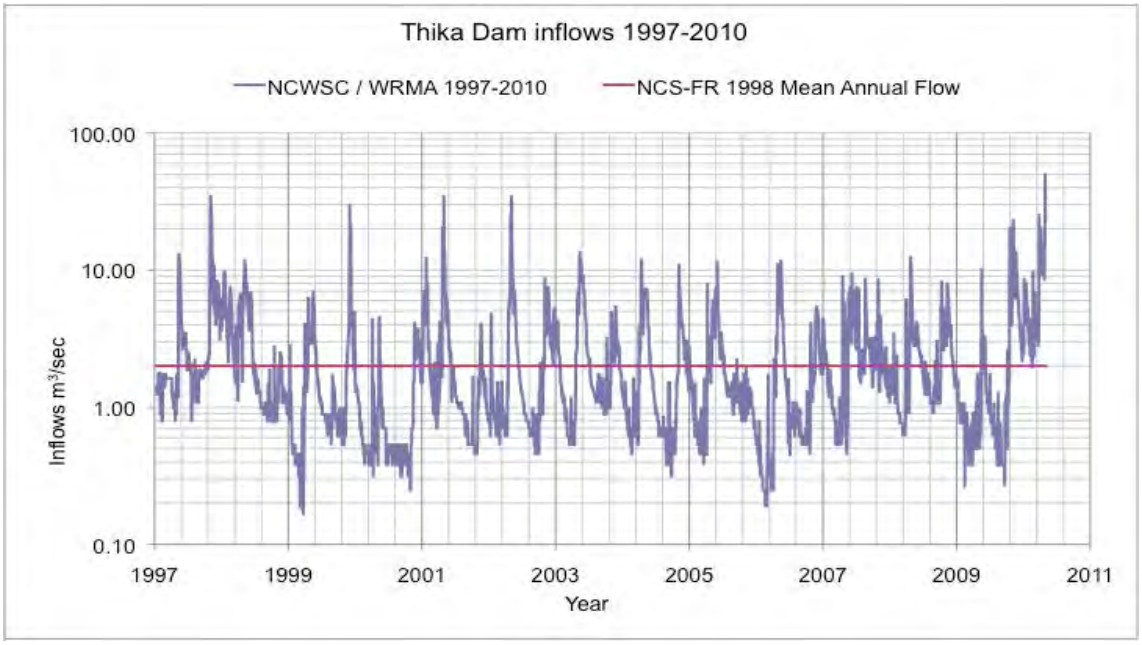


Figure 5-75: Thika Dam Inflows Since Commissioning (2 x RGS 4CB5 flow)

Figure 5-76 presents the Thika Dam downstream release record provided by the Dam Operator NCWSC. The record shows adherence by the Dam Operator to the agreed Thika reservoir operating rules in regard to compensation flow throughout.

Until 2009, the compensation flow was set at 0.250 m^3/sec. Based on the present analysis of RGS 4CB5 flows, assuming that Dam Inflow MAI = 2 x RGS 4CB5 flow, the 0.250 m^3/sec release equates to the 99.9% exceedence flow (equivalent 4CB5 flow 0.125 m^3/sec in Figure).

After 2009, AWSB and WRMA agreed to reduce the compensation flow to 0.124 m^3/sec. This flow value equates to the lowest flow in the river, with exceedence almost 100% (equivalent flow 0.062 m^3/sec in Figure 5-75). The consequence of flow sustained at this very low level on the aquatic ecology below the dam will be interesting to assess.

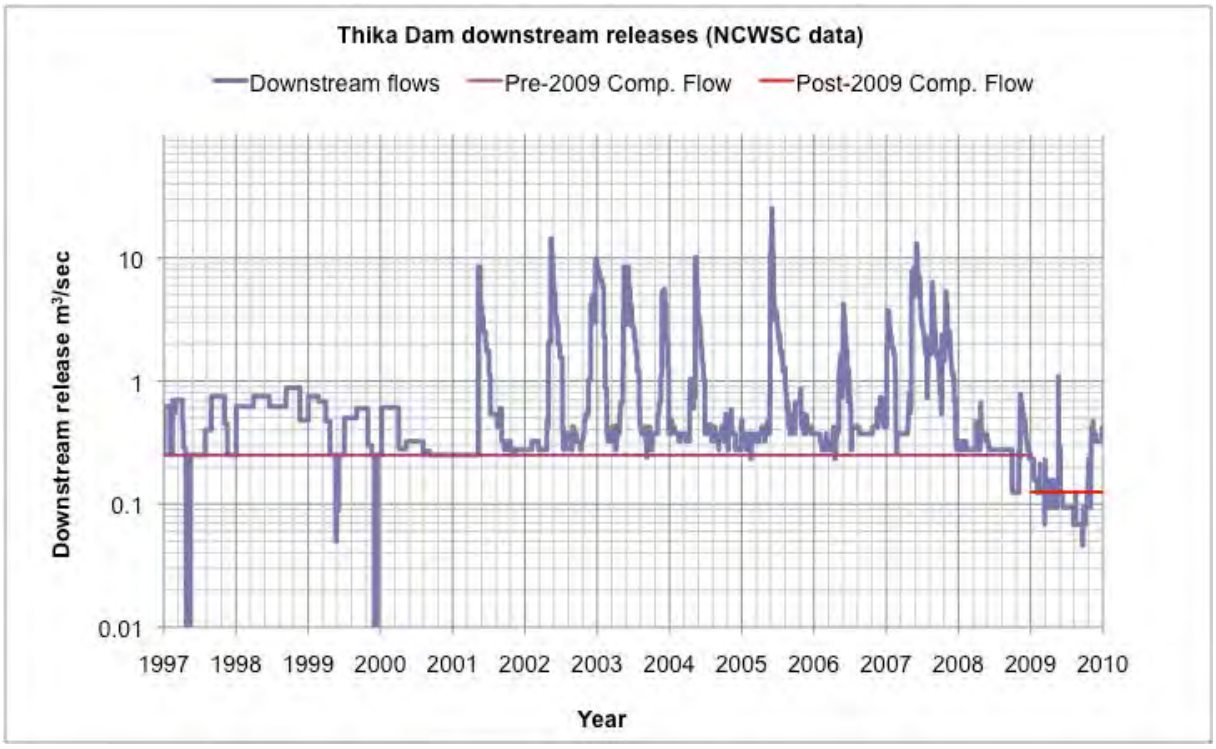


Figure 5-76: Thika Dam - Downstream Flow Releases

8.5.4 Thika Dam – Storage Change with Time

Thika Dam stores 70 $M.m^3$ of water, with live storage 68.5 $M.m^3$, 1.5 $M.m^3$ being set aside for sediment deposition. A recent sedimentation study commissioned by WRMA has reported that there has been no change to the dam's storage volume (Antonaropoulos and Associates, 2010).

Figure 5-77 on page 5-82 shows the drawdown record for Thika Dam, showing the periods during which yields were sustained through drawing from storage. Two "critical drawdown" periods are evident.

The long-term daily time series at RGS 4CB5 is presented in **Figure 5-79** on page 5-83. The record dates from 1950. The influence of the Kandara Water Supply scheme abstraction is very evident in the chart. In the early years prior to the 1980s, the low flows at RGS 4CB5 were "stronger". The Kandara Water Supply was commissioned in the early 1980s. The scheme

abstracted 0.18 m^3/sec in 1995, forecast increasing to 0.30 m^3/sec (HH, Hydrology Review, Table 8.1, 1995). The diminished RGS 4CB5 low flows evident on the chart since the 1980s are consistent with the Kandara Water Supply abstraction rate upstream (in Figure, the year 1980 on the X-scale = 30 x 365 days = 10,950 days).

The two "critical drawdown" periods recorded at Thika Dam are summarised in Table 5-24. The "drawdown period" was assumed to start once the reservoir level fell below 2041 masl, and to end when this level was restored. The critical drawdown was almost 3 years.

Table 5-24: Thika Dam – Critical drawdown periods

Critical drawdown period	1998 -2001	2008-2010
Number of consecutive days of drawdown	1008 days	847 days
Number of months consecutive drawdown	33.1 months	27.8 months

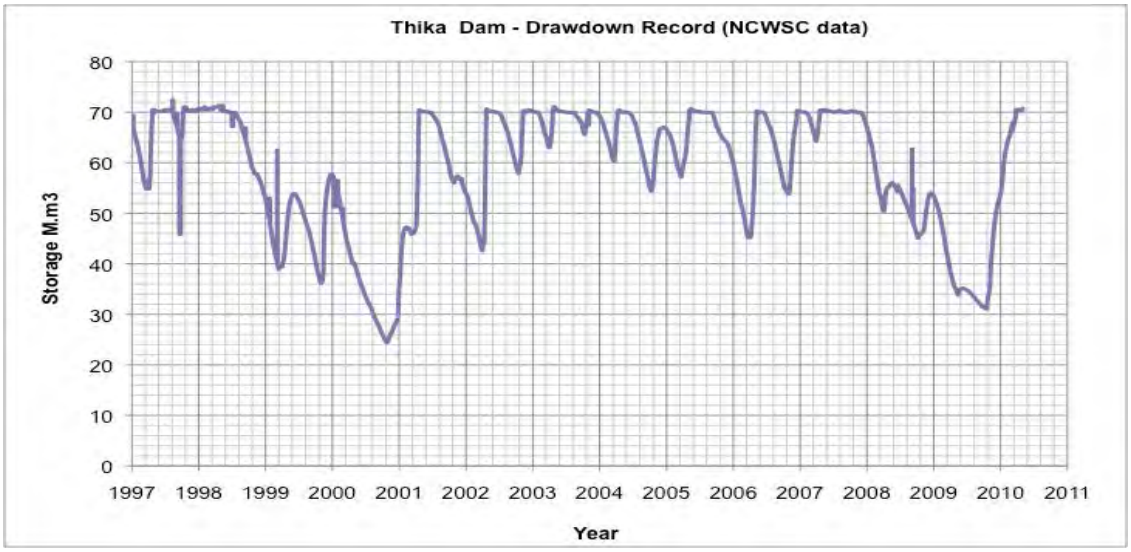


Figure 5-77: Thika Dam – Storage Changes With Time

8.5.5 Thika Dam – Tunnel Discharges

Figure 5-78 on page 5-83 presents the record of water diverted from the Thika dam. The water is diverted through the tunnel to supplement the Kiama River in the adjacent catchment, which is in turn diverted by tunnel under Kimakia River to supplement the adjacent Chania River flow. The Chania River through its Mwagu Intake then supplies the Ngethu Water Treatment Plant, which supplies Nairobi.

An average tunnel discharge of 1.35 m^3/sec was sustained during the two critical periods analysed, without failure – see Table 5-25. This yield equates to 56% of the mean annual inflow (MAI) to the reservoir.

Table 5-25: Thika Dam – Yield During Critical Drawdown Periods

Critical Drawdown Period	1998 -2001	2008-2010
Yield to tunnel in the critical period	1.387 m^3/s	1.319 m^3/s
Yield as percent mean annual inflow	57%	54%

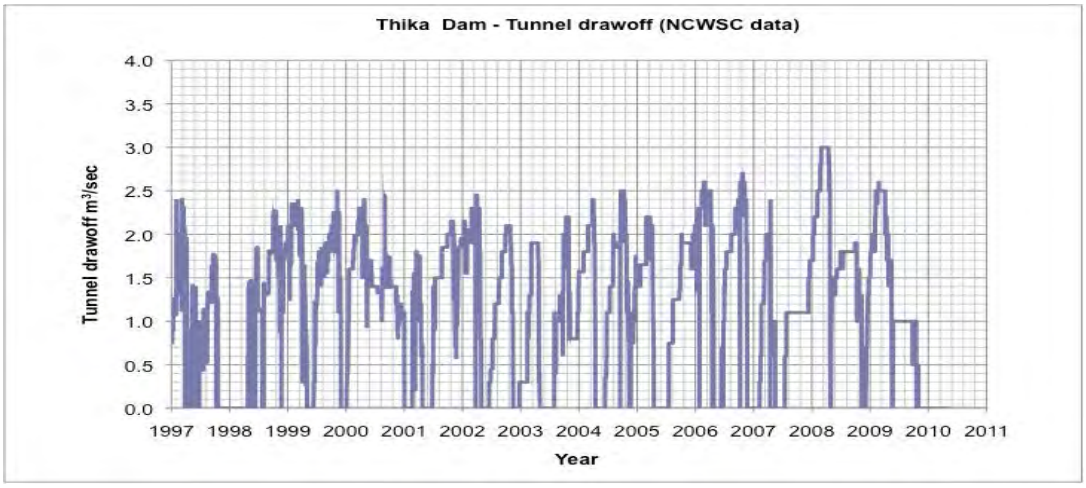


Figure 5-78: Thika Dam - Tunnel Drawoff Record

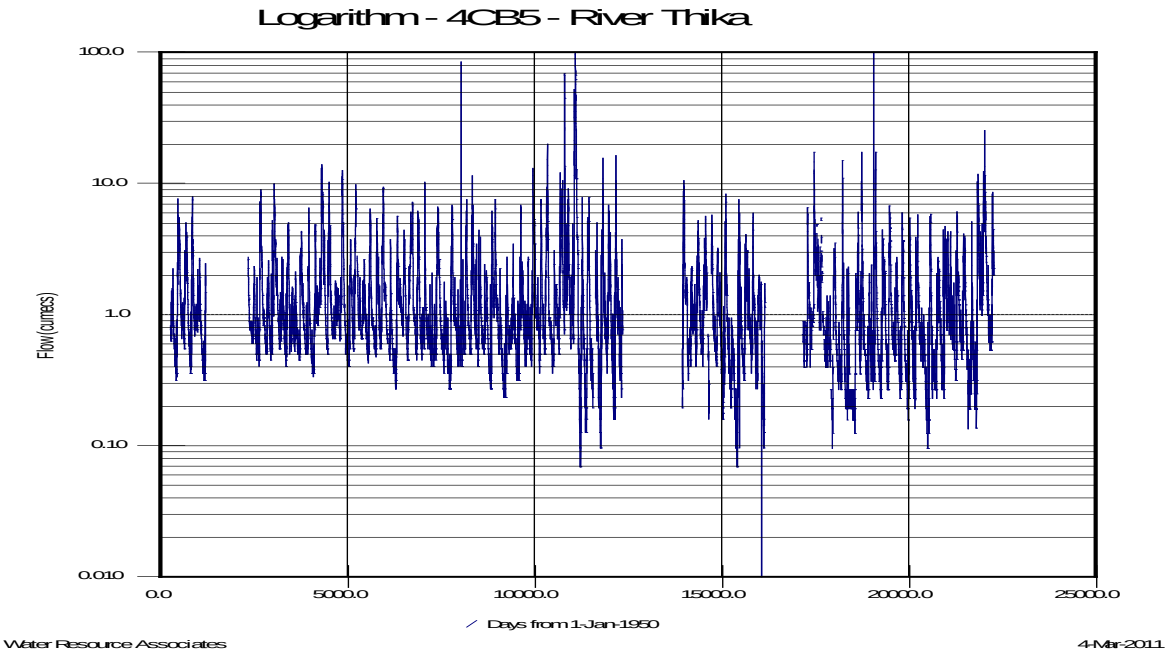


Figure 5-79: RGS 4CB5 actual record – 1950 to 2010

8.5.6 Thika Dam – Simulation Using 1997-2010 Flow Record

Figure 5-80 presents a simulation of the reservoir for two hypothetical constant draw-off rates (in practice, this does not happen, as the tunnel releases vary according to demand at Mwagu Intake).

Figure 5-81 presents the yield / storage drawdown relationship for the 1997-2010 record. The "reliability" in the graph is the number of months failing to meet full supply, expressed as a percentage of the total number of months in the record. The constant "yield" at 90% reliability over this record period would have been 2.36 m^3/sec, and the reservoir would not have spilled for over ten years. This is greater than the design yield derived in 1986, which was 1.70 m^3/s + 0.25 m^3/s compensation = 1.95 m^3/sec gross. The 1986 yield was based on a differing definition of reliability as discussed earlier.

It was reported earlier (Chapter 9, Version 02, Water Sources Options Review Report, August 2011) that the yield calculated by the WEAP Model (v2) with the equivalent reliability definition is 2.20 m^3/s, which is larger than the 1986 computed yield, but this is consistent, as the measured mean annual inflow (MAI) was higher than assumed in 1986 in the proportion 2.42 / 2.06.

Also presented in **Figure 5-81** on page 5-85 is the yield derived from the earlier generalised yield/storage relationship established for RGS 4CB5 (Stage 1 Report, 1979). The mean annual inflow based on that record was 2.22 m^3/sec. This earlier yield is larger than the 1986 yield, which was depressed because of inclusion of the 1984 drought. The generalised yield/storage relationships from the 1979 study used different methodology, namely the Rippl Method, but are a very useful conservative estimation method applicable still today.

The mean annual inflow over the period 1997-2010 was higher than the average yield derived in the design simulations. Provided there are no changes upstream of the reservoir, and provided there are no added abstractions upstream, the design "yield" can be expected to sustain.

The "spill" during the 1997-2010 simulated record was no more than 0.28 m^3/s daily, about 11% of the calculated yield only.

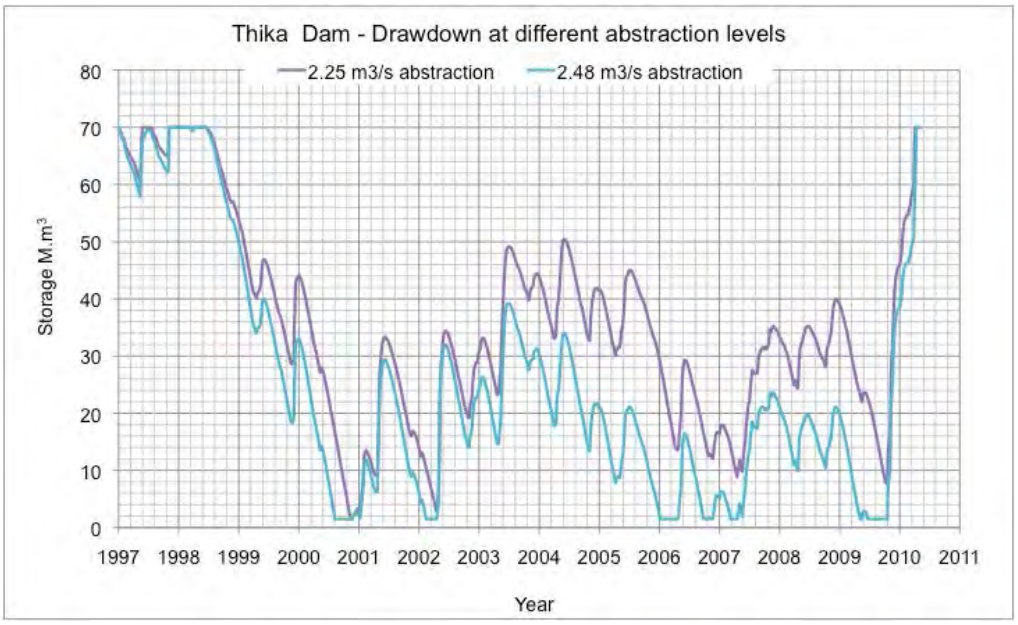


Figure 5-80: Thika Dam simulation – 1997 to 2010 data

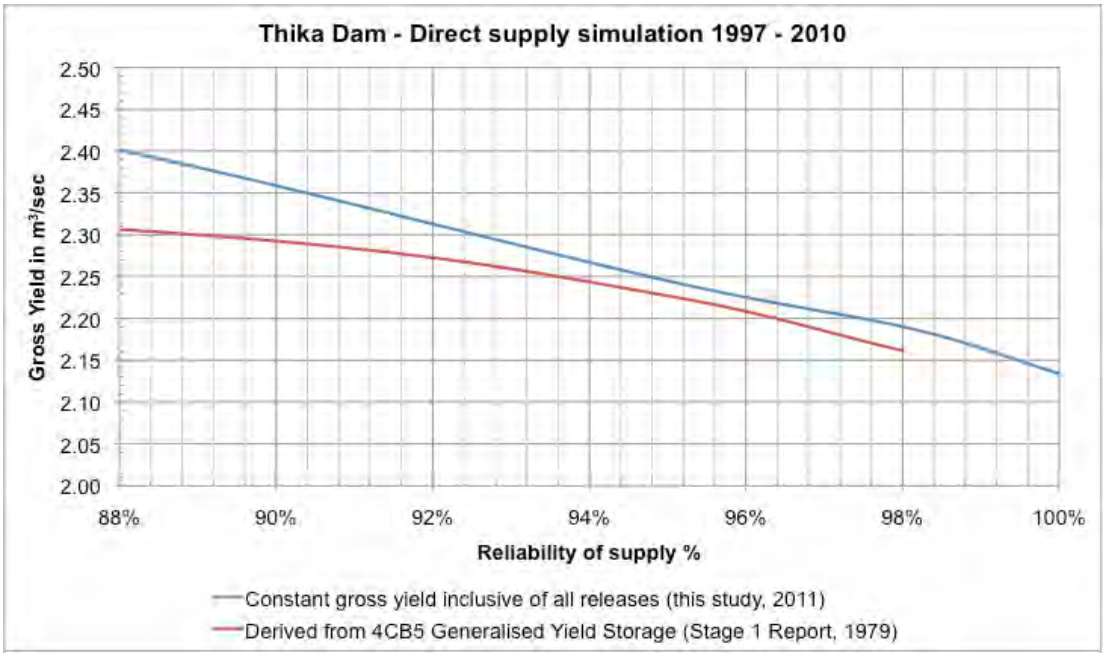


Figure 5-81: Thika Dam – Gross Yield Reliability, 1997 to 2010

8.5.7 Thika Dam – Comparison of Yields With Earlier Studies

Figure 5-82 on page 5-86 was the comparison of Thika Dam yield estimates presented earlier (Egis/MIBP, August 2011). The 1979 assessment was based on the generalised yield / storage relationship presented for the naturalised RGS 4CB5 flow data (Stage 1 Report, Part 2B). The yield methodology was based on the Rippl Method, and hence was different. The 1980 Thika-Chania "direct supply" yield assessment differs slightly, but is otherwise similar. The estimated reservoir yield was reduced appreciably in the 1986 Long Term Development Plan following the 1984 severe drought.

The 1997-2010 assessment (this Study) is plotted as a single point on the graph below, falling intermediate between the curves plotted, but very close to the "1979" curve. The yield is "net". Hence, this yield is shared between abstraction and downstream release (the 1979 curve is "gross" and based on different methodology). Note that the reliability definition also differs between this study and the previous studies. The effect of this is demonstrated with the WEAP Model results elsewhere in this report, and the final adopted yield storage curve based on World Bank preferred methodology is presented in the WEAP Model (v2) results presented in a separate Chapter.

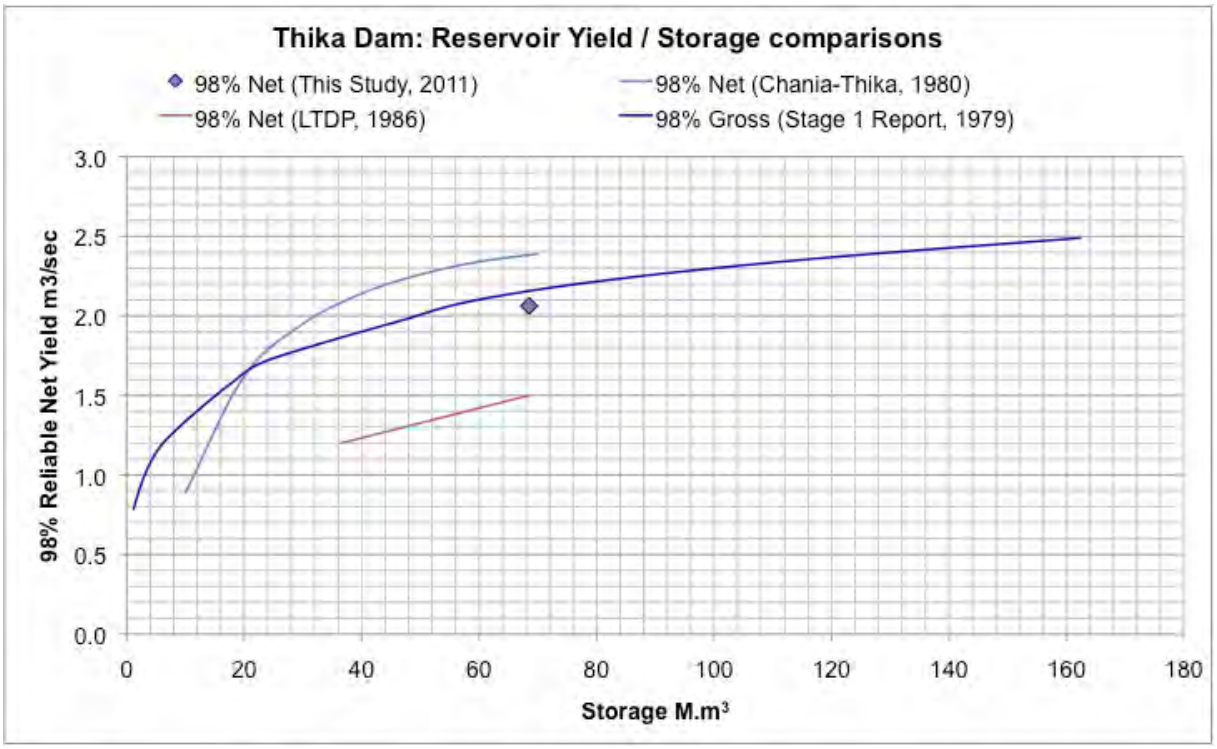


Figure 5-82: Thika Dam – Comparison of 1997-2010 Yield with Earlier Estimates

8.6 Maragua Dam Hydrology (Maragua 4)

AWSB has been considering the development of a reservoir at the site previously identified as Maragua 4. The site was among many sites reported in 1986, and is located to the north of Thika Dam within the Tana Basin. The proposed reservoir site is downstream of the confluence of the Gikigie and Little Maragua Rivers, whose flows are measured respectively by RGS 4BE8 and RGS 4BE9. These rivers are amongst the many rivers that rise in the moorlands and forests of the Eastern Aberdare Mountains. The combined catchment area of the two rivers is the same size as the Thika Dam catchment, and the catchments share similar land usage, topography, soils and geology. However, the northern rivers drain a higher rainfall area of the Aberdares, and hence the unit runoff is higher than in the Thika Dam catchment (see Table 5-18, RGS 4BE8 and 4BE9).

The Maragua 4 reservoir inflow is a function of the sum of flows measured at RGS 4E8 (Gikigie River) and RGS 4BE9 (Little Maragua River), the transposition relationship being tabulated in Table 5-5 and Table 5-6. This study has had some difficulties with the daily river flow data for these gauges, but infilled and extended sequences were derived. The resultant daily flow sequences for the gauging stations were combined and transposed to the proposed dam site, and the resultant inflow sequence is presented with the WEAP Model (v2) reported elsewhere.

Note that the elevation/area/ storage has been derived from topographical survey undertaken during this study – presented in **Figure 5-83** on page 5-87. The yield storage relationship for the dam site has been studied through the WEAP Water Balance Model (v2) analysis presented in a separate chapter. To determine “net” yield, deductions will be made for forecast upstream abstractions, for the adopted compensation release derived from the water demand and ecological assessments, and for seepage losses. It will be necessary to take account of proposals to construct a new intake upstream to abstract 0.28 m^3/sec for the Murang’a North

and Murang'a South Water Supply Project (Howard Humphreys 2010). If there are any other planned abstractions, these will also need to be deducted.

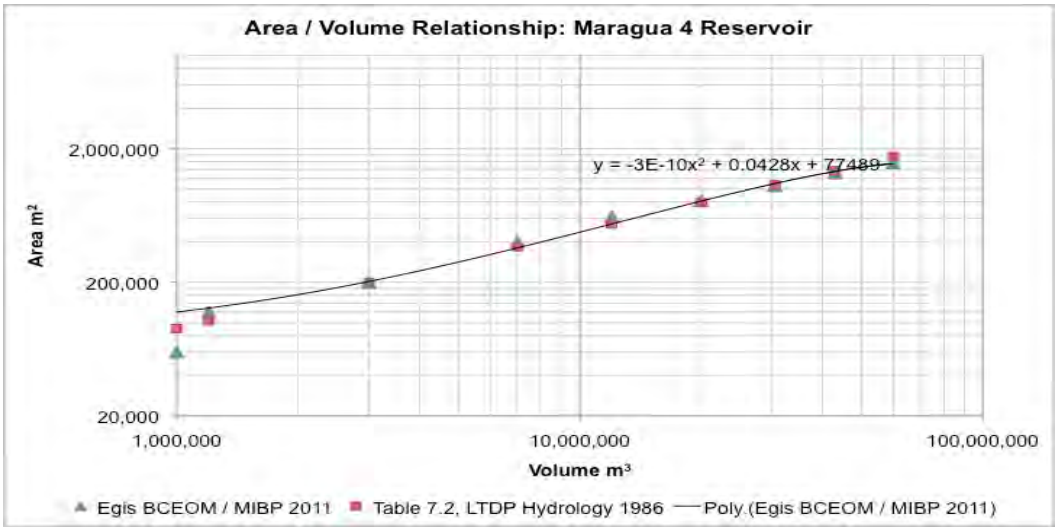


Figure 5-83: Surface Area / Volume Relationship – Maragua 4 Reservoir

9 Reservoirs to Serve Satellite Towns

9.1 Methodology for Yield Assessment

Various potential reservoir sites were presented in Chapter 5 of the Water Sources Options Review Report Version 02 (Egis/MIBP, August 2011) together with the impounded area and storage potential of each site derived from contours available on 1:50,000 topographical maps. Also presented were the available generalised 90% Reliable Yield/Storage relationships for selected river gauging stations in Sub-Basins 4CA and 4CB derived from the Howard Humphreys Stage 1 Reports (HH, Stage1, 1979) – see **Figure 5-84** on page 5-88. These generalised relationships were derived from historic river flow data. The relationships are non-dimensional, with yield and storage expressed as a proportion of the mean annual flow. Based on comparison with recent data for Thika dam above (in Sub-Basin 4CB), these generalised relationships were found to be still representative.

It was earlier reported that that the proportion of storage that is required increases with the decreasing unit runoff that occurs as one progresses south towards Nairobi (Egis/MIBP, 2010). The existing Thika Dam has a live storage equating to 90% of the mean annual flow, and the yield obtainable is 90% of the mean annual flow. For the southern rivers, a yield approaching the mean annual runoff requires storage of a very much higher proportion of the mean annual runoff. In the case of RGS 4CA19, the proportion is 300%.

Equivalent relationships for reservoirs close to Nairobi in Sub-Basin 3BD, 3BC and 3BA have been further developed in this report for master planning purposes only, as follows. The 1979 generalised relationships have been developed further by analysing annual flow sequences at selected sites and applying the Gould-Dincer methodology described by McMahon (McMahon et al, 2007). Good correlation is displayed in the various graphs listed below, although becoming less so with storage levels with increasingly smaller proportion of MAI. This departure is to be expected with annual flow sequences.

It has been concluded that the following graphs will usefully serve the purpose of assessing the yield / storage relationships at master planning level.

- **Figure 5-85**: Standardised **Yield** / Storage in Sub-Basins 4CA and 3CB
- **Figure 5-86**: Standardised **Yield** / Storage in Sub-Basins 4BE, 4CB, 3BC
- **Figure 5-87**: Standardised **Yield** / Storage in Sub-Basin 3BC
- **Figure 5-88**: Standardised **Yield** / Storage in Sub-Basins 3AA, 3BA, 3BB, 3BC

Should any of the reservoir sites be considered for development, more detailed hydrological assessments would be of course be required based on an extensive data collection programme.

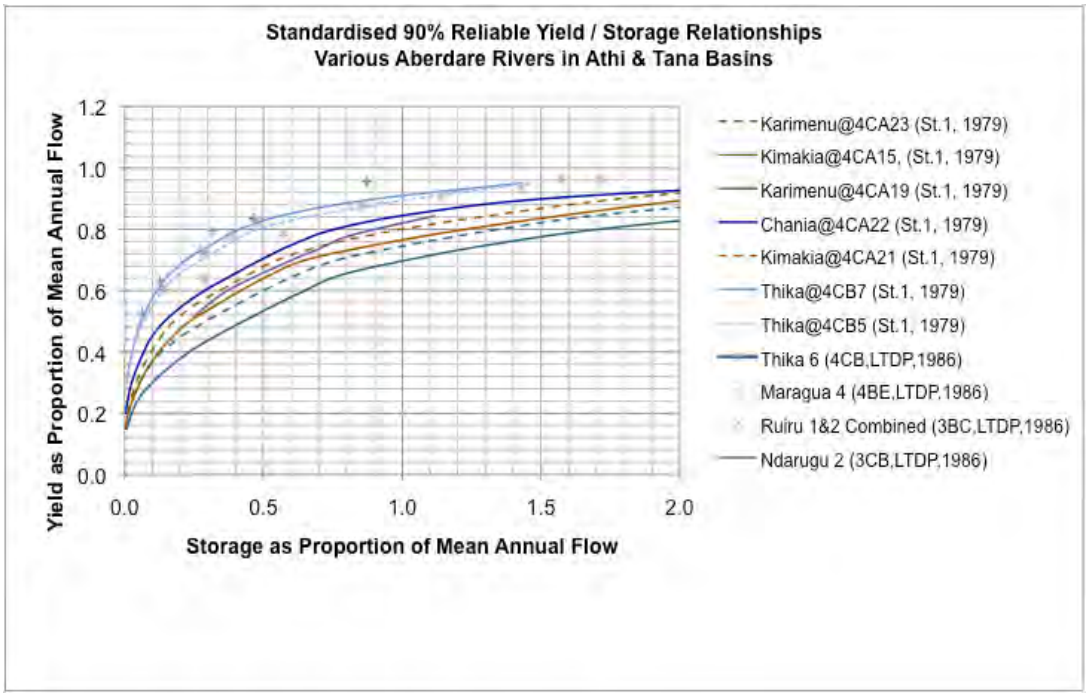


Figure 5-84: Standardised Yield / Storage Relationships in upper Athi & Tana Basins (Egis/MIBP, 2011)

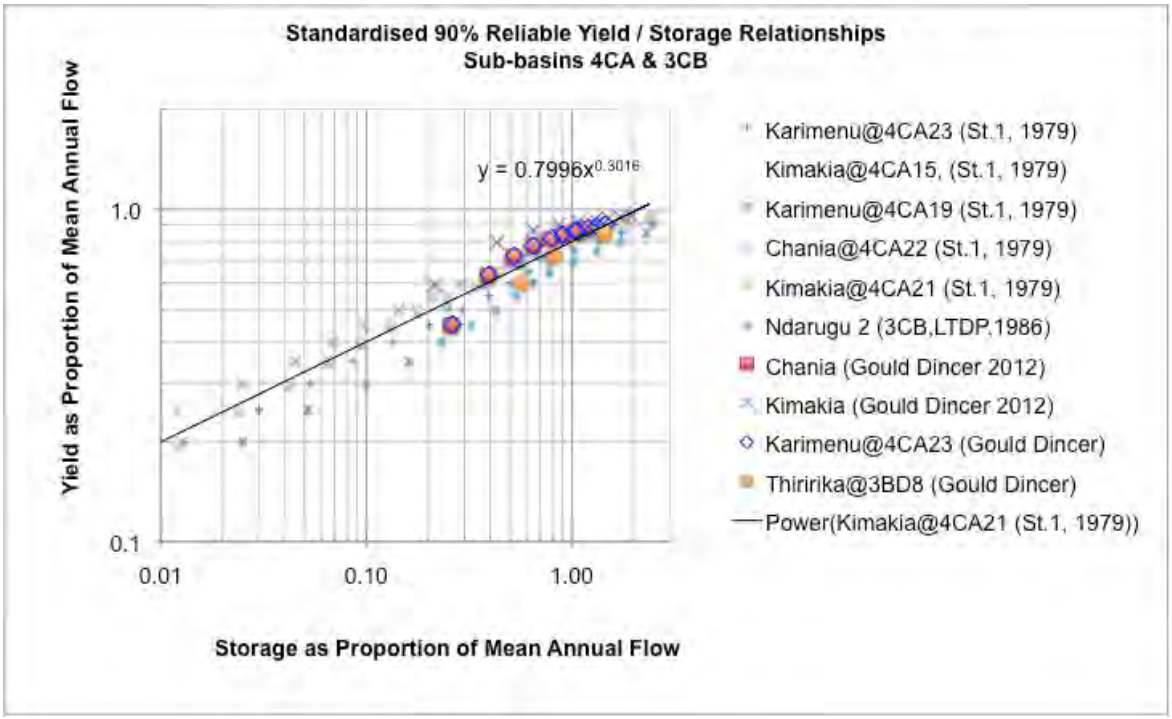


Figure 5-85: Standardised Yield / Storage in Sub-Basins 4CA and 3CB

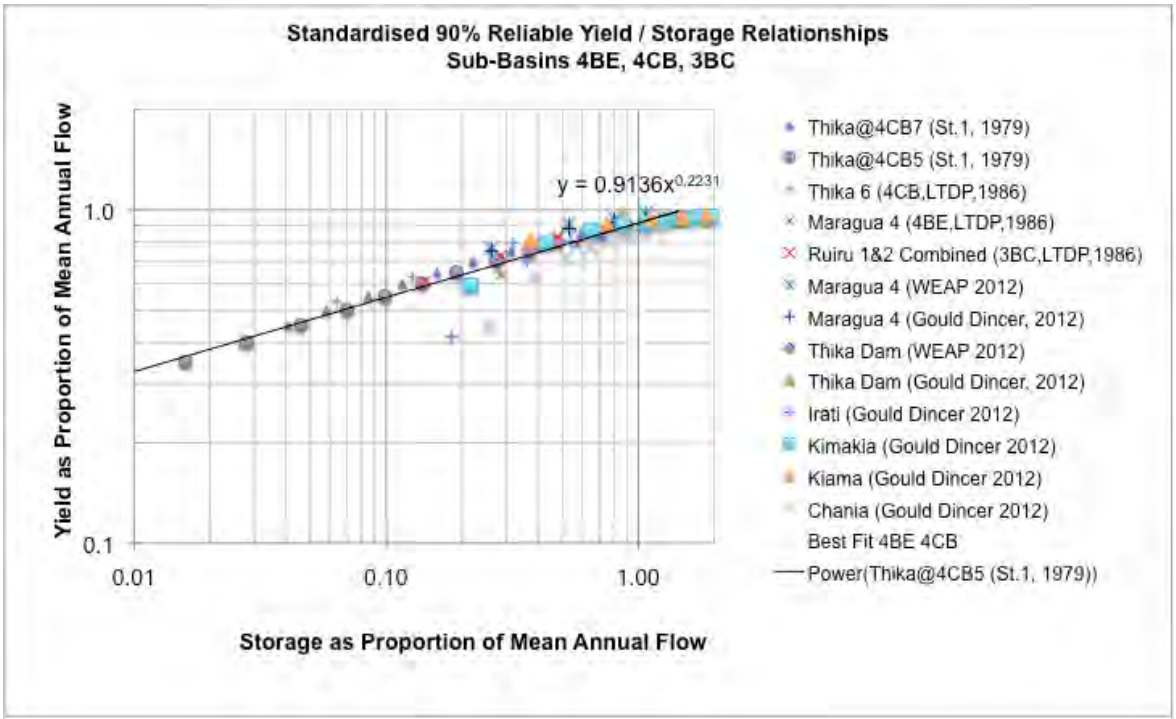


Figure 5-86: Standardised Yield / Storage in Sub-Basins 4BE, 4CB, 3BC

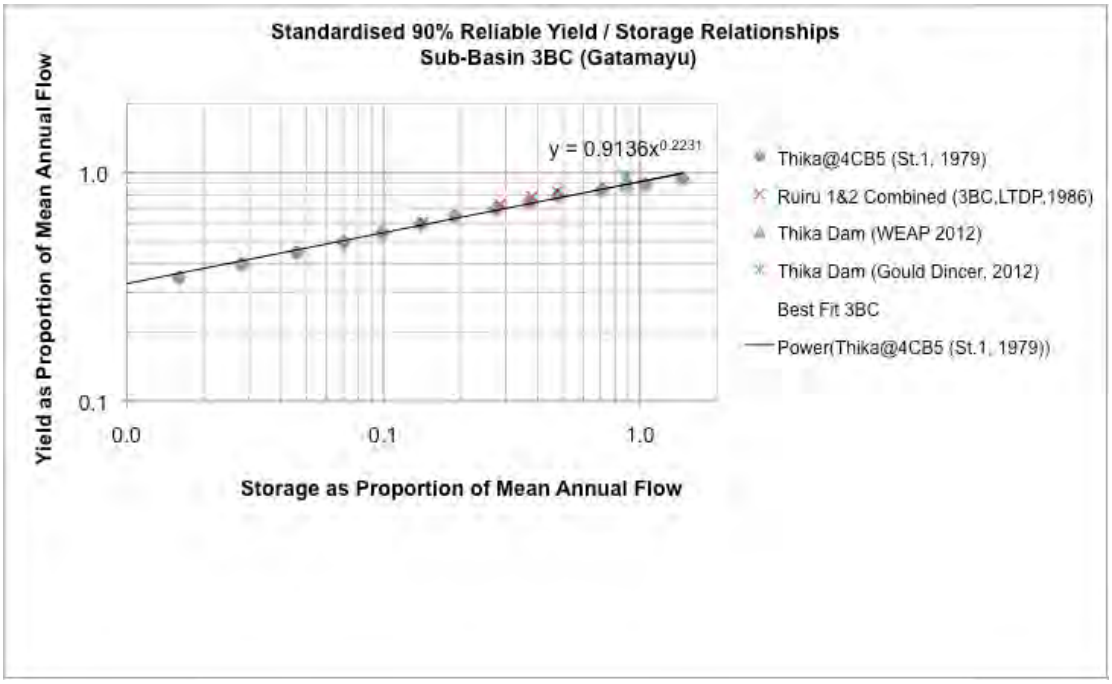


Figure 5-87: Standardised Yield / Storage in Sub-Basin 3BC

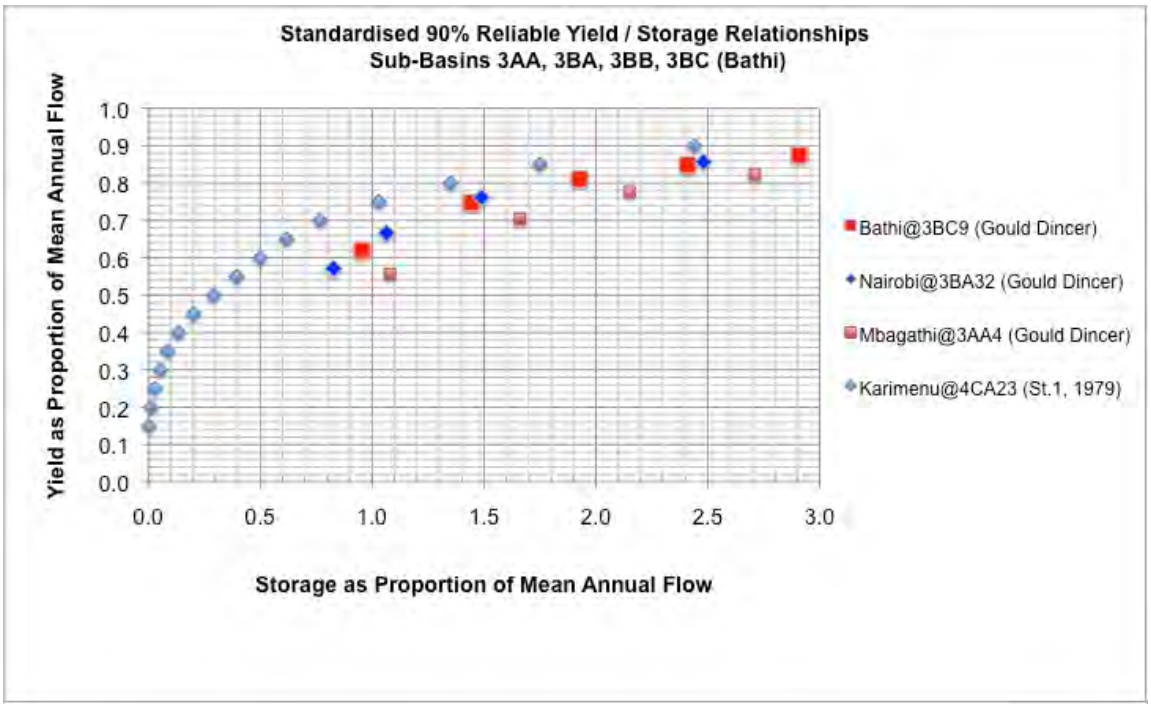


Figure 5-88: Standardised Yield / Storage in Sub-Basins 3AA, 3BA, 3BB, 3BC

9.2 Yield Assessment for Reservoirs to Serve Satellite Towns

Table 5-26 provides a preliminary estimate of the gross yield of various small dams derived from the generalised yield / storage curves. Feasible dam sites were identified by the engineering team, and the catchment area (Area) and mean annual inflow (MAI) estimates are tabulated in Column 1 of the table.

MAI is derived from earlier analysis presented in **Figure 5-12** to **Figure 5-19**.

The net yield can be determined from the table by deducting downstream needs, which can be initially based on the tabulated 95% exceedence daily flow Q95. For comparison purposes, Q95 as %MAI is also tabulated, as is the flow value 10% MAI. In the stronger baseflow Northern Collector Rivers, Q95 is a much higher proportion of MAI than in the weaker baseflow / more seasonal southern rivers. Hence the Q95 criterion might warrant review in the southern rivers, as in practice such dams might be designed to enhance the low flows to a level higher than normal.

Q95 is derived from earlier analysis presented in **Figure 5-59** to **Figure 5-63**.

Note that the actual site yields will be based on the topographical and geotechnical constraints determined by the Dams Engineer, which is not included in this chapter.

The yields of the Northern Collector dams are analysed as part of the water balance modelling and system yields reported elsewhere in the water balance modelling sections of this report.

Table 5-26: Yield at Selected Reservoir Sites

Site Details	Dam Ht (m)	Cum. Stored Vol. ($M.m^3$)	90% Gross Storage /MAI	90% Gross Yield/ MAI	90% Gross Yield (m^3/s)	Comp Q95 (m^3/s)	Comp Q95 as %MAI (%)	Comp 10% MAI (m^3/s)
Karimenu 2	15	1.055	0.022	0.254	0.381			
4CA	20	2.202	0.047	0.317	0.476			
Area=89km^2	25	3.936	0.083	0.378	0.567			
MAI=1.5m^3/s	30	6.368	0.135	0.437	0.655			
	35	9.721	0.205	0.496	0.744			
	40	14.234	0.301	0.557	0.835	0.300	20%	0.150
Ndarugu 3	15	0.194	0.011	0.204	0.116			
3CB	20	0.431	0.024	0.260	0.148			
Area=29km^2	25	0.953	0.053	0.330	0.188			
MAI=0.57m^3/s	30	1.974	0.110	0.411	0.234			
	35	3.471	0.193	0.487	0.278			
	40	5.409	0.301	0.557	0.317			
	45	7.877	0.438	0.623	0.355			
	50	11.184	0.622	0.693	0.395	0.090	16%	0.057
Ruabura	15	0.220	0.011	0.208	0.127			
3CB	20	0.566	0.029	0.276	0.168			
Area=34km^2	25	1.277	0.066	0.353	0.215			
MAI=0.61m^3/s	30	2.433	0.126	0.429	0.261			
	35	4.062	0.211	0.500	0.305			
	40	6.224	0.324	0.569	0.347			
	45	8.989	0.467	0.636	0.388			
	50	12.389	0.644	0.700	0.427			
	55	16.427	0.854	0.762	0.465			
	60	21.122	1.098	0.822	0.502			

Site Details	Dam Ht (m)	Cum. Stored Vol. ($M.m^3$)	90% Gross Storage /MAI	90% Gross Yield/ MAI	90% Gross Yield (m^3/s)	Comp Q95 (m^3/s)	Comp Q95 as %MAI (%)	Comp 10% MAI (m^3/s)
	65	26.533	1.379	0.881	0.537	0.100	16%	0.061
Thiririka	15	0.266	0.013	0.218	0.137			
3BD	20	0.599	0.030	0.278	0.175			
Area=61km^2	25	1.339	0.067	0.354	0.223			
MAI=0.63m^3/s	30	2.700	0.136	0.438	0.276			
	35	4.698	0.236	0.518	0.326			
	40	7.367	0.371	0.593	0.373			
	45	10.701	0.539	0.663	0.418			
	50	14.699	0.740	0.730	0.460	0.068	11%	0.063
Gatamayu 1	10	0.152	0.012	0.341	0.136			
3BC	15	0.463	0.037	0.437	0.175			
Area=29km^2	20	0.958	0.076	0.514	0.206			
MAI=0.4m^3/s	25	1.805	0.143	0.592	0.237			
	30	3.170	0.251	0.671	0.269	0.120	30%	0.040
Gatamayu 2	25	0.728	0.022	0.390	0.409			
3BC	30	1.367	0.041	0.449	0.471			
Area=131km^2	35	2.225	0.067	0.500	0.525			
MAI=1.05m^3/s	40	3.365	0.102	0.549	0.576			
	45	4.958	0.150	0.598	0.628			
	50	7.085	0.214	0.648	0.680	0.310	30%	0.105
Komothai 1	15	0.206	0.022	0.389	0.117			
3BC	20	0.532	0.056	0.481	0.144			
Area=17km^2	25	1.174	0.124	0.574	0.172			
MAI=0.3m^3/s	30	2.163	0.229	0.657	0.197			
	35	3.468	0.367	0.730	0.219	0.090	30%	0.030
Komothai 2	10	0.114	0.009	0.320	0.128			
3BC	15	0.506	0.040	0.446	0.178			
Area=28.7km^2	20	1.270	0.101	0.547	0.219			
MAI=0.4m^3/s	25	2.607	0.207	0.643	0.257			
	30	4.942	0.392	0.741	0.297	0.120	30%	0.040
Ruiru 2	25	1.640	0.050	0.467	0.491			
3BC	30	2.875	0.087	0.530	0.556			
Area=130km^2	35	4.621	0.140	0.589	0.618			
MAI=1.05m^3/s	40	6.903	0.208	0.644	0.676			
	45	9.740	0.294	0.695	0.730			
	50	13.206	0.399	0.744	0.781			
	55	17.408	0.526	0.792	0.831			
	60	22.534	0.681	0.838	0.880			
	65	28.796	0.870	0.886	0.930			
	70	36.369	1.098	0.933	0.980	0.320	30%	0.105
Kamiti 1	15	0.388	0.044	0.140	0.039			
3BB	20	0.891	0.101	0.230	0.064			
Area=18km^2	25	1.704	0.193	0.300	0.084			
MAI=0.28m^3/s	30	2.813	0.319	0.380	0.106			
	35	4.227	0.479	0.460	0.129			
	40	6.762	0.766	0.570	0.160			
	45	10.872	1.231	0.700	0.196			

Site Details	Dam Ht (m)	Cum. Stored Vol. ($M.m^3$)	90% Gross Storage /MAI	90% Gross Yield/ MAI	90% Gross Yield (m^3/s)	Comp Q95 (m^3/s)	Comp Q95 as %MAI (%)	Comp 10% MAI (m^3/s)
	50	16.360	1.853	0.810	0.227			
	55	23.460	2.657	0.860	0.241	0.039	14%	0.028
Kamiti 2	5	0.001						
3BB	15	0.388	0.029	0.100	0.042			
Area=33km^2	20	0.923	0.070	0.180	0.076			
MAI=0.42m^3/s	25	1.717	0.130	0.250	0.105	0.050	12%	0.042
Kamiti 3	15	0.412	0.030	0.140	0.062			
3BB	20	1.090	0.079	0.200	0.088			
Area=35km^2	25	2.215	0.160	0.270	0.119			
MAI=0.44m^3/s	30	3.750	0.270	0.340	0.150	0.050	11%	0.044
Riara	10	0.456	0.047	0.160	0.049			
3BB	15	1.394	0.145	0.260	0.079			
Area=21km^2	20	2.797	0.291	0.360	0.110			
MAI=0.30m^3/s	25	4.700	0.489	0.470	0.143			
	30	7.265	0.755	0.560	0.171	0.030	10%	0.031
Ruiruaka 1	5	0.090						
3BA	10	0.426	0.016	0.100	0.085			
Area=93km^2	15	1.250	0.047	0.160	0.136			
MAI=0.85m^3/s	20	2.892	0.108	0.220	0.187	0.090	11%	0.085
Ruiruaka 2	5	0.035						
3BA	10	0.331	0.034	0.120	0.037			
Area=22km^2	15	1.035	0.108	0.220	0.067			
MAI=0.30m^3/s	20	2.132	0.222	0.320	0.098			
	25	3.710	0.386	0.400	0.122			
	30	5.889	0.612	0.500	0.153	0.030	10%	0.031
Mbagathi Dam	10	1.322	0.038	0.070	0.077			
3BA	15	5.293	0.153	0.190	0.209			
Area=409km^2	20	12.471	0.359	0.310	0.341			
MAI=1.1m^3/s	25	22.986	0.663	0.420	0.462			
WHO MAI 1.36m^3/s	30	36.694	1.058	0.530	0.583			
JICA MAI 1.90m^3/s	35	53.357	1.538	0.680	0.748	0.050 (WHO 0.060)	5%	0.110
Stony Athi	10	0.250						
3AA	15	2.410	0.016	0.050	0.235			
Area=1750km^2	20	8.977	0.061	0.100	0.470			
MAI=4.7m^3/s	25	23.025	0.155	0.200	0.940	0.250 (WHO< 0.260)	5%	0.470
WHO MAI<1.75								
HH MAI 2.8-5.6								
JICA MAI 4.7								

10 Sediment Runoff and Catchment Management

10.1 Thika Dam Sediment Inflow

The Thika Dam was designed on the following basis (Project Definition, HH, 1986):

1. Sediment yield rates assumptions as per Table 5-27;
2. Sediment deposit density = 1.3 T/km^3;
3. Annual unit sediment yield for Thika catchment = 340 T/km^2/year;
4. Average annual sediment volume inflow = 20,000 m^3 = 1M.m^3 in 50 years.

Table 5-27 shows the dramatic impact of changing land usage. Changing from "tea" to "maize" leads to tenfold increase in sediment runoff. Similarly changing from "forest" to "tea".

Table 5-27: Sediment Yield Rates

Vegetation Cover	Sediment Yield Rate (T/km^2/year)
Bamboo	15
Forest	20
Tea	220
Maize	2,000
Pasture	110

Source: Section 7.3, Project Definition, Short Term Plan to 1995, HH, June 1986

10.2 Thika Dam Sediment Inflow

The sediment runoff in the Upper Tana catchment has been studied in detail by a study commissioned by WRMA (Antonaropoulos & Karavokyris, 2010). That study was establishing a monitoring network.

The above WRMA commissioned study included bathymetric studies of existing dams, including the Masinga Dam, Sasumua Dam, and Thika Dam (Ndakaini). The Draft Report included the following findings:

- Previous sediment runoff rates for Masinga Dam varied in the range 1099 to 1,750 T/km^2/yr (ibid, Table 6.6, Draft Report, 2001).
- The bathymetric survey for Masinga Dam produced similar sediment figures to the study undertaken in 1983 by HR Wallingford (ibid, Table 6.3).
- The survey for Ndakaini (Thika Dam) concluded that "sedimentation is not significant and the volume calculated is very close to the original design ".
- The survey for Sasumua reported difficulties, but concluded "sedimentation is not significant".

WRMA's ongoing Upper Tana study will be followed with interest, as monitoring stations are being established, and the results are of relevance to this study's execution.

10.3 Riparian Zone Protection and Water Quality

It would appear that the original sediment runoff design assumptions for Thika Dam have been confirmed. However our recent field inspections revealed grounds for concern in regard to catchment management. Howard Humphreys earlier expressed the same concern (Hydrology Review, 1995).

We have observed riparian areas along rivers being altered by interventions by farmers.

In order to preserve the water resource and the investment in dams, it is fundamental that the riparian zones be protected. Unless this is done, runoff response to rainfall will increase, flood peaks will increase, and sediment runoff will increase. All of these impacts jeopardise the national investment in reservoirs.

Under the Water Act of 2002, the Water Resources Management Rules dated 2007 were issued. These Rules define the riparian zone as the width of the watercourse up to a maximum 30 metres. Within this zone, no unlicensed interference is permitted. Tillage or cultivation is forbidden under the Sixth Schedule of the Rules, as is any activity that "may degrade the water resource". Swamp or wetland drainage can only be undertaken with the approval of the Authority (Fifth Schedule).

The Eastern Aberdare Rivers have characteristic narrow flood plains. In the tea zones, these are often suitable areas for livestock grazing. These flood plains are frequently utilised by farmers, not only through grazing livestock, but through active cultivation as well. In addition, swampy areas adjacent to the river are being drained. The drained areas provide more suitable grazing for livestock, but the destruction of these wetlands means that the sponge / water storage capacity of the swampy areas is being lost, plus the loss of associated swamp vegetation means that the purification qualities of the swampy zones are also being destroyed. These swamps purify through arresting sediment transport. They also attenuate surface water runoff, all to the benefit of the water resource quality.

It is also worth noting that there has been widespread effort to remove Eucalyptus trees from rivers in the project area. This followed a Ministerial directive. If extensive denudation results, there will be increases in runoff and sediment runoff as well. The process of tree clearance needs to be carefully managed. It is also worth bearing in mind that the widespread popular perception that Eucalyptus trees damage the water resources is not supported by data. The Kenya Forestry Research Institute recently advertised the launch of informative booklets on Eucalyptus (Daily Nation, April 11, 2011). The following statements are worth reproducing:

- "…Scientific evidence has shown that Eucalyptus controls stream flows, surface runoffs, evapo-transpiration, and supports water infiltration in the soils… " (KFRI, 2011).
- "…Further studies have proven that the Eucalyptus plantations do not harm or exhaust the water reserves in aquifers or the groundwater reservoirs…" (ibid).

The survey of riparian zone activities and their positive regulatory effects on water quality and runoff is beyond the scope of this Study. The observations in this Report are based on site visits to some of the rivers only, but it is the experience of the Project Hydrologist that the adverse utilisation of riparian zones by farmers is a widespread national challenge.

It is also worth repeating that previous studies recommended a catchment management plan for Thika Dam.

It is also worth mentioning that the sediment problems at the Mwagu intake are also very likely the consequence of poor catchment management in the Chania River upstream of the intake.

11 Flood Hydrology

11.1 Criteria

The following criteria were adopted in previous studies (TNWS, Long Term Development Plan, Hydrology, Chapter 9, HH, 1986):

- River diversion works – 50 year return period
- Temporary works during dam construction – 50 year return period
- Dam spillway structures – Probable Maximum Flood (PMF)

11.2 Flood Estimates – Previous Studies

Four different approaches have been presented in the Long Term Development Plan (LTDP, Hydrology, Section 9.2, HH, 1986):

- Frequency analysis of annual maximum daily or peak flows at selected gauging stations.
- TRRL East African Flood Model.
- Unit hydrograph derived from records at RGS 4CA22, Chania River, and transposed to other catchments.
- Comparison with published historic and estimated flood flows from other sources.

The results were summarised conveniently as the graph reproduced below - **Figure 5-89**. Also included is the Ministry of Water Development flood envelope curve based on floods up to 1973.

New flood studies have not been undertaken for this Study. This is because the river flow data is full of gaps and the gauging station rating curves are generally poorly presented for the flood flow range. The peak discharges needed for the extended analysis are not available.

The previous analysis was very thorough, and included stations for which chart flood hydrograph records were available. Where catchments have not changed, the previous results are expected to provide good estimates today for preliminary design purposes. For detailed design, more careful investigation is needed, on a site-by-site basis.

11.3 Maragua 4

The following preliminary flood estimates were previously reported for the Maragua 4 dam.

- PMF = 817 m^3/sec
  (1984 Supplement Table 1, estimated using Creager's Formula with C=49)
- Design Spillway Flood taken as "PMF x 0.5" = 410 m^3/sec
  (1984 Supplement, Table 1)
- PMF = 600 m^3/sec
  (1986 Short Term Plan, Fig C.30)
- 50 yr flood = 155 m^3/sec
  (1986 Short Term Plan, Table C.28, and Fig. C.30)
- 2 yr flood = 41 m^3/sec
  (Short Term Plan, Table C.28)

Later reports utilised the Short Term Plan flood values, as there was no data with which to improve upon them.

The preliminary flood calculations for Maragua 4 are as follows:

Table 5-28: Maragua 4 Floods – Preliminary Estimates

Return Period Yrs	Flood Peak m^3/sec	Growth Factor
2		1
10	103	2.5
100	209	5.1
1,000	350	8.5
10,000	520	12.7
PMF	600	14.7

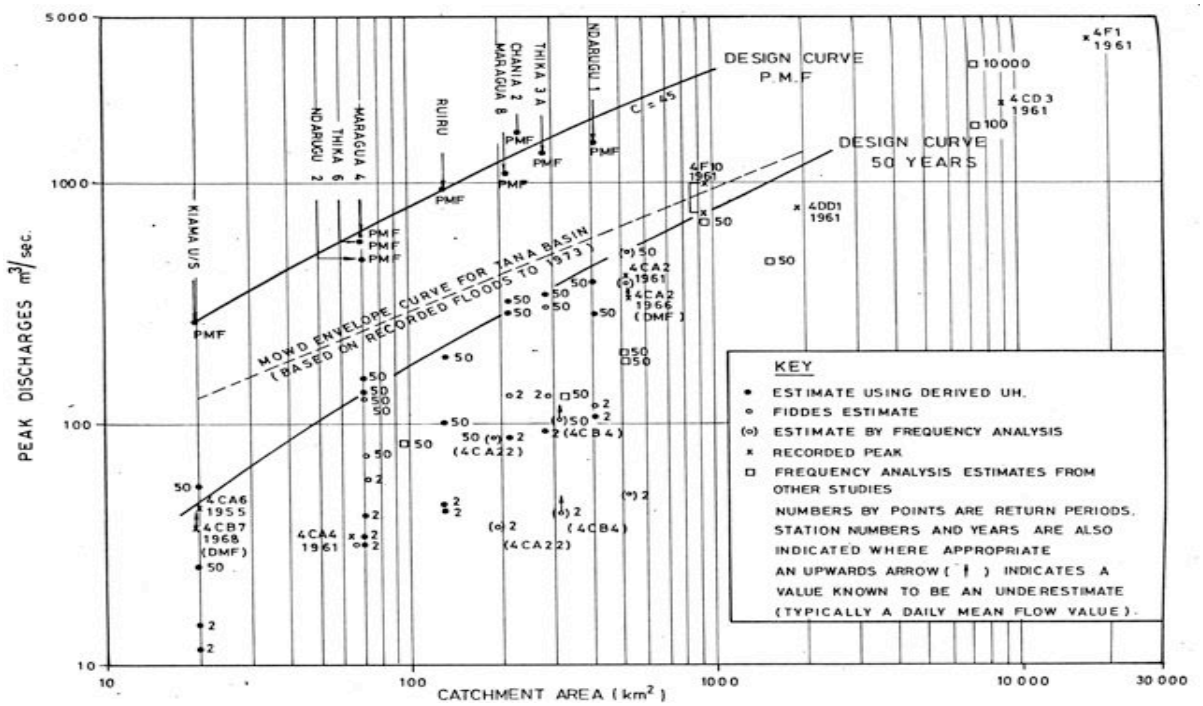


Figure 5-89: TNWSP Flood Estimates

Source: TNWSP-Long Term Development Plan (Regional Studies), Hydrology, Fig.9.2, July 1986

12 Conclusions And Recommendations

12.1 Documentation review

All available documentation has been reviewed in regard to the hydrological findings. The following documents were requested but have still not been obtained:

- Howard Humphreys, Future Water Supply Study, Report, Volume 1, April 1970
- Howard Humphreys, Chania-Thika Study, Vol. 3, Water Resources, 1980 (only the Volume-Appendices was obtained)
- Agrar-und Hydrotechnik Athi River Basin Pre-Investment Study, 1981 (only the feasibility report was seen)
- Nairobi City Commission, Hydrological Data, 1987-88, Chania-Thika-Kimakia Catchment
- Nairobi City Commission, Hydrological Data, 1989-90, Chania-Thika-Kimakia Catchment

The absence of the above documents is not considered critical, although for the sake of completeness, access would still be useful.

12.2 WRMA and KMD Database

The raw database was obtained for rivers associated with the Northern Collector. Raw data for rivers in the Ngethu Sasumua system were not analysed as these were being analysed by the BRLi/Seureca study being undertaken in parallel for AWSB. Similarly, raw data for rivers near Nairobi was not obtained, as these rivers were beyond the study scope and were not proposed sources for the Northern Collector system. Some manuscript data for the Northern Collector Rivers remains to be digitised and added to the database, and this could be considered at a later stage.

There are numerous gaps in the WRMA database, and the data had not been subjected to quality checking by WRMA. It is strongly recommended that WRMA routinely undertake data quality checking, so that only quality assured data is availed. Data problems include spurious entries and also the need to constantly update rating curves.

Previous Third Nairobi Water Supply Project reports reported many quality problems with the data collected up until 1984, including fabrication of data. From 1984-92, there is greater assurance about data quality as Howard Humphreys were responsible for preparing several yearbooks and reports.

Since 1992, the river gauging effort by the Ministry of Water Development declined, and because of the infrequency of visits to stations, it was impossible to verify the accuracy of river gauge readings recorded during this time. Hence, the data can only be used with caution.

12.3 Rainfall Analysis

Up to date rainfall data was hard to obtain from the Kenya Met Department (KMD). KMD is not current with its data entry processing, and some stations no longer file returns to KMD. Two of the four key stations used in the Howard Humphreys Feasibility Report rainfall modelling have not returned data since the time that the Feasibility Report was done. Manuscript records were available, but the record books have not yet been located.

The quality of rainfall data collection and submission to KMD has deteriorated in recent years, with many more gaps apparent.

Rainfall analysis has been performed, including an assessment of long term rainfall changes over the past 100 years. The annual rainfall totals continue to follow the long-term trend of average annual rainfall. The previous two decades are drier than average at some stations.

12.4 Low Flow Analysis

The river flow database was infilled and extended, and then analysed. The results of this analysis were comparable with previous studies, notably the Howard Humphreys studies which worked with data to 1992. Although there are quality concerns with data collected since that time, the analysis in this report does not reveal any change to the hydrology of the Northern Collector Rivers studied. This finding was anticipated as these river gauges are close to the Aberdare Forest boundary. The Aberdare Forest is within the Aberdare Conservation Area, which is a protected area that has not been subject to widespread catchment degradation through forest clearance and settlement. In fact, in recent years it has been the target for higher protection, which has included the recent completion of an electric fence encircling the entire conservation area.

A separate study by another Athi Water Services Board Consultant, in the Chania – Thika catchment, has reached a similar conclusion concerning the hydrology of the Chania and Thika rivers that were studied. The hydrology was “confirmed” (BRLi/Seureca for AWSB, 2010).

12.5 Abstractions, Naturalisation and Compensation Flows

The WRMA river flow data is raw, is subject to quality assessment, and the flow sequences have not been naturalised.

WRMA is currently working nation-wide to update the national database of licensed water abstractions. There are also numerous illegal abstractions to be regularised, and hence the process of naturalising the river flow hydrology is challenging. In the case of the Northern Collector rivers, this is less of a problem as the key river gauges are close to the gazetted forest boundary, and there are very few upstream abstraction intakes, and these can be quantified with some certainty.

The existing WRMA water abstraction permit database was obtained, but it is hard to work with, as most of the abstraction licenses are not geo-referenced.

The basis for deriving compensation flows is presented elsewhere in this report. WRMA requires that the downstream release be sufficient to meet the ecological requirements and the downstream water license requirements.

12.6 Conclusion on Yields and Proposed Further Assessment

Previous studies utilised differing methodology for deriving yields. The earliest studies adopted 98% reliability as the design yield, whereas later studies adopted 90% reliability. The Terms of Reference do not specify what is required. Based on review of Working Papers submitted by Egis/MIBP, and several discussions with AWSB and the World Bank, this study has adopted 90% reliability.

The methodology adopted for calculating reliability was initially based on the WEAP Model definition, which is an event-based definition. The method is logical but can lead to bias if failures are lumped together rather than scattered uniformly through the record. The previous studies were based on annual event methodology, and the World Bank prefers this. The results are markedly different. The effect of the differing definitions was presented in the yield comparisons derived using the WEAP Model, which were presented earlier (Chapter 9, Version 02, Egis/MIBP August 2011). Essentially, the 90% traditional yield equates to 98% yield under

WEAP methodology. Hence to achieve similar reliability, the WEAP 98% would need to be adopted. The model usage was modified in order to achieve the desired results at the traditional 90% reliability level.

Northern Collector river gross yields have not changed since the studies reported in 1998. However, in that time, population and water demand have increased, and hence the water abstractions will have increased, potentially diminishing the flows in the rivers downstream.

The compensation flow requirements will be higher today, thereby reducing the net yield that is available to the Nairobi Water Supply or any other requirements. Hence, future schemes are only sustainable with adequate storage provision from which to supplement yield in low flow periods. It is very important to note that water permit provisions generally require that during low flow periods, irrigation schemes should be drawing water from their 90 day storage provisions, but unfortunately this requirement is not always enforced. As water becomes scarcer, enforcement will become critical.

The ecological and compensation flow releases are assessed elsewhere. The general assumption is that the 95% exceedence flow (Q95) will be released to cater for ecological and downstream user needs.

The BRLi/Seureca study has confirmed the Chania/Thika hydrology, and this study analysis has reached a similar conclusion. Within the constraints of the data, the river flow hydrology is unchanged.

The diversion of flows and water balance is a separate detailed exercise that has been presented elsewhere in this report through the WEAP Model (v2) conjunctive use water balance modelling results presentation.

12.7 Climate Change Modelling and Risk Assessment

The possibility of utilising the HYSIM rainfall / runoff model to infill missing data and to produce naturalised flow sequences from the available data was discussed in earlier reports, although this was not allowed within the Consultancy Proposal forming the basis for this contract.

Howard Humphreys adopted the HYSIM model in their 1998 Feasibility Report.

HYSIM has been recently modified to enable climate change scenarios to be run, in order to assess future changes in the water resource – see http://www.climatedata.info/

HYSIM is a Water Resource Associates / Ron Manley product. The developer of HYSIM, Ron Manley, is a Director of Water Resource Associates. Mr. Manley trained Howard Humphreys staff in the application of HYSIM to the 1998 Northern Collector Feasibility Report, and he assisted with resolving problems with data infilling.

Alternatively, a risk assessment approach can be presented through changing parameters on the WEAP Model (reported elsewhere). This is the approach that was adopted. Use of the HYSIM model could be considered if more detailed assessments are required for future stages.

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Chapter 6 - Groundwater Assessment

1 Introduction

This Chapter outlines the Preliminary Groundwater Assessment within the Study Area i.e. Nairobi and Satellite Towns. The Preliminary Design for the proposed Wellfields of Kiunyu and Ruiru is given in the Preliminary Design Report – Northern Collector Phase I Project, Version 02 and summarised in Chapter 8 of this Report.

2 Data Availability

Most of the data used for groundwater assessment comes from drilling records.

Up to 2005 upon establishment of the Water Resources Management Authority, all official groundwater data was kept by the Groundwater Division of the Ministry of Water Resources. Once a borehole was drilled, returns were made to the Drilling Section (for issuance of borehole numbers) with a copy to the Groundwater Division. The approved bore-hole site locations, together with the bore-hole completion numbers, were recorded on topographical map sheets by the "Maps and Records" Section. Other data (e.g. the depth of the borehole, water strikes, and static level) were stored in data sheets, which could only be retrieved via the bore-hole completion number. In a number of cases, no returns were made to the Ministry, hence such boreholes were not recorded. On the other hand, poor coordination between Drilling Section and Groundwater Division ensured that some data was not captured because it remained in the Drilling Section. The National Water Master Plan (1992) initiated the National Water Resources Database (NAWARD) at the Ministry. NAWARD compiled as much as possible a computer database of all records from the Maps and Records Section and the Drilling Section. The last data captured by NAWARD was in 2005 when the data record role was transferred to WRMA. However, by 2005 NAWARD was capturing fewer and fewer data.

With transfer to WRMA, the data capture role of the Drilling Section was eliminated completely. All new borehole returns went to WRMA for issuance of borehole numbers but there was a slow start to the process as authority was just beginning to establish itself. Returns were slow and there was confusion with some returns still going to the Ministry. It was not until 2010 that WRMA embarked on a program to digitize its borehole database for Nairobi Aquifer only. This exercise was not complete at the time of preparation of this report hence this project did not benefit from this data.

Instead, the project had to rely heavily on NAWARD data, which captures data only up to 2005. A small proportion of data was collected from the Maps and Records Section (especially the paper records) and from WRMA (paper records).

Groundwater monitoring was the duty of the Groundwater Division until 2005. However, due to lack of funds, there was practically no monitoring after 1992. Previously there had been intermittent monitoring – spot data actually, of which no consistent records are available. From 2006 WRMA established 18 private boreholes within the Nairobi Conservation Area whose water levels were dipped on a monthly basis. These are not dedicated monitoring wells. This data has been made available but is of limited use – at best, it has been used to conduct

comparative piezometric level checks between levels established in earlier studies until the present time.

Hydrological data was until 2005 collected and stored by the Surface Water Division of the Ministry of Water Resources. This role like with groundwater information was handed over to WRMA in 2005. Stream flow data was collected from the Surface Water Division because the WRMA data largely consists of abstraction. Furthermore, the stream-flow gauging system almost collapsed after 1992, so that the longest records are those still at the Ministry.

The project has also relied on information from previous work, like that of Gevaerts (1964), Chilton (1970), JICA (1992), BCEOM (1998) and NORKEN (2010). These reports provide empirical data collected in the field and thus have been valuable for analysing groundwater trends over the years. They mainly focus on Nairobi City and do not propose resource evaluation for the whole groundwater body.

3 Groundwater Inventory

3.1 Existence of Groundwater Body

Existence of the groundwater resource beneath the Nairobi area is evident: this area is subject to significant precipitations (from 500 to more than 2000 mm/year) and the geological terrains are mainly volcanic and sedimentary formations, some of them being like basalts widely known as major water bearing formations. Local aquifer levels (more or less permeable) beneath and around the Nairobi area, are hydraulically connected to each other and/or to the main regional aquifer layers. These aquifer formations altogether form a multi-layer aquifer system combining layers with porosity and inter-granular flow (the Kerichwa Valley and Upper Athi series), and layers with fracture flow (as Limuru Trachyte, Ngong Basalt and Kapiti Phonolite). But the overview of knowledge of this groundwater resource demonstrated the poor understanding of this resource so far: no limit and/or definition of the aquifers or of an aquifer system were established, and as a consequence no global water balance was ever proposed.

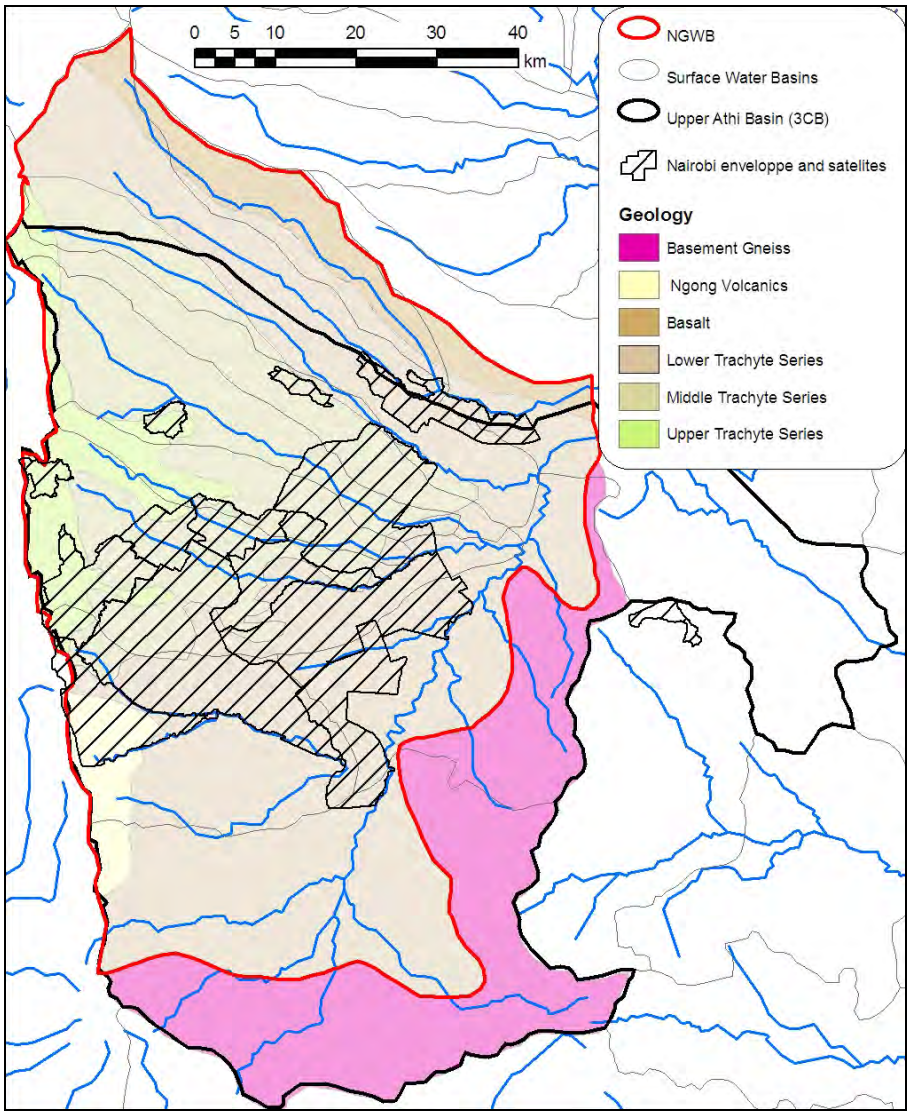
As the limits of the whole aquifer system are far from being known, a Nairobi Groundwater Body[1] (NGWB) is defined. As a first approximation, it is similar in extent to the upper Athi surface water basin up to Munyu, minus the basement outcrops, and plus sub-basin 4CA and 4CB of the upper Tana basin. It is covering Nairobi City, Nairobi Envelope, and satellites towns except Tala-Kangundo. Considering the geological limits in South and East, the structural limit at the Western boundary and the supposed no-flow boundary at North caused by the river parallel to this border, this NGWB should be rather close to an aquifer system. **Figure 6-1** on page 6-3 shows the extent of the NGWB.

Considering the passed prospection, there is no indication of very high or very low productive layers. According to the present knowledge of the aquifer formations, and even if the groundwater resource is sparse at some specific location due to the discontinuous type of the

[1] A GWB is "*a distinct geological stratum of sufficient porosity and permeability to allow a significant flow of groundwater that, if it entered a body of surface water, it might be expected to significantly to affect its ecology*" (EU Water Framework Directive guidelines for the assessment and management of groundwater resources).

aquifers, **there is no indication of a particular spatial distribution of the aquifer potential**: borehole depth and productivity is globally similar for all of the aquifer units of the NGWB.

Figure 6-1: Extension of the Nairobi Groundwater Body (NGWB)



3.2 Wells and Groundwater Abstraction

The total number of boreholes in the NGWB is estimated in 2010 to more than 5,500 units. The abstracted volumes can be evaluated per usage as follows.

3.2.1 Individual Domestic Boreholes

An estimate of the groundwater abstraction from individual domestic boreholes is established by sector, based on data extracted from the Drilling Permit Application Database (WRMA) records, and considering a global 86% of the boreholes for domestic purpose. The average daily abstraction is estimated based on the NORKEN hydro-census for the investigated areas, and on the comparison of settlement type and availability of surface water for other areas. For year 2010, it comes to a total of 25,100 m^3/day for Nairobi, 26,300 m^3/day for Nairobi Envelope and an additional 100 m^3/day for the remaining Satellite Towns.

3.2.2 Abstraction from Water Companies for Public Water Supply

Abstraction rate in the boreholes pumped by the registered Water Companies were collected for all of the operational boreholes. These figures were obtained from direct reading (usually daily) at flowmeters, or from estimates (based on pumping hours and pumping rate) provided by the operators themselves. In Nairobi city, the 8 boreholes are operated by NWC are extracting some 2,300 m^3/day. For the whole Nairobi Envelope, the groundwater abstraction from Water Companies comes to 17,600 m^3/day. And about 3,000 m^3/day is abstracted for the remaining Satellite Towns.

3.2.3 Community Water Supplies

Apart from the Water Companies, groundwater is abstracted by small community water supplies (CWS) in the whole area to supply water to a limited public. The average production for this type of facility is 200 m^3/day. There are at least 121 registered CWS in the upper Athi basin. However, according to the WRMA Nairobi sub-regional office, many property developers are also supplying water to localised neighbourhoods but apply for domestic water permits instead of public water supply. Considering the 66 AWSB boreholes registered in Nairobi city and the 5 registered CWS, the abstraction for Nairobi comes to 1,140 m^3/day. It goes up to 17,700 m^3/day when the registered CWS in Nairobi Envelope are considered and to 4,000 m^3/day for the Other Satellite Towns. It is important to note that some consumers depend on the CWS for minor irrigation as well, so the total amount of water consumed may not necessarily match the population.

3.2.4 Other Public and Institutional Water Supply

In addition to the abstraction from the Water Companies and the CWS, numerous boreholes are used for public and institutional water supply (as for hospitals, administration offices, schools, college campus, religious centre…). These boreholes represent some 7% of the total number of operational boreholes. The average daily production for such boreholes is estimated to be 36 m^3/day from the NORKEN hydro-census.

3.2.5 Boreholes for Industrial and Commercial Purpose

In addition to the abstraction from the main water users, numerous additional boreholes are used for industrial and commercial purpose (as for small industry, small hotel, shopping mall, office block…). These boreholes represent some 4% of the total number of operational boreholes. The average daily production for such boreholes is estimated to be 16 m^3/day from the NORKEN hydro-census.

Table 6-1: Existing Wells and Groundwater Abstraction (NGWB)

		Public water supply			Industrial and commercial		
	Domestic	Water Companies	AWSB & CWS	Others public & institutionnal	Main consumers	Others	Irrigation
Nairobi	**25 086**	**2 293**	**1 140**	**7 719**	**7 000**	**1 968**	**700**
Ongata Rongaï / Ngong	290	5 500	3 400	176	2 600	48	2 000
Kikuyu	324	4 700	7 400	907	300	224	3 000
Karuri	197	1 100	600	552		144	500
Kiambu	283	3 600	4 200	396	100	96	200
Ruiru / Juja	58	280	-	164		48	
Mavoko Athi River	53	150	1 000	212	660	48	1 500
Total Nairobi Envelope	**26 290**	**17 623**	**17 740**	**10 125**	**10 660**	**2 576**	**7 900**
Gatundu	8	50	-	23		-	200
Thika	18	-	-	71	1 000	16	500
Limuru	57	2 450	3 400	159	100	48	1 000
Githunguri	28	550	600	78		16	200
Total Other satellite Towns in NGWB	**110**	**3 050**	**4 000**	**330**	**1 100**	**80**	**1 900**
Rest of the area in NGWB	2 694	1 270	-	3 480	250	880	9 700
Total in the NGWB	**29 095**	**21 943**	**21 740**	**13 936**	**12 010**	**3 536**	**19 500**
Tala-Kangundo (outside the NGWB)	7	500	1 000	20		-	100

3.3 Overall Groundwater Resource

The global available water resource in the NGWB was not evaluated yet. The figures proposed below are then mainly estimates.

A tentative water balance can be proposed, with two major uncertainties on the infiltration from the rivers and the lateral outflow at the extreme East of the NGWB, these two figures having the same order of magnitude:

Table 6-2: Groundwater Balance

	In	Out
Direct Infiltration (MCM/Year)	370	
Infiltration from Rivers (MCM/Year)	17	
Drainage to Rivers (MCM/Year)		335
Abstraction (MCM/Year)		44
Lateral Outflow (MCM/Year)		8
Total (MCM/Year)	**387**	**387**

3.3.1 Direct Recharge Over the NGWB

The precipitation beneath the NGWB area is rather large, from 600 to more than 2000 mm/year (see details about rainfall and climate in the Hydrology section). An estimate of the total volume of precipitations beneath the area gives a total of 6200 MCM/year over the 5126 km² of the area. Part of this rainfall infiltrates in the ground and contributes to the aquifer recharge. It is called “direct recharge”. There is no indication that this direct recharge does not occur everywhere beneath the NGWB, except in the central part of Nairobi City where the soil is covered by impermeable asphalt. In such smooth slope terrains, with a slightly developed soil, the usual values for direct recharge range from 4 to 10% of the precipitations, the lowest values being applied for large rainfalls. Considering a standard 6% coefficient, the total direct recharge can be estimated to some 370 MCM/year for the whole NGWB (a minimum of 250 MCM/year if a conservative 4% coefficient is considered).

3.3.2 Groundwater Exchange with Rivers

A significant part of the aquifer outflows by drainage to the rivers. This water forms the river baseflow. Considering the Athi Munyu gauging stations (3DA02), baseflow calculated using HYDATA from the 1956-1962 data (before naturalisation, i.e. conservative figures) is found to be 290 MCM/year. Some 45 MCM/year should be added to this figure in order to include the northern part of the aquifer system, drained by the Thika and Chania rivers. The total drainage of the NGWB to the rivers can then be estimated to some 335 MCM/year.

Contribution of the rivers to the aquifer recharge should also be considered: where important abstraction occurs (e.g. beneath Nairobi City), local water depletion is observed. In these sectors, the rivers are not draining the aquifer but contribute to the recharge. This contribution is difficult to evaluate. BCEOM (1998) estimates it to some 4 MCM/year for a limited part of the aquifer. As a first estimate, the order of magnitude for the whole NGWB is probably around 17 MCM/year.

3.3.3 Groundwater Abstraction

Groundwater abstraction is estimated to 44 MCM/year for the whole NGWB

Part of the groundwater is outflowing the NGWB in the extreme East sector, beneath the Athi and Thika rivers. As the piezometric gradient is not known, neither than the transmissivities, no quantitative evaluation can be proposed: the volume should be limited (as the sector is rather small) and should be consistent with a balanced water budget.

This balance demonstrates that a large flow is going through the aquifer, fed by direct infiltration and drained by the rivers. The present groundwater abstraction is probably limited to some 10% of the groundwater flow. Such hypothesis is consistent with the observed piezometric levels: except in areas where there is important pumping (badly alimented centre of the aquifer), the general piezometry of the aquifer seems to be unchanged since the 1960ies, showing that there is no major modification of the general equilibrium of the aquifer.

The groundwater abstraction can very certainly be increased easily by 2 or 3 times, without major impact on the river baseflow.

- In order to limit the impact on the groundwater levels, the groundwater development should be located close to the rivers. **A potential of some 75,000 m^3/day** should be available in these sectors. The best sectors for such groundwater development will be identified once groundwater prospection will be conducted.
- In the other sectors, where groundwater abstraction for public water supply already exists, this abstraction can certainly be increased significantly without major problems: the exact location for such additional boreholes should be set up after hydrogeological prospection in order to limit the local drawdown.

4 Groundwater Data for Water Balance Model

4.1 Present Situation

Table 6-3: Present Groundwater Contribution to Water Demand

	GW Contribution to Water Demand (m^3/day)
Nairobi	**45,205**
Ongata Rongai / Ngong	12,014
Kikuyu	13,855
Karuri	2,593
Kiambu	8,674
Ruiru / Juja	550
Mavoko Athi River	2,123
Total Nairobi Envelope	**85,015**
Gatundu	81
Thika	1,104
Limuru	6,213
Githunguri	1,272
Total Other Satellite Towns in NGWB)	**8,670**
Tala & Kangundo (Outside the NGWB)	1,527

4.2 Probable and Possible Changes for Groundwater Abstraction in Study Area

4.2.1 Nairobi City

In Nairobi, the present contribution of groundwater is estimated to 45,000 m^3/day. The main GW abstraction comes from the individual domestic wells with 25,000 m^3/day. Considering the present 2,700 individual domestic boreholes in the city, and applying a 15% growth rate (as recorded since 1994), it should be some 400 new wells each year. Assuming an average daily abstraction of 2.5 m^3/day/well, the GW abstraction will probably increase by 1,000 m^3/day.

4.2.2 Possible Well-fields Developments Outside Nairobi City

The « Review of Groundwater Resources » Report pointed out that high yielding well fields developments can be made in the next years.

A significant use of this groundwater resource as part of the Nairobi water supply could be planned: it could consist of well-fields producing a minimum of 30,000 m^3/day each. Due to operational constraints, the well-fields should not be more than 20 boreholes, i.e. each borehole should be able to produce some 60 m^3/h or more. Such figures are quite common in basalts when thick and fractured. They can also be found in sedimentary formations like gravels or thick coarse sands, rarely present in the sub-surface of the NGWB, but possibly present in the deepest levels. Such yield can also be expected in poor yielding formations when sufficiently thick.

An investigation program is required in order to locate high yielding formations and to give precise estimation of the well-fields' potential. Taking into account this investigation program, such a well-field can be implemented within a four (4) to five (5) years period.

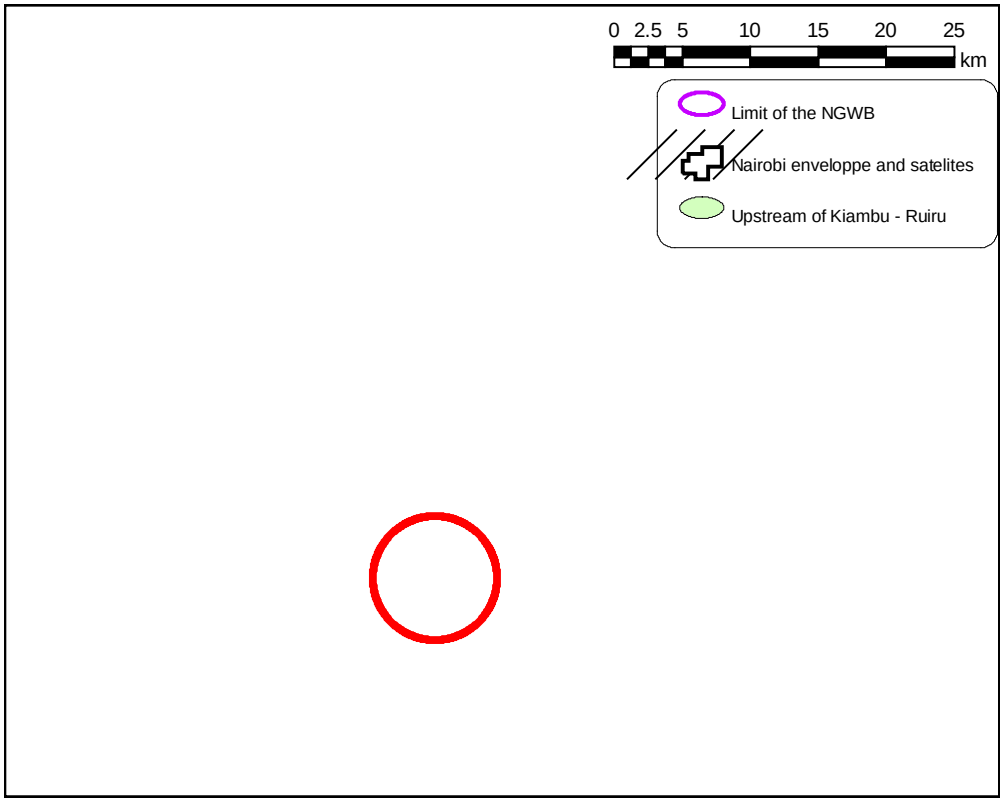
Located outside Nairobi City, the planned well fields could be connected to the Nairobi City transmission system as an emergency measure before other surface water resources are mobilised in sufficient volume. Then, the well fields resources will be allocated to water supply schemes for the concerned satellite towns as a complement to other water resources.

Nairobi Envelope – Deep Groundwater Development in the Athi Series

In the Satellite Towns of the Nairobi Envelope, the increase in groundwater abstraction will mainly come from the Water Companies. The present groundwater contribution to water supply can be double anytime beneath all of the towns, within a one (1) year period. For Kiambu and Ruiju, a 30,000 m^3/day deep well field can be implemented within a five (5) years period. This well field will recognise the Athi series of the NGWB up to basement, expected to be 400 to 600 m deep.

Figure 6.2 shows the possible location (red circle) of a 30,000 m^3/day wellfield in the north of Kiambu - NW of Ruiju area (590 km^2, with an average rainfall of 1300 mm/year).

Figure 6-2: Possible Location of a Wellfield in the North of Kiambu

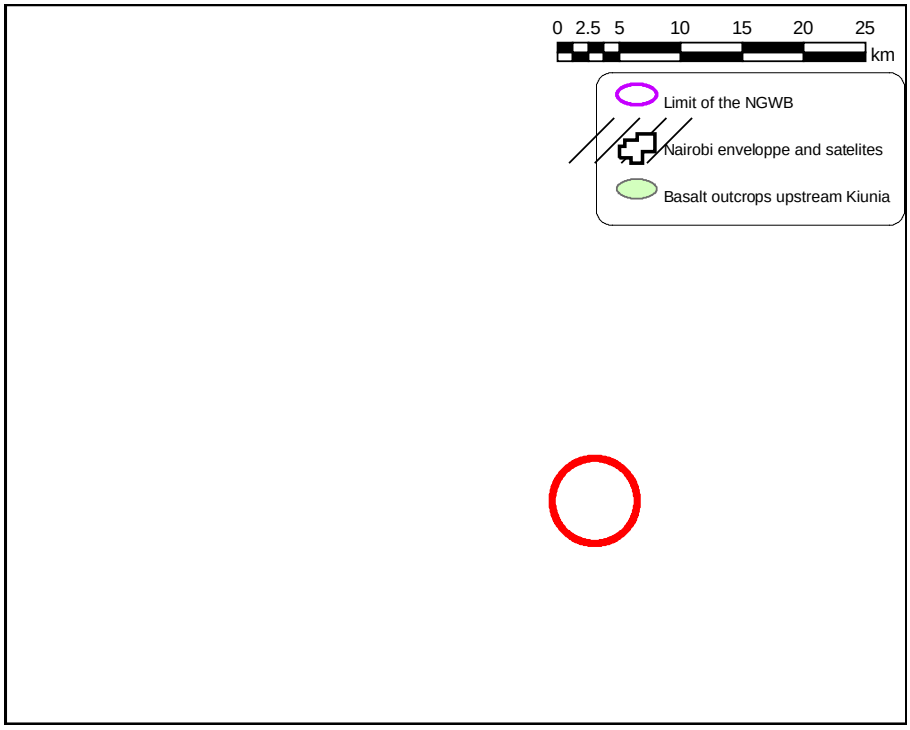


Satellite Towns outside Nairobi Envelope – Basalts in the Kiunyu Sector

Outside of Nairobi Envelope, in Gantungu, Limuru and Githunguri, the present groundwater contribution to water supply through the Water Companies can be double anytime beneath all of the towns, within a one (1) year period. For Thika, a 35,000 m^3/day well field can be implemented in the outcropping basalts within a four (4) years period.

Figure 6.3 shows the possible location (red circle) of a 35,000 m³/day well field in Kiunyu sector, downstream of basalts outcrops (230 km², with an average rainfall of 1,800 mm/year).

Figure 6-3: Possible Location of a Well Field in Kiunyu Sector



4.2.3 Groundwater Potential for Other Satellite Towns

Kikuyu Area

Kikuyu area is a nett groundwater recharge zone. Discharge takes place at the eastern and southern fringes through base flow in rivers which originate from the area, the Kikuyu springs and Ondiri Swamp.

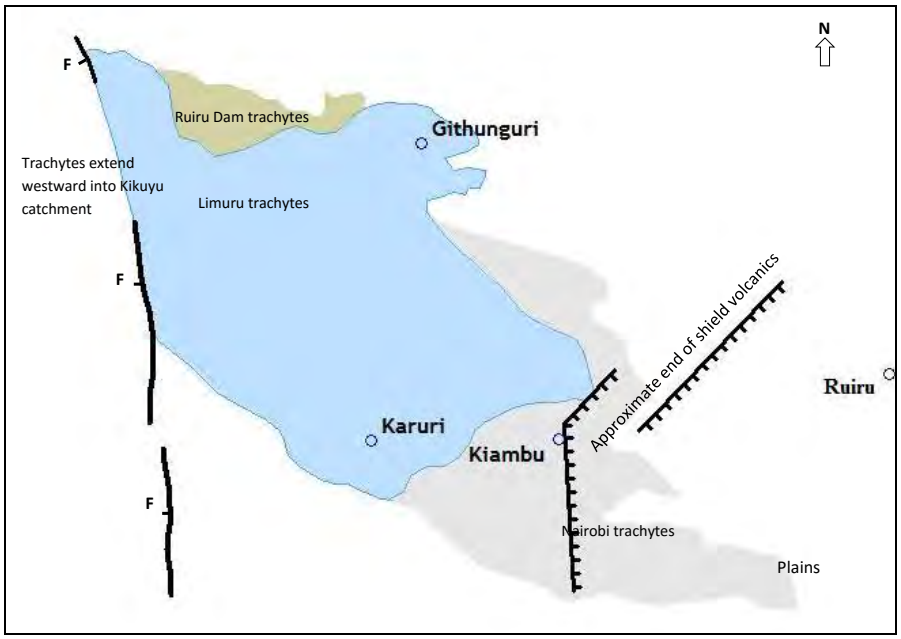
The study on the aquifer that feeds Kikuyu springs (Norken 2011) that included a water balance analysis indicates that groundwater abstraction accounts for 6.7 MCM of the annual groundwater discharge for the entire aquifer. This amounts to 18,000 m³/ day and represents nearly 50% of the estimated annual recharge. Assuming 30% Ecological Reserve, an increase in abstraction of up to 7,000 m³/ day is feasible. This includes water for other uses as well hence a well-managed allocation plan is required.

The Kikuyu springs abstracted flow was at least 2 MCM annually – a daily abstraction of 6,000 m³. This water is presently used in the Nairobi Envelope, not in Kikuyu area. If this abstraction is transferred to Kikuyu area then groundwater use could be increased by 13,000 m³/ day.

Kiambu and Karuri Areas

These areas physiographically lie in the zone where the volcanic pile rises westwards into the recharge zone, but eases eastwards into the Ruiru plains. The area therefore has the potential for large groundwater supplies. The surface geology is composed of trachytic rocks that are the main recharge area rocks in the Kikuyu neighbouring catchment. The potential for direct recharge is however lower than for Kikuyu because the area is less faulted and rocks probably less fractured. Nonetheless the area benefits from inflow from the Kikuyu catchment recharge.

Figure 6-4: Geological Layout of Limuru, Karuri, Kiambu and Ruiru Areas



The proposed Ruiru Wellfield for Nairobi Envelope water supply is 7 kilometres north of Kiambu. It is therefore consequently possible to supply Kiambu and Karuri with groundwater if surface water sources are found inadequate. The Wellfield could provide primary supply for these Towns and developed with extra capacity to supplement Nairobi Envelope or provide emergency supply.

An important observation is that the Athi Tuffs and Lake Beds and the Simbara Basalts which are the basal volcanic flow in the Nairobi volcanic aquifer suite outcrop east of Ruiru. This means that the Basement/ volcanic contact probably runs along the orientation of the termination of the surface flow of the shield volcanics. Kiambu and Karuri are located immediately west of the supposed contact hence the likelihood of strong directional groundwater flux is significant.

Ruiru-Juja Area

It is demonstrated in Figure 6-4 above that Ruiru is placed on the plains beyond the shield volcanics. Preliminary structural analyses indicate there is groundwater movement northeast and south, skirting eastern Ruiru which has rather poor groundwater potential. It is therefore unlikely that groundwater will be an option for Ruiru in the long term.

Mavoko Municipality

Mavoko Area is located on the eastern side of Nairobi, where rainfall is limited (less than 600 mm p.a) and the rock outcrops are mainly Basement metamorphics with low recharge potential (1-3%). There is limited distribution of Kapiti phonolites which have better recharge potential and groundwater often occurs at the contact of the Basement metamorphic rocks and the phonolite. The alignment of Athi River is partially structurally controlled. These structures lead to groundwater storage at specific localities along this lineament (e.g. the Isinya Aquifer). However, in Mavoko area such groundwater potential enhancing conditions do not exist, making this a non-option for long term water supply for Mavoko Area.

North-western Mavoko is located in the Embakasi plains, where volcanic rocks overlie Basement rocks. This is an area where there is limited potential for development of independent borehole sources that serve specific communities, not for centralised distribution

system. Nonetheless, this area is on the lowest end of the Nairobi Aquifer Suite(NAS) and furthest from the recharge zone, making it susceptible to pollution. The fluoride level is among the highest in the NAS in this area as a direct result of rock-water interaction along the path of groundwater movement.

Ngong, Ongata Rongai and Kiserian Areas

These areas lie on the southern boundary of the Nairobi Aquifer Suite and receive recharge from the Ngong hills watershed to the west and inflow from the Kikuyu Escarpment watershed in the northwest. A swarm of NW-SE trending faults transmit recharge from the Kikuyu Escarpment watershed and trap the recharge flow from the Ngong hills watershed. This makes the Bulbul, Olkeri and Ngoroi areas rich in groundwater potential. Boreholes drilled in these areas currently provide the bulk of groundwater supply for this area. The Ngong catchment area is approximately half of the Kikuyu catchment, with slightly lower rainfall. Water supply requirement is 60% that of the Kikuyu and Limuru area in the Kikuyu catchment. Given that at present only 1,250 m^3/ day is supplied from boreholes, this figure can be easily doubled without danger to the aquifer.

Limuru Town

Current groundwater abstraction by the water company stands at 1,800 m^3/ day. The area is located on the northern quarter of the Kikuyu springs aquifer and receives an estimated 5.5 MCM annual recharge (Norken 2011) and subsurface inflow into the area of a similar amount. However, the recharge is shared for use between Kikuyu and Limuru Aeas. Therefore, while it is possible to comfortable abstract say 70% of the recharge alone (15,000 m^3/day) this must be read in the context of the whole catchment water use. Thus the planning for Limuru should incorporate Kikuyu area as well: it is noteworthy to observe that abstraction in Limuru area has direct effects on groundwater availability in Kikuyu Area.

Githunguri Town

On Figure 6.4, Githunguri Town is located in the periphery of the trachytic outcrop recharge area, with the greater part of its groundwater recharging into tuff outcrops. This has a net effect of slower recharge (lower transmissivity). As a result, while there is sufficient groundwater recharge in its catchment, the flux through the area is not expected to be as high as for Kiambu and Karuri Towns. The current daily abstraction of 1,000 m^3 can therefore be doubled.

Gatundu Town

Gatundu has somewhat lower groundwater potential than Githunguri, being located within the tuff geological cover. It is not unexpected that the existing borehole source is used as a standby facility only.

Tala and Kangundo Towns

These Towns are located in predominantly Basement rock areas which are poor aquifer material; Talaalbeit sits on tuffs hence has better groundwater prospects in contact aquifers. The option of groundwater supply is a last resort, even though currently it is the main source. The potential for recharge exists on Kangundo hills and the Kanzalu Range: Tala is found on the leeward of Kanzalu hence effective recharge rainfall is reduced. Based on existing borehole yields, it is feasible that between 10 to 15 boreholes located in the highest potential areas can meet a capped supply volume of 1000 to 2000 m^3/day. Data available leads to the conclusion that a well field is not feasible for this aquifer hence the challenge will be the distribution of these boreholes vis-à-vis the points of use.

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Chapter 7 - Development Strategy for Nairobi City and Water Balance Modelling

1 Introduction

Under the Water Resources Options Review Report (Version 02 – August 2011) prepared under the on-going Consultancy Assignment, Six (6) Scenarios to meet the water supply to Nairobi upto the Design Horizon of 2035 were studied and presented.

The six Scenarios have been reviewed in the context of the Extended Water Balance Modelling which has been carried out for the combined Northern Collector System and the Existing Thika / Chania / Ngethu Systems. The Water Balance Modelling work has been extended under Addendum 1 of the Consultancy Services. Based on discussions and meetings (see attached Minutes – **Appendix 7.1** between AWSB, World Bank and Egis /MIBP JV), the Water Balance Modelling was extended to include Yield Analysis based on the following criteria:

- Yield Analysis based on Annual Occurrence. 90% Reliability, Daily Time Step Simulation (This is equivalent to approximately 98% WEAP Reliability and similar to criteria adopted by HH in 1986 Study)
- The Time series (Simulation Period) for Data was extended from 26 Years (1985 – 2010) to 37 Years (1973 – 2010)
- Compensation Flows (Reserve Flow / IFR)
    - Analysis done based on Q_{95} Downstream Release for all Rivers except $1.4xQ_{95}$ for River Irati.
    - Northern Collector Rivers – Analysis done on $2xQ_{95}$ Downstream Release as per agreement between WRMA and AWSB / NCWSC
    - Thika Dam Variable Release to Mwagu based on flows in Chania, Kimakia and Kiama Rivers,
    - Maximum Abstraction at Mwagu Intake limited to $4.8m^3/s$

The Six Scenarios are briefly described in Section 2 of this Chapter for ease of reference.

Under the Water Resources Options Review Report, which adopted Multi Criteria Analysis to identify the most suitable development Scenario - Scenario 2 and 3A are very close in the rating. At that stage, Scenario 2 was ranked the best development option.

Based on the results of the Extended Water Balance Modelling, Scenarios 2 and 3A have been reviewed further using the Multi-Criteria Analysis.

The Review has indicated that Scenario 3A ranks much higher than Scenario 2 due to the following reasons:

- Additional Storage provided in Phase II – Maragua 4 Dam
- Water supply from Maragua 4 Dam is by gravity

- Chania / Komu Transfer to Ndarugu 1 Dam not required to meet the 2035 Horizon Demand (under Scenario 2 this would be required and as supply from Ndarugu 1 Dam is by Pumping, this option will have higher operations costs).

In all the Six Scenarios, Phase I development is common and involves Northern Collector Tunnel Phase I and Treatment / Transmission System via Ngorongo to Nairobi.

Under Scenario 3A, Phase II of the Development will involve Northern Collector 2 and Maragua 4 Dam with associated Treatment / Transmission System to Nairobi via Ndunyu Chege.

2 Summary of Scenarios Contemplated at Water Sources Option Review Level

2.1 Water Resources Development Criteria

The criteria used in the water resource development strategies ensure that:

- all water supply demands are fully met up to the Year 2035 horizon,
- new sources of development are considered,
- all supplies are created to a common standard for potable water supply,
- New water sources and facilities increase the reliability and security of water supply for Nairobi and Satellite Towns through:
    - optimal use of the existing facilities,
    - an increase of surface water storage sources,
    - diversification of water sources (surface water, groundwater, rainfall roof harvesting) , etc. when appropriate,
    - Development of local or mixed water supply systems for satellite towns.

To meet these broad strategic objectives, the following key principles have been considered for preparing the long term development strategy:

- The water sources development strategy should meet the growing demand for water supply up to Year 2035, through a staged investment process;
- The water sources development strategy should make the optimal use of the existing facilities (reservoirs, transmission lines, water treatment works, etc.);
- The strategy should propose diversification of water sources and the development of schemes providing more safety and operational flexibility;
- Small water production schemes for Nairobi City should be limited in order to avoid multiplicity of the Water Supply systems, to reduce costs and optimize the operation.
- Independent water schemes should be preferred for the Satellite Towns where local surface or groundwater water sources are available;
- Efforts to reduce to minimum level physical water losses along the system (intakes, transmission pipes, treatment works, distribution schemes, etc.)
- Diversification of sources:
    - promote the steady development of boreholes to tap groundwater;
    - promote alternative water sources such as rainwater harvesting;

- Limit or avoid where possible competition between water users on the water source (hydropower production, agriculture & livestock, downstream users and environmental flow);
- Priority to be given to scenarios with less social and environmental impacts;
- Minimize the cost of the new water sources facilities through (i) limiting the length of water distribution, (ii) limiting or avoiding pumping requirements and maximize gravity transmission, (iii) optimizing dam reservoir size and dam location, and (iv) best use of existing water system infrastructure through rehabilitation/upgrading, interconnection and expansion;
- Consistent phasing of investments: any new step in the development of new sources, should be consistent with the previous ones and with the next planned steps;

The above principles compose the strategy for the development of new water sources for Nairobi Water Supply.

2.2 Building Development Scenarios

The planning for Future Development of Water Resources for Nairobi and the Satellite Towns involves a comparison between known sources availability and projected Water Demands. The following water supply development scenarios were studied in the Water Sources Options Review Report – Version 02.

2.2.1 Proposed Scenarios

Based on the Consultant's review of previous studies and on analyses and processing of data collected, the Consultant selected new main sources to be mobilised to meet projected Water Demand till the Project horizon and prepared various development scenarios. The development criteria discussed in Section 2.1 was used as a guidance to select the proposed Scenarios for the mobilisation of new water sources for Nairobi Water Supply.

Six (6) main Scenarios were established in context of meeting the water demand for Nairobi up to Year 2035. These Scenarios were prepared in view to meet the water demand of Nairobi City without taking into account Satellite Towns for which supply options are discussed in Chapter 9.

The Scenarios involved the combination of different sources, arrangement of the Northern Collector Tunnel and scheduling. The various sources considered in the Scenarios are:

- Wellfields in Kiunyu and Ruiru Areas
- Northern Collector Phase I to Thika Dam
- Irati River Transfer to Thika Dam
- S. Mathioya River Transfer to Thika Dam
- Maragua 4 Dam at the confluence of Maragua and Gikigie Rivers
- S. Mathioya River Transfer to Maragua 4 Dam
- Northern Collector Phase II to Thika Dam
- Northern Collector Phase II to Maragua 4 Dam
- Ndarugu 1 Dam at the confluence of Ndarugu and Komu Rivers
- Chania River Transfer to Komu River.

A brief discussion of Scenarios considered and the sequences of development of the new water sources is given below:

- **Scenario 1**: Wellfields in Kiunyu and Ruiru followed by Northern Collector Phase I, Maragua 4 Dam with S. Mathioya Transfer to the Dam, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. In this Scenario, water transmission of additional water at Thika Dam will be via Ndunyu Chege Water Treatment Works to Gigiri Reservoirs.
- **Scenario 1a**: Similar to Scenario 1 but transmission of additional water at Thika Dam will be via Ngorongo Water Treatment Works to Kabete Reservoirs.
- **Scenario 2:** Wellfields in Kiunyu and Ruiru followed by Northern Collector Phase I, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. Transmission of additional water at Thika Dam will be via Ngorongo Water Treatment Works to Kabete Reservoirs.
- **Scenario 3**: Wellfields in Kiunyu and Ruiru followed by Northern Collector Phase I, S. Mathioya River Transfer to Thika Dam and Maragua 4 Dam, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. Transmission of additional water at Thika Dam will be via Ndunyu Chege Water Treatment Works to Gigiri Reservoirs.
- **Scenario 3A**: Similar to Scenario 3 but transmission of additional water at Thika Dam will be via Ngorongo Water Treatment Works to Kabete Reservoir.
- **Scenario 4**: Wellfields in Kiunyu and Ruiru, Northern Collector Phase I (Irati River Transfer to Thika Dam), Maragua 4 Dam with S. Mathioya River Transfer to the Dam, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. Transmission of additional water at Thika Dam will be via Ndunyu Chege Water Treatment Works to Gigiri Reservoirs.

2.2.2 Preliminary Water Balances for Contemplated Scenarios

Considering the results of the Water Demand Projections, the Water Resources availability and expected yields of the proposed facilities a preliminary water balance was prepared for each of the contemplated scenarios.

The main figures are as follows:

- Estimated water demand from about 578,600 m^3/day (year 2010) increasing to 1,205,300 m^3/day (year 2035)
- Existing water resources providing about 542,400 m^3/day (year 2010) and slightly increasing to about 567,000 m^3/day (year 2035) due to the steady development of groundwater supply
- The deficit was estimated to be about 36,200 m^3/day in year 2010; the requirement for new resources mobilisation is estimated to be about 638,300 m^3/day (or 7.4 m^3/s) by year 2035.

The existing water resources availability is based on supply capacities of the existing production / transmission facilities, after completion of the recent rehabilitation works.

All Proposed Scenarios will meet the forecast Water Demand at the Project horizon with mobilisation of the identified new sources.

For the Proposed Scenarios, the contribution of treated wastewater from Nairobi was not taken into account for the Project Horizon. The use of treated wastewater requires relatively large volumes of wastewater being available in addition to the required sophisticated technologies and skills to run a wastewater treatment and recycling plant. In most cases, recycled wastewater / grey water is used for irrigation or industrial, not potable use. This requires a parallel transmission system. Implementation of a pilot scheme is proposed before embarking on a major investment programme using recycled treated wastewater as a resource.

Rainfall harvesting is not a major source for water supply to Nairobi City, primarily as the rainfall pattern is seasonal over two periods (long rains- March / April, short rains – October / November), therefore the availability of this source is not regular / continuous. Furthermore, the infrastructure / buildings development on-going within Nairobi is not conducive to rainfall harvesting i.e. mainly high rise structures are being constructed instead of single dwellings with pitch roofs.

However, rainfall harvesting can be considered as a resource during low flow / emergency period when source limitations occur. Also rainfall harvesting is a relatively cheap resource in the Satellite Towns and should therefore be encouraged.

2.2.3 Scenarios Components

The Proposed Scenarios were built by combining several works components as part of the selected schemes (dams, diversion weirs, tunnels, shafts, pipelines, treatment works, pumping plants, etc.) which were designed at preliminary level. The main structures involved in the various components are as follows:

- Northern Collector Phase 1: tunnel, Maragua, Gikigie and Irati weirs and intakes, Irati shaft, Kaanja access;
- Northern Collector Phase 2: tunnel, Maragua outlet, South Mathioya, Hembe, Githugi weirs and intakes, Hembe shaft;
- South Mathioya Transfer: weir, intake, tunnel, outlet;
- Ngorongo Water Treatment Works and Transmission Line from Thika Dam to Kabete Reservoirs.
- Maragua 4 Dam: dam, spillway, intake;
- Ndunyu Chege Treatment Works and Transmission Line: transmission line from Maragua to Ndunyu Chege WTP, Transmission Line to Gigiri Reservoir;
- Ndarugu 1 Dam: dam, spillway, intake, check dam, diversion of electric line, diversion of sewerage line;
- Chania River to Komu River Transfer: weir, Intake, tunnel, outlet;
- Ndarugu Pumping Stations, Treatment Works and Transmission Line: Pumping station from Ndarugu to WTP, transmission line to WTP, Ndarugu WTP, Pumping station from WTP to Gigiri, Transmission line from WTP to Gigiri.

2.2.4 Summary of Water Balance for Contemplated Scenarios (Ref. Water Options Review Report - Version 02)

The Water Balance for the 6 Scenarios studied under the Water Options Review Report - Version 02 and details of sequential development, schematic diagrams and planned implementation schedules are given in **Appendix 7.2**. The yields used in the comparison of the

6 Scenarios were based on Preliminary Hydrological and Water Balance Analysis which subsequently changed marginally as shown in the following Sections of this Chapter.

3 Extended Yield Analysis of the Northern Collector System and Water Balance Modelling

3.1 Introduction

Continuous population growth, urbanization and industrialization have increased water demand and strained the availability of water resources in Kenya today. Moreover, water scarcity is accentuated by uneven spatial distribution and degrading water quality. An assessment of the available water resources is a pre-requisite for the analysis of water resources stress and for the subsequent adoption of proper management strategies and hydraulic projects in order to:

- Ensure sufficiency of water supply according to demand
- Regulate flow distribution in time
- Distribute water in space
- Protect from flood or drought impacts
- Maintain water quality and
- Reconcile conflicts between different users.

Precipitation and evapo-transpiration, in combination with the natural characteristics of aquifers, determine the main climatic variables and can define the quantity of water resources. Precipitation is the main component of the surface water and groundwater resources.

Despite major advances in natural processes controlling the water balance, and although various monthly water balance models have been proposed by many hydrologists, it remains a difficult task to develop models that can be used for quantitative hydrological predictions at the basin scale. This is partly because of the fact that such models must meet the requirements of parsimony in terms of data inputs and model parameters. In order to ensure practical applicability, these models require sufficiently simple simulation procedure and parameter estimation based on available climate and catchment characteristics.

This Section presents the Extended Yield Analysis which has been carried out in addition to previous analysis presented in Chapter 6 of the Water Sources Options Review Report Version (02). Results from the Extended Yield Analysis are thereafter used in determination of potential sources and sizing of the infrastructure for the development of a Master Plan for Nairobi Water Supply. The following Chapters outline the Model Setup and Final Results of the Extended Yield Analysis for different Options of Water Infrastructure Development to meet the growing water demand for Nairobi City.

The Yield Analysis has been extended under Addendum 1 of the Consultancy Services. Based on discussions and meetings, the Yield Analysis was extended to include the following criteria:

- Yield Analysis based on Annual Occurrence. 90% Reliability, Daily Time Step Simulation (This is equivalent to approximately 98% WEAP Reliability and similar to criteria adopted by HH in 1986 Study)
- The Time series (Simulation Period) for Data was extended from 26 Years (1985 – 2010) to 37 Years (1973 – 2010)

- Compensation Flows (Reserve Flow / IFR)
- Analysis done based on Q_{95} Downstream Release for all Rivers except 1.4xQ_{95} for River Irati.(WRMA Guidelines indicate minimum downstream releases as Q_{95} flows)
- Northern Collector Rivers – Analysis done on 2xQ_{95} Downstream Release to check sensitivity on downstream release.
- Thika Dam Variable Release to Mwagu based on flows in Chania, Kimakia and Kiama Rivers,
- Maximum Abstraction at Mwagu Intake limited to 4.8m^3/s

3.2 Previous Studies

Detailed hydrological studies have been previously carried out by Howard Humphreys & Partners for the proposed resource developments in this Study. The Present Study therefore mainly comprises of a review of the Yield Analysis carried out in the previous studies.

Proposals for development of new sources after construction of Thika 6 dam site were initially studied and presented in the Long Term Development Plan (Regional Studies) by Howard Humphreys & Partners in 1986. The recommendations, were that after construction of Thika 6 (now Thika Dam), the next source was to develop the Northern Collector as part of the Third Nairobi Water Supply Project (TNWSP).

The specific studies by Howard Humphreys & Partners which form the basis of the present hydrological studies are:

- Long Term Development Plan (Regional Studies): Hydrology, (1986)
- Short Term Plan to 1995, (1986)
- Hydrology Review (Yield and Operations Studies) Volumes 1 & 2, (1995)
- Northern Collector Feasibility Study (1998)

3.2.1 Long Term Development Plan (Regional Studies): Hydrology, (1986)

This Study presented an overview of the water resources of a wide area and a range of options for resource development including the Northern Collector and Maragua 4 Dam were investigated.

The Study comprised of detailed hydrological studies of the region's major rivers, and defined the potential surface water resources available for development up to the planning horizon of 2010. In addition to assessment of reliable yields, particular attention was given to sediment delivery rates in the area, and a comprehensive analysis of low flows and flood discharges for the region.

The Regional Studies recommended that following the construction of the initial phase of the Thika 6 scheme, the next resource development would involve the construction of the Northern Collector into two stages. The first stage would involve construction of the collector to the South Mathioya River while the second stage was to extend to the North Mathioya River.

3.2.2 Short Term Plan to 1995, (1986)

This Study carried out detailed hydrological studies to evaluate the water resources potential of the Chania-Thika basin with a regulation reservoir on the upper Thika River. The Study also estimated the flood peaks and sedimentation rates in the catchments.

The Study established that the reliable yield from the construction of Thika 6 regulating Mwagu and diversions from Kiama and Kimakia Rivers will provide a total reliable supply of 3.8 m^3/s (328,320 m^3/d) at Mwagu for gravity supply to Nairobi.

3.2.3 Hydrology Review (Yield and Operations Studies) Volumes 1 & 2, (1996)

This Study was carried out to summarise the work undertaken in the previous hydrology by Howard Humphreys for the Third Nairobi Water Supply Project. The Study also detailed the control rules for application in the operation of the Thika-Chania system.

The work undertaken specifically involved yield studies of the Thika Dam at Ndakaini working in association with the Chania-Thika tunnel, which diverts water from the Thika reservoir to Chania river, intercepting Kiama and Kimakia rivers en route.

The Study confirmed previous hydrological studies by Howard Humphreys that the Thika-Chania system at Mwagu can provide 3.8m^3/s (328,320m^3/d) to Nairobi with a 90% reliable supply and sustain the required minimum compensation releases at Mwagu weir of 0.3 m^3/s (25,920 m^3/d).

3.2.4 Northern Collector Feasibility Study (1998)

The hydrological studies carried out in this Study were to quantify the water resources available in the rivers identified in the 1986 Regional Studies as being suitable for diversion and to define a scheme consistent with the requirements for water use within the catchments of these rivers asset by the compensation flows that meet the required increases in yield.

In this Study, it was recognised that the Northern Collector would form a part of an extended water resource system. This system would comprise of the existing Thika-Chania system which involves Sasumua Dam, Mwagu intake, Kiama and Kimakia river transfers, Thika Dam and the proposed Northern Collector comprising of transfers from Irati, Gikigie, Maragua, S. Mathioya, Hembe, Githugi and N. Mathioya rivers. This required the analysis to focus on the increase in yield obtainable from the system as a whole rather than the tunnel in isolation.

The objectives of the hydrological studies carried out under this Study were to:

- Assess the available water resources.
- Define the yields available from the system for different configurations of tunnel length, number of rivers diverted and diversion capacity.
- Determine design flood flows at the diversion sites.
- Assess sedimentation issues and the implications for the diversion works and tunnel design.
- Assess the impact on local run-of-river hydropower generation.

The Study recommended that the Northern Collector be developed to intercept a proportion of the flow in rivers to the north of Thika reservoir into two phases. The two phases of construction and the additional reliable yields are:

- Phase I (Irati, Gikigie & Maragua) - 1.5m^3/s
- Phase II (S. Mathioya, Hembe, Githugi & N. Mathioya) - 2.3m^3/s
- Total Yield - 3.8m^3/s

The Study also carried out a preliminary analysis on the benefits of additional storage within the configuration of the Northern Collector. This was for the reason that the diverted flows from the collector significantly reduce the buffering capacity of Thika reservoir and additional yield can be accrued from the provision of additional storage.

As the general hydrology is adequately described in this Study and the 1986 Regional Studies, not much attempt has been made to describe regional patterns of rainfall, runoff, drought flows, floods, water quality, sedimentation and the project impact on the local run-of-river hydropower generation in the present Study.

3.3 Modelling the Integrated Water Resource System

The Integrated Water Resource System comprises of the

- Existing System comprising of Sasumua and Thika Dams with diversions from Kiama, Kimakia and Chania rivers.
- Proposed System comprising of the
    - Northern Collector Phase I which will divert water from Irati, Gikigie and Maragua rivers and
    - Northern Collector Phase II which will divert water from S. Mathioya, Hembe, Githugi and N. Mathioya rivers.

3.3.1 Hydrology

Detailed hydrological analysis was carried out for all the rivers within the catchments of the Existing System and Proposed Northern Collector System. This has been presented in the Water Resources Options Review Report v02 (Egis/MIBP JV).

Data from this analysis was used to set up the Computer Model for simulation of the Water Resource System.

Reference is therefore made to the aforementioned Report for any information required regarding hydrology of the rivers of interest.

3.3.2 The Operation of the Water Resource System

The Existing and Proposed Systems will operate as an integrated system delivering optimal yield at Mwagu and Thika Dam. However, simulation of the system has to follow a particular operational logic based on how it will be practically operated.

Based on the current operation, water is first diverted from Kiama and Kimakia Rivers into the Chania River to meet the demand at Mwagu. If this is insufficient, the deficit is met by additional supply from Thika Dam.

Upon introduction of NC I, water will be diverted from Irati and Gikigie Rivers first to meet the demand at Thika Dam. Any deficit will then be supplied from Maragua River. This means that the diversion at Maragua River will be regulated. Maragua River was selected for regulation because it is relatively larger than Gikigie and Irati Rivers.

On the same principle, the diversions for NC II will commence with South Mathioya River, thereafter moving north to North Mathioya River.

It should be noted that all diversions except Maragua are unregulated hence water will continuously be diverted to intake capacity whenever possible irrespective of demand and storage situation at Thika Dam.

3.3.3 Modelling Data and Parameters

The stream flow time series for additional rivers studied was collected from the Water Resource Management Authority (WRMA) and the data quality verified and corrected where necessary.

General Parameters

i) The Simulation Period and Time Step

The Simulation Period adopted was the 38 year period spanning year 1973 – 2010.

Looking at the historical context of climate extremes in East Africa, a large variability in rainfall with extreme events in terms of droughts and floods have occurred in the past as follows[1]:

- Droughts in the last 20 years - 1991/92, 1995/96, 1999/2001, 2004/2005.
- El-Nino related floods of 1997/98 which were a very severe event enhanced by unusual pattern of SST in the Indian Ocean[2]

The above events were all captured within the period that was analysed. The most recent El Nino (1997/98) and La Nina (1999/2000) were the most severe in 50 years. The above occurrences are evident in the stream flow hydrographs. The low and high flows in the data corresponded to the stated periods of climate extremes.

The Daily Time Step was adopted since data at this resolution was available for simulation.

ii) Reliability of Supply

Reliability can be defined using the time-based concept where the number of time steps experiencing deficit in supply is expressed as a percentage of the total number of time steps. This is mathematically expressed as follows:

$$R = \left(1 - \frac{Number\ of\ Time\ Steps\ with\ Failure}{Total\ Number\ of\ Time\ Steps}\right) x\ 100\%$$

On the other hand, the Annual Occurrence based concept of Reliability defines all failures within any one year as a single failure for that particular year. This is irrespective if the magnitude of the failure in any particular year. The reliability is then expressed as follows:

$$R = \left(1 - \frac{Number\ of\ Years\ with\ Failure}{Total\ Number\ of\ Years}\right) x\ 100\%$$

[1]Accessed from http://weadapt.org/knowledge-base/wikiadapt/climate-changes-in-east-africaon 15th May 2011

[2]IPCC (2007): Climate Change 2007: The Physical Science Basis, IPCC Secretariat, Geneva, Switzerland.

Therefore, 90% Reliability is defined as 10% of years experiencing some level of failure within a year, irrespective of the actual period of that failure within that year. For the Simulation Period, this is equivalent to 3.8 years of failure.

After discussions with the Client and World Bank, the 90% Annual Occurrence Based Reliability definition was adopted.

The Existing System

i) Hydrological Data

The stream flow time series for the Chania, Kiama and Kimakia Rivers were obtained from BRLiIngenierie, which was the lead Consultant for the recently completed hydrological Study for Ngethu-Sasumua System[3]. The data was taken as-is and no further analysis on its quality carried out, as this checking exercise was reported already completed under the BRLi Study.

ii) Diversion Capacities of Intakes

The diversion capacities for the existing Kiama, Kimakia and Chania River Intakes are based on the following design capacity:

- Kimakia - 1.0m^3/s
- Kiama - 5.8m^3/s
- Chania (Mwagu) - 5.3m^3/s

iii) In-stream Flow Requirement (IFR)

"In-stream Flow Requirement" (IFR), also known as Reserve Flow, is categorized as the demand that must first be met downstream of the Diversions. This demand comprises the Ecological Flow and Compensation Flow. The Ecological Flow is the flow required to sustain the downstream river environment whereas the Compensation Flow is the flow required to meet the demands of the downstream users.

Detailed river studies are ideally required, as every river system has differing ecological needs. In the absence of such studies, the Water Resource Management Authority (WRMA) guidelines suggest calculating the IFR as the flow in the river equalled or exceeded 95% of the time (Q_{95}). This flow is intended to be sufficient for the environmental requirements and basic human water needs downstream.

The In-stream Flow Requirements as adopted from the Howard Humphreys Report are as follows:

- Kiama River: 0.05m^3/s
- Kimakia River 0.14m^3/s.
- Chania River: 0.158m^3/s as the minimum statutory compensation. A later report by Howard Humphreys[4] used 0.3m^3/s as the compensation flow downstream of Mwagu Weir. However, the BRLi Study used the minimum requirement of 0.158m^3/s in their Study.

[3]BRLi Ingenierie in Joint Venture with Seureca, 2011. Consultance Services for Hydrological Study and Water Management for the Ngethu – Sasumua System. Client: Athi Water Services Board.

[4]Howard Humphreys (K), 1998. Third Nairobi Water Supply Project, Northern Collector Scheme Feasibility Report Volume I, page 4-56

The currently allowed downstream release for Thika Dam is 0.125m^3/s. This rate is authorised by the WRMA.

The Yield Assessment of the entire System has been carried out using both options of IFR values (0.158m^3/s and 0.30m^3/s) for the Chania River for comparison purposes. The results are presented in Chapter 5.

iv) Existing Dams

Data for Thika and Sasumua Dams was obtained from the relevant Authorities and previous reports. The data comprised of the following:

1) Volume – Area – Elevation Curves
2) Dam storage time series
3) Inflow time series into the dams

v) Dam Operational Rules

Development of operational rules for Thika Dam is beyond the Scope of this Study. However, as a preliminary analysis, a simple set of rules based on depth zones established in the Thika Dam Operation Philosophy prepared by Howard Humphreys was developed to assess the yields that would be available under realistic constrained conditions of dam release during extreme low flows.

As a starting point, the reservoir was simulated without any operational rules, which provided the 90% reliable yield available irrespective of the reservoir draw down within the period. Therefore, in some instances, the reservoir storage was zero.

The reservoir was thereafter divided into five storage zones based on the inlets in the existing draw-off tower. Each zone was assigned a maximum yield allowable. The allowable yield therefore was tapered downwards from the topmost zone.

The yields were derived through an iterative process guided by two criteria:

1) The revised yield was maintained at 90% reliability, and

2) The reservoir was not allowed to dry up completely but the lowest level ranged between storage volume of 5 -10Mm^3.

vi) Existing System Configuration

The Modelling exercise commenced with the setup and simulation of the Existing System which is defined as the integrated operation of Sasumua Dam, Thika Dam and intakes on Kimakia, Kiama and Chania rivers which supply the Mwagu offtake from where the raw water is supplied to the Ngethu Water Treatment Plant (NWTP). The water demand for NWTP is first met from the Chania, Kiama and Kimakia Rivers, with any deficit then diverted into these rivers from Thika Dam. Therefore, there is a varied release from Thika Dam to meet NWTP demand as and when required. Sasumua Dam has been included in the Model to capture the contribution of the dam spills in the water balance of the Chania River.

Proposed System

The “Proposed System” comprises the Northern Collector (NC) Phases I and II. The NC system will divert water from seven rivers in the Tana Basin north of Thika Dam. These are the Irati, Gikigie, Maragua, South Mathioya, Hembe, Githugi and North Mathioya Rivers.

i) Hydrology

A summary of the hydrology of the Project Rivers is already presented in Chapter 1 of this Report. Reference is made to the Water Resources Options Review Report v2 and Preliminary Design Report v2 for more details.

The aforementioned hydrological analysis carried out in-filling of gaps for observed flow sequences for related River Gauging Stations. In line with previous studies, the flows at diversion sites have been transposed assuming they are correlated to the associated nearest gauging station in proportion to respective catchment areas. The Transposition Factors are given in Table 7-1.

Figure 7-1: The Existing System

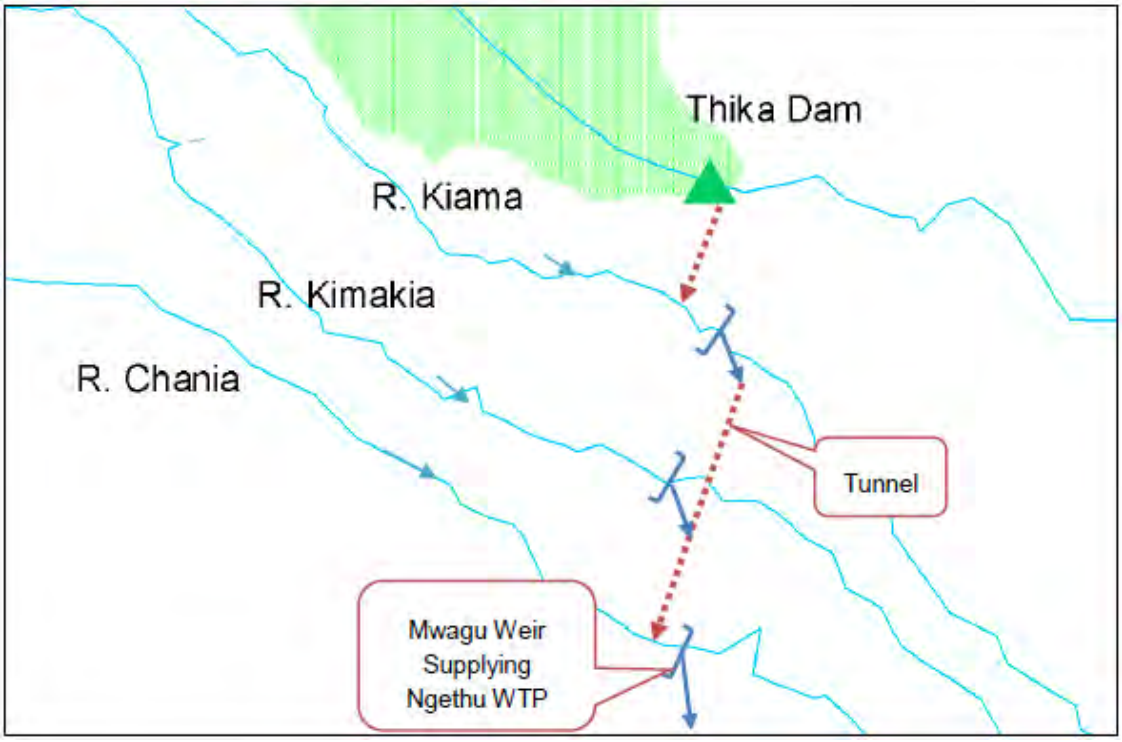


Table 7-1: Transposition Factors for Diversions on the NC Rivers

	River	Associated RGS	Ratio
Northern Collector I	Irati	4BE6+4BE7	1.00
	Gikigie	4BE8	1.00
	Maragua	4BE9	0.917
Northern Collector II	South Mathioya	4BD6	0.677
	Hembe	4BD7	0.227
	Githugi	4BD7	0.192
	North Mathioya	4BD7	0.513

Source: Table 4.7, Northern Collector Scheme, HH, June 1998

The time series of stream flow at each Diversion location has been input to the Model from an external Excel file database.

ii) Diversion Capacity

The recommended diversion capacity[5] for each river in the NC system is given in Table 7-2. It was ensured that the downstream requirement for each diversion is fully met before any diversion takes place.

Table 7-2: Recommended Diversion Capacities for each River

Phase	River	Diversion Capacity (m^3/s)	Tunnel Capacity (m^3/s)
I	Maragua	3.0	12
	Gikigie	1.0	
	Irati	2.0	
II	North Mathioya	2.5	6
	Githugi	1.0	
	Hembe	1.0	
	South Mathioya	1.5	

Source: Northern Collector Scheme Feasibility Report Volume I, 1998

iii) In-stream Flow Requirement (IFR)

Two different values of IFR, namely Q_{95} and $2xQ_{95}$, were applied to the NC Rivers in the modelling exercise, and the resulting system yields were contrasted at Thika and Maragua 4 Dams.

In addition, a variation equivalent to $1.4Q_{95}$ for Irati River was also tested since Q_{95} was deemed inadequate to meet the IFR. The results are presented in later sections of this Report.

The revised Q_{95} values based on the extended stream flow series for the Project Rivers are presented in Table 7-3.

A preliminary analysis of downstream water users has been carried out, details of which are presented in **Appendix 7.3**.

Table 7-3: Allocated In-stream Flow Requirement for the Project Rivers

	River	Q_{95} (m^3/s)
NC I	Maragua	0.645
	Gikigie	0.100
	Irati	0.340[6]
NC II	North Mathioya	1.170
	Githugi	0.435
	Hembe	0.520
	South Mathioya	0.625

3.3.4 WEAP: A Decision Support Tool

The Water Evaluation and Planning (WEAP) software is a desktop tool for Integrated Water Resource Planning which has been developed by the Stockholm Environment Institute's (SEI)

[5]Howard Humphreys (K), 1998. Third Nairobi Water Supply Project, Northern Collector Scheme Feasibility Report Volume I, pg 4-56

[6]This value varied to $1.4Q_{95}$

Boston Center. Over the past fifteen years since its first application in the Aral Sea region, the Model has undergone major improvements such as a user-friendly graphical user interface (GUI), a more robust water allocation algorithm and the integration of hydrologic sub-modules that include a conceptual rainfall-runoff, a groundwater and stream water quality Model. Furthermore, additional coupling options to external models such as Modular Three Dimensional Groundwater Flow Model (MODFLOW) and QUAL2E water quality model is also available in case the Modeller finds the built-in sub-modules inadequate.

The WEAP Model is a user-friendly tool that incorporates an integrated approach to Water Resource Management, which over the last decade, has placed more emphasis on demand side management, water quality and ecosystem preservation and protection. The Model integrates simulation of both the natural and engineered components of a water resource system by placing demand side issues such as water use patterns, equipment efficiency, re-use strategies, costs and water allocation schemes on an equal footing with supply-side resources such as available surface and groundwater, reservoir storage and inter-basin transfers. This gives the water manager the freedom of a more comprehensive view of the consequences of various planning and operation decisions on the system.

The literature presented herewith on the WEAP Model has largely been drawn from the accompanying user guide prepared by SEI.

i) Model Features

WEAP operates on the basic principle of a Water Balance and can be applied to Municipal and Agricultural systems, a single watershed or complex Trans-Boundary River Basin Systems. Moreover, WEAP can simulate a broad range of natural and engineered components of these systems, including rainfall runoff, base flow, and groundwater recharge from precipitation; sectoral demand analyses; water conservation; water rights and allocation priorities, reservoir operations; hydropower generation; pollution tracking and water quality; vulnerability assessments; and ecosystem requirements. A Financial Analysis module also allows the user to investigate cost-benefit comparisons for projects.

WEAP applications generally include several steps. The Study definition sets up the time frame, spatial boundary, system components and problem configuration. A baseline year is defined as the ‘current accounts’ in the Model for which the actual data of confident quality is available. Alternative sets of future assumptions are then developed based on for example policies, costs, water demands, pollution, supply and hydrology. Thereafter, scenarios are constructed using either a single or a combination of these sets of assumptions and evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets and sensitivity to uncertainty in key variables.

At each time step, WEAP first computes the hydrologic response of the Study Area, which is then transferred to the respective river and groundwater components. The network allocation is then processed for the given time step, based on different priorities assigned to reservoirs, water distribution network, environmental flows *etcetera*. As in reality, all flows in the Model occur instantaneously, thus a demand site can withdraw water from the river, consume some, optionally return the remainder to a Wastewater Treatment Plant and then return it to the river in the same time step. The simulation time steps in the Model can vary from daily, to weekly, to monthly or even seasonally with a time horizon from as short as a single year to more than 100 years.

So the question arises, why use WEAP? The following highlights its suitability and advantages:

- Integrated Water Resources Planning System

- Built-in models for: Rainfall runoff and infiltration, evapo-transpiration, crop requirements and yields, surface water/groundwater interaction, and in-stream water quality
- GIS-based, graphical "drag and drop" interface
- Model-building capability with a number of built-in functions
- User-defined variables and equations
- Dynamic links to spreadsheets and other models
- Flexible and expandable data structures
- Powerful reporting system including graphs, tables and maps

WEAP has been applied in water assessments in various countries, including the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, South Africa, Mozambique, Egypt, Israel, Oman, Central Asia, India, Sri Lanka, Nepal, China, South Korea, and Thailand. It has also been applied in some projects in Kenya.

ii) Application of WEAP

WEAP has been applied in water assessments in various countries, including the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, South Africa, Mozambique, Egypt, Israel, Oman, Central Asia, India, Sri Lanka, Nepal, China, South Korea, and Thailand. It has also been applied in some projects in Kenya.

iii) Data Requirements

Hydrology

The hydrology of a basin can either be modelled within WEAP or simulated using secondary data from other sources. WEAP offers 4 different built-in hydrological modelling methods namely:

- Irrigation Demands Only Method (FAO Crop Requirements Method)
- Rainfall Runoff Method (FAO Crop Requirements Method)
- Rainfall Runoff Method (Soil Moisture Method)
- MABIA Method (FAO 56, Dual Kc, Daily)

Data can be entered manually into WEAP. If a time series of stream flow data is available, it can either be typed into the Model or dynamically linked via an excel spreadsheet. The latter method is easier because any changes made in the spreadsheet are automatically updated in WEAP.

Water Infrastructure

Reservoirs

Reservoirs can either be modelled as on-river, with rivers draining to them or off-river whereby a transmission link is placed from a river to supply the reservoir. The physical parameters required to adequately simulate a reservoir are: inflows, initial and total storage capacity, volume elevation curve, evaporation and losses to groundwater.

Operation of reservoirs can also be simulated but in a simple manner. The reservoir storage is divided into four zones which are, from top to bottom, the flood control zone, conservation, buffer and inactive zones. The conservation and buffer zones constitute the active storage.

WEAP allows the reservoir to freely release water from the conservation pool to fully meet withdrawal and other downstream requirements, and demand for energy from hydropower. Once the storage level drops into the buffer pool, the release will be restricted according to the buffer coefficient, to conserve the reservoir's dwindling supplies. Water in the inactive pool is not

available for allocation, although under extreme conditions evaporation may draw the reservoir into the inactive pool.

Inter-Basin Transfers

Inter-basin transfers are modelled as 'diversions' in WEAP. Diversions are like rivers and can have a series of reservoirs, run-of-river hydropower schemes, In-stream Flow Requirements (IFR), withdrawals, other diversions, tributaries, catchment inflows and return flows from waste water treatment plants etc.

Water Demand

Water demand can be categorized as Human or Environmental water demand. For human demand, the extent of detail to which it can be modelled depends on necessity and the availability of data. For example, water demand for a city can be aggregated to an annual volume, or expressed as monthly values if inter-monthly variation is significant. Furthermore, the demand can be broken down to represent different types of consumers.

The Environmental Demand known as the In-stream Flow Requirement (IFR) in WEAP is the water requirement in a river at a particular location to maintain *status quo* in the downstream environment.

All entered values can be altered to develop different scenarios. This allows the planner to capture the combined effects of separate changes at many levels, for example, the growth in the total population or change in household structure.

An important feature of WEAP is the ability to assign priorities to the different water demands. This allows for a very flexible environment to simulate the actual operations of a water resource system. For example, the In-stream Flow Requirement can be assigned the highest priority thereby ensuring that the Model always meets this demand first before satisfying other demands.

The same principle can also be applied to demand sites dependent on conjunctive use of surface and groundwater resources. Therefore, if surface water is the preferred source, it is assigned a higher priority. The Model will then attempt to meet the demand from surface water only, and then supplement the deficit from the groundwater source.

Figure 7-2: The Graphical User Interface (GUI) of WEAP

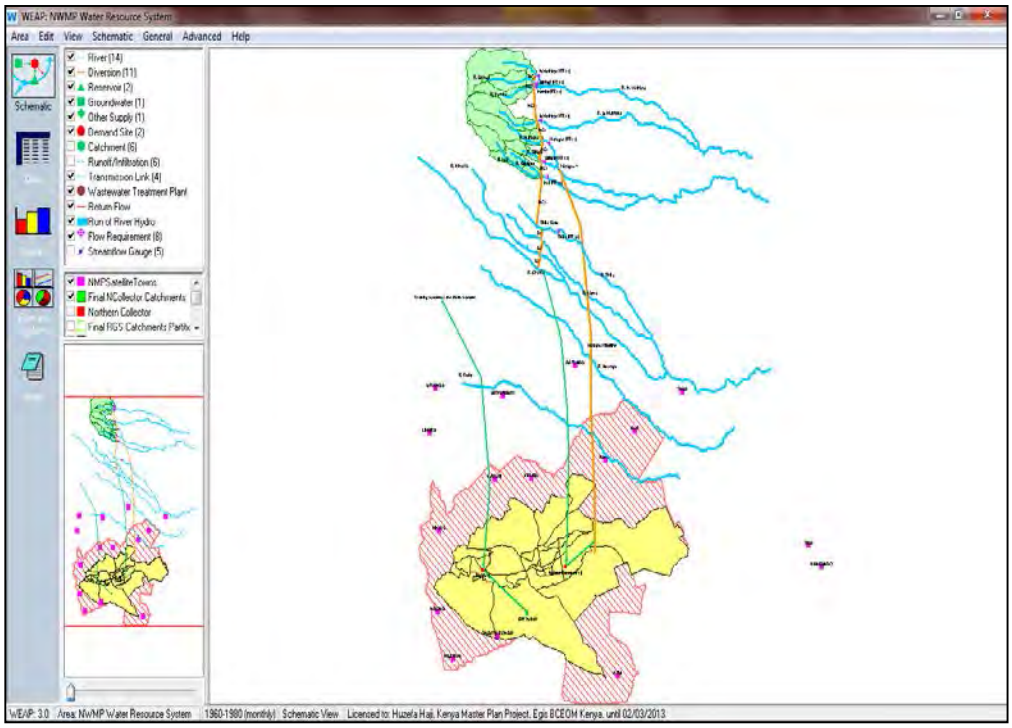


Figure 7-3: The Different Components of the Side Panel of GUI

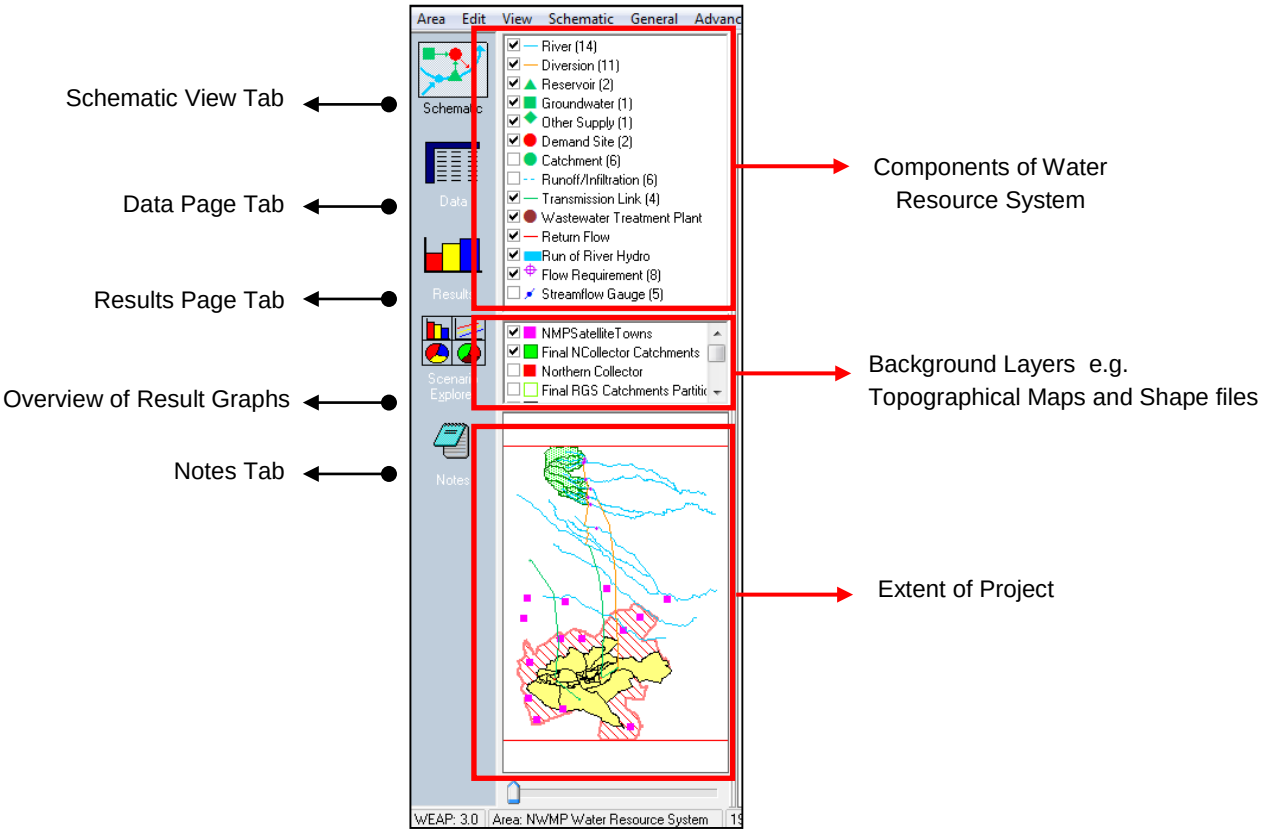
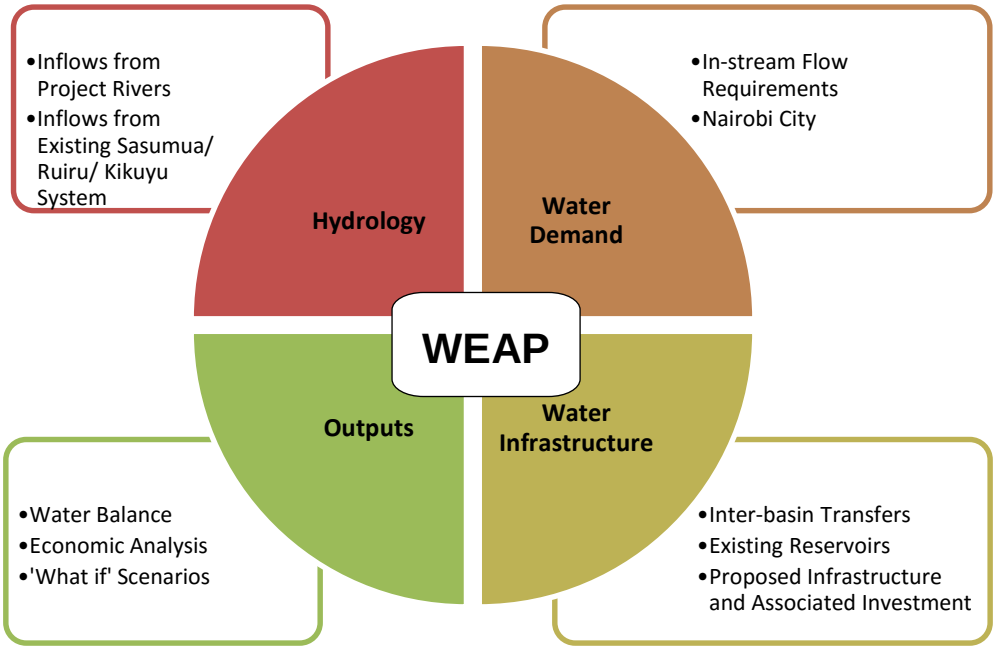


Figure 7-4: Summary of Model Setup and Data Requirements



3.4 Analysis of the Existing System

As a first step towards building the Integrated Water Resource Model, the Existing System was set up in WEAP using the Parameters outlined in Sections 3.3.3. This enabled an insight into the workings of the Existing System and also to validate the Model. Reference is made to Figure 7-1 for a schematic of the Existing System.

3.4.1 Yield Analysis

Yield at Mwagu and Thika Dam

The Model was run to determine the available yield at Mwagu and the gross yield at Thika Dam. Thika Dam was simulated with and without Operational Rules. Table 7-4 gives the results.

Table 7-4: Yield Analysis of Existing System

90% Reliable Yield (m^3/s)	Without Operational Rules at Thika Dam	With Operational Rules at Thika Dam
Thika Dam (Gross)	2.20	-
Mwagu (Chania IFR = 0.158m^3/s)	5.03	4.60

Discussions with the Nairobi City Water & Sewerage Company (NCWSC) revealed that the current average abstraction from Mwagu Weir is approximately 4.6m^3/s.

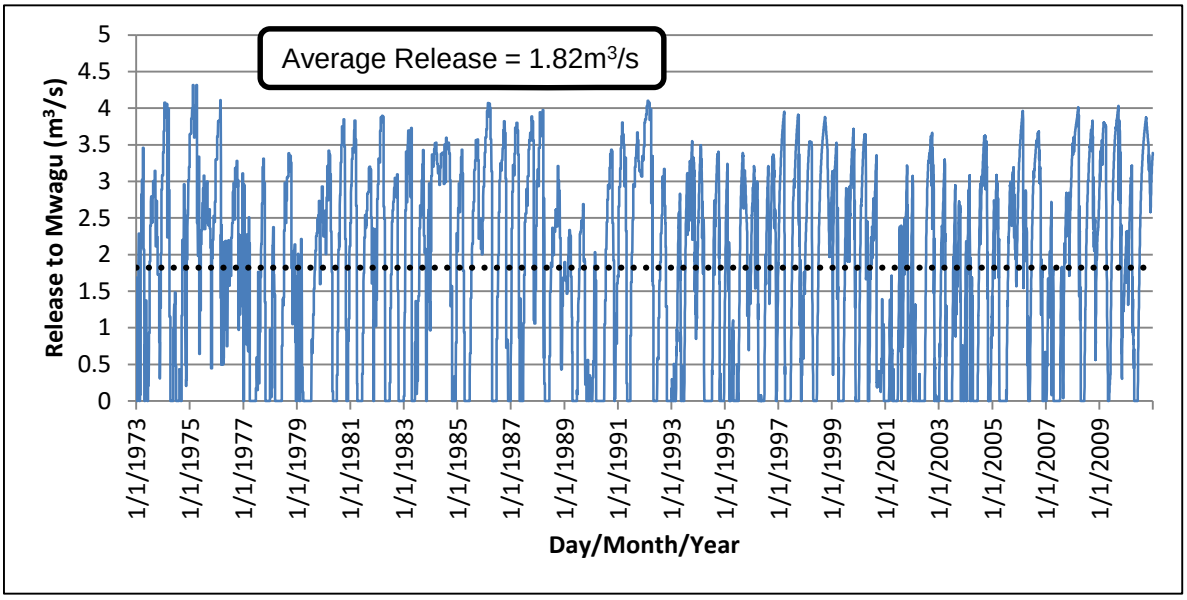
The simulated 90% Reliable Yield of the Existing System at Mwagu is 4.93m^3/s when considering Chania River IFR equal to 0.3m^3/s.

The Design Capacity of the Existing System is 5.3m³/s.

Varied Release from Thika Dam

Since Thika Dam is primarily used to augment supply to Mwagu in case of any deficit, the dam release varies with time. The simulated time series of varied release from Thika Dam to Mwagu is given in Figure 7-5. On average, the dam releases 1.82m³/s to augment supply at Mwagu.

Figure 7-5: Simulated Daily Release from Thika Dam to Mwagu



3.4.2 Conclusion

The results obtained from the analysis of the Existing System are in agreement with the reported abstractions at Mwagu and the BRLi Study results. Therefore, the Model setup has been validated. The simulated yield at Mwagu incorporating reservoir operational rules was 4.6m³/s which corresponds to the reported average abstraction of approximately the same magnitude. Furthermore, the simulated average varied release from Thika Dam to Mwagu is 1.82m³/s which is close to the reported release of 1.91m³/s by BRLi. The difference can be attributed to the different Simulation Period used in this Study.

The regulatory capacity of Thika Dam is limited in case the inflows are increased. The Storage Ratio shows that there is inadequate capacity of the reservoir to buffer any additional inflows. This concurs with previous studies and the necessity of augmenting storage within the system is highlighted.

3.5 Analysis of the Northern Collector System

The Model setup outlined in Section 3.4 was extended to include the Northern Collector System (NC). This System is phased into two namely NC I and NC II.

The NC I comprises of intakes and tunnel diversions from 3 rivers namely Irati, Gikigie and Maragua.

The NC II comprises of intakes and tunnel from 4 additional rivers namely South Mathioya, Hembe, Githugi and North Mathioya.

The diversion parameters for both NC I and NC II are given in Table 7-2 in Section ii).

Figure 7-6 shows the WEAP setup for the Existing System, NC I and NC II systems.

3.5.1 Practical Capacity of Existing System

Although the reported design capacity of Ngethu WTP is 5.3m^3/s, the plant operators have advised that the actual treatment capacity is less. The recently completed rehabilitation works of the raw water pipeline from Mwagu to the Plant yielded a marginal increase in capacity to a maximum of approximately 4.8m^3/s.

Flow measurements and assessment of raw water transmission capacity from Mwagu Weir to Ngethu Water Treatment Works carried out by BRLi Seureca and presented in the Report dated March 2012 have confirmed the above mentioned optimum capacity of 4.8m^3/s for the existing transfer system.

It was therefore agreed with the Client to set the required yield at Mwagu to the more practically achievable capacity of 4.8m^3/s, rather than the original design capacity 5.3m^3/s.

The simulation of the Northern Collector System was categorized into 3 main Options which comprise of different combinations of IFR and With/Without Operational Rules at Thika Dam. The results are presented in the following Sections.

3.5.2 Yield Analysis of Northern Collector Phase I

Simulation of the Existing System with NC I was carried out under the following conditions:

- IFR for Thika, Chania, Kiama and Kimakia of 0.125m^3/s, 0.158m^3/s, 0.05m^3/s and 0.14m^3/s respectively.
- IFR of Q_{95} and $2Q_{95}$ for the NC rivers.
- With and without Operational Rules for Thika Dam

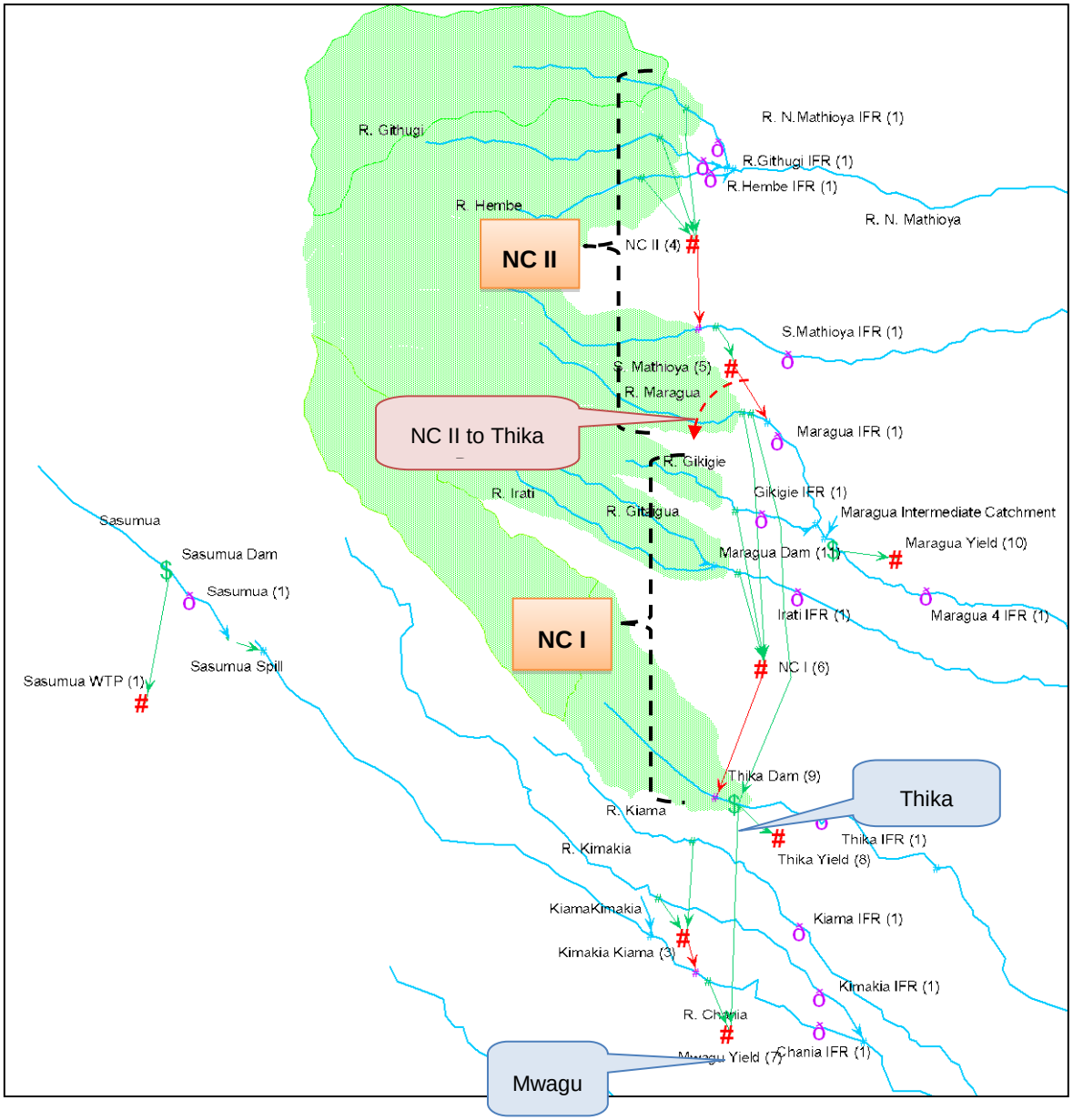
The results of the simulation are presented in Table 7-5.

Table 7-5: Simulated Yields (m^3/s) for the Existing System with NC I

Component	Without Operational Rules		With Operational Rules For Thika Dam Only	
	Q_{95}	$2xQ_{95}$	Q_{95}	$2xQ_{95}$
Mwagu	4.80	4.80	4.80	4.80
Additional Thika Yield	1.68	0.85	1.23	0.50

Note: Chania IFR = 0.158m^3/s, Irati IFR = Q_{95}

Figure 7-6: WEAP Schematic of the Entire Water Resources System



A preliminary assessment of downstream demand on the NC Rivers indicates the release of Q_{95} for Irati River may be inadequate to meet the downstream ecological and human demand. (Water Options Review Report, Version 02, Egis / MIBP JV). The downstream release was thereby increased by a Factor of Safety of 1.2 to meet the demand.

Furthermore, the use of 0.158m^3/s for Chania River corresponds to the minimum statutory requirement, and a higher value of 0.3m^3/s has been used previously by Howard Humphreys.

Therefore, simulations were carried out using three different combinations of the changed IFR values for Irati and Chania Rivers. The combinations are given in Table 7-6.

Table 7.6: Case Definitions

	IFR	
Case	Chania (m^3/s)	Irati
1	0.3	Q_{95}
2	0.3	1.4x Q_{95}
3	0.158	1.4x Q_{95}

The cases for Chania IFR = 0.158m^3/s and Irati IFR = Q_{95} have already been presented in Table 7-5. Table 7-7 gives the yield results for the above cases.

Table 7-7: Simulated System Yields (m^3/s) for Different Combinations of IFR for Chania and Irati rivers

	Without Operational Rules			*With Operational Rules*		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Component	Chania – 0.3 Irati - Q_{95}	Chania – 0.3 Irati – 1.4xQ_{95}	Chania – 0.158 Irati – 1.4xQ_{95}	Chania – 0.3 Irati - Q_{95}	Chania – 0.3 Irati – 1.4xQ_{95}	Chania – 0.158 Irati – 1.4xQ_{95}
Mwagu	4.80	4.80	4.80	4.80	4.80	4.80
Additional Thika Yield	1.50	1.40	1.54	1.10	0.95	1.08

The mean annual inflow to Thika Dam after introducing NC I increases from 2.49m^3/s to 4.96m^3/s. The Storage Ratio is concurrently reduced to 0.44 from 0.87.

Table 7-8: Thika Dam Storage Ratios

Project Phase	MAI (m^3/s)*	MAI (Mm^3/Year)	Storage/MAI
Existing (Thika Dam Natural	2.49	78.5	0.87
Thika Dam+ NC Phase I	4.96	156	0.44

**MAI is net of releases for Downstream Users*

3.5.3 Yield Analysis of Northern Collector Phase II

The Model setup under Section 3.5.2 was further extended to include NC II under the same conditions used for NC I. Therefore, water transfer into Thika Dam is now simulated with transfer from 7 additional rivers.

The results of the simulation are presented in Table 7-9.

Table 7-9: Simulated Yields (m^3/s) for the Existing System with NC I and NC II

	Without Operational Rules		**With Operational Rules For Thika Dam Only**	
Component	**Q_{95}**	**2xQ_{95}**	**Q_{95}**	**2xQ_{95}**
Mwagu	4.80	4.80	4.80	4.80
Additional Thika Yield	3.58	1.66	3.05	0.80

Note: Chania IFR = 0.158m^3/s, Irati IFR = Q_{95}

Similar to NC I, the different Cases of varied IFR for Chania and Irati were also used. Table 7-10 gives the yield results for the above cases.

Table 7-10: Simulated System Yields (m^3/s) for the Existing System with NC I and NC II

	Without Operational Rules			*With Operational Rules*		
	Case 1	**Case 2**	**Case 3**	**Case 1**	**Case 2**	**Case 3**
Component	**Chania – 0.3 Irati - Q_{95}**	**Chania – 0.3 Irati – 1.4xQ_{95}**	**Chania – 0.158 Irati – 1.4xQ_{95}**	**Chania – 0.3 Irati - Q_{95}**	**Chania – 0.3 Irati – 1.4xQ_{95}**	**Chania – 0.158 Irati – 1.4xQ_{95}**
Mwagu	4.80	4.80	4.80	4.80	4.80	4.80
Additional Thika Yield	3.45	3.30	3.50	2.92	2.80	2.90

Buffering Capacity of Thika Dam

The Storage Ratio is defined as the ratio of the net available storage of an impounding reservoir to the mean annual flow of the feeding river. A low ratio implies limited capacity of the reservoir to provide storage and regulation for additional inflow. Table 7-11 shows the Storage Ratios for Thika Dam for augmented inflows from the development of NC I and NC II.

Table 7-11: Thika Dam Storage Ratios

Project Phase	MAI (m^3/s)*	MAI (Mm^3/Year)	Storage/MAI
Existing (Thika Dam Natural Inflow)	2.49	78.5	0.87
Thika Dam+ NC I	4.96	156	0.44
Thika Dam + NC I + NC II	8.40	265	0.26

*MAI is net of releases for Downstream Users

The consistent reduction of Thika Dam's Storage Ratio after introduction of NC I and NC II indicates the constrained ability of the reservoir to provide storage for the additional inflow. Therefore, more frequent spills can be expected.

However, these can be partially regulated by providing controls at the River Intakes for NC I and NC II. Incorporation of a control on the Maragua River Intake has been carried out in the Model.

3.5.4 The Selected IFR and Operational Rule Scenario

The IFR has been proven to significantly dictate the yields available from the Integrated Water Resource System. Therefore, the selection of which IFR scenario to adopt for determination of infrastructure capacity is critical towards the solution proposed and the magnitude of investment required.

The selection of the IFR Scenario has been guided by the paramount importance of downstream release. Therefore, in the case of Chania River, the maximum release of $0.3m^3/s$ is proposed to be adopted. Similarly, the release for Irati River is proposed to be $1.4Q_{95}$ so as to allow adequate water for downstream use.

Another dimension which affects the Yield is the incorporation of Reservoir Operation Rules. Reference is made to Table 7-5 and Table 7-9 which clearly show the effect of these rules on available Yields. The Reservoir Operation Rules are generally in effect during periods of

extreme low reservoir inflows or when such periods are expected in the near future. During some periods, the inflows would probably be adequate to avail the maximum yield for abstraction. Therefore, if the sizing of water infrastructure such as pipelines and treatment plants were to be based on the yields available when operation rules are in effect, the infrastructures would not have adequate capacity during periods of normal or higher flows.

However, on the other hand, if these infrastructures were to be designed on the maximum yields available without any Reservoir Operation Rules, then it would provide the opportunity to abstract the maximum Yield when flows allow and operate under capacity only during low flow periods. This would give flexibility to the system to optimise performance between the high and low flow periods.

Therefore the following parameters have been adopted:

- **An IFR of 0.3m^3/s for Chania River and 1.4Q_{95} for Irati River (Case 2)**
- **An IFR of Q_{95} for all other Northern Collector Rivers**
- **No reservoir operational rules are incorporated in the model**

The simulated System Yields based on the above parameters is given in Table 7-12.

Table 7-12: Summary of Final System Yields (m^3/s)

	System Yield (m^3/s)	
Component	NC I	NC I + NC II
Mwagu	4.80	4.80
Additional Thika Yield	1.40	3.30

3.5.5 Requirement of Additional Storage

The trend in Storage Ratio for Thika Dam with the introduction of NC I and NC II implies that additional storage is required in the System to capture the additional flows from the Water Transfers. If storage is not provided, then the water diverted through the NC System will overwhelm the Thika Dam and simply spill downstream.

Howard Humphreys (1998) briefly investigated possible options for providing additional storage listed below:

1. Increasing the capacity of Thika Dam
2. A new reservoir downstream of Thika Dam to regulate increased spillage arising because of the Northern Collector operation.
3. Reservoirs at one or more of the Northern Collector diversion points to regulate the river flows and hence increase the inflows to the Collector during the dry season.
4. Independent reservoirs on one or more of the Northern Collector rivers but with no connection to the Northern Collector.

Option 1 is not feasible since it has already been established that the Thika Dam embankment cannot be raised any further. Option 2 would be ideal in capturing the spills from Thika Dam. However, more detailed investigations are required to conclude on its feasibility. The same can be said for Option 3. All the intakes for the NC System are located within the Aberdares and therefore impoundment of these rivers at the intake locations will require extensive technical and environmental studies. Therefore, Option 4 remains the most feasible at this stage.

The Chania-Thika Study Supplementary Report by Howard Humphreys (1980) investigated eight potential dam sites to the north of Chania-Thika catchment and recommended provision of storage on Maragua River downstream of the NC diversion site at the confluence with Gikigie River. This is henceforth referred to as Maragua 4 Dam.

The location of the Maragua 4 Dam is appropriate since it allows the option of either sharing the NC II water with Thika Dam or diverting it entirely to Maragua 4 Dam depending on the location of the NC II tunnel outfall.

3.5.6 Conclusion

The Existing System together with the Northern Collector System were successfully modelled holistically as an Integrated System thus capturing the effects of one on the other. The maximum Yield from the Existing System at Mwagu was determined to be 4.6m^3/s and 5.08m^3/s with and without Reservoir Operation Rules respectively. It was agreed however, to limit the yield at Mwagu to 4.8m^3/s due to operational constraints of the transfer system from Mwagu Intake to Ngethu Treatment Works and also operational constraints at the Ngethu Treatment Works. This meant the additional yield which could be abstracted at Mwagu is transferred to Thika Dam for alternative use. It should be noted that the IFR used for the rivers in the Existing System were as per the current practice and not changed.

The Northern Collector Phase I and II were simulated with different combinations of IFR and respective System Yields of the Water Resource System assessed. These have been presented in Sections 3.5.2 and 3.5.3.The objective of using different IFR values was to assess its impact on System Yield. Appreciating the importance of downstream release, the higher value of 0.3m^3/s for Chania River and 1.4Q_{95} for Irati River is recommended. IFR equivalent to Q_{95} for the other NC rivers is also adopted based on the requirements of WRMA.

The main outcome of the modelling exercise was the sensitivity of System Yields to IFR, which is consistent with the findings of the earlier studies of Howard Humphreys. Basically, any change in IFR values either in the Existing or Northern Collector System has appreciable changes in the System Yields. Therefore, selection of which scenario to base the Engineering Design of the water infrastructure is critical.

Based on the importance of downstream release and the logic on using the maximum Yield available without Reservoir Operation Rules, it is proposed to adopt Case 2 without Reservoir Operation Rules for sizing the water infrastructure. The maximum available 90% reliable System Yields are given in Table 7-12.

In addition, the storage capacity of Thika Dam is not adequate to accommodate the additional inflows from the Northern Collector System as shown in Sections 3.5.2 and 3.5.3. Therefore, additional storage within the System is recommended. The most feasible dam site is Maragua 4 Dam which was initially proposed by Howard Humphreys. The Present Study also recommends the same proposal.

The Model has therefore been modified to incorporate Maragua 4 Dam with the NC System and various options of water transfer simulated. These are presented in Chapter 6.

3.6 Analysis of Northern Collector System with Maragua 4 Dam

This Chapter outlines the extended modelling exercise including Maragua 4 Dam in the System. The proposed Maragua 4 Dam site is located at the confluence of Maragua and Gikigie rivers downstream of the NC intakes. The following criteria were adopted under this simulation:

- Instead of only simulating the entire NC System, diversions from individual NC Rivers have also been investigated. These rivers are Irati and S. Mathioya which are part of NC I and NC II respectively.
- The storage capacity of Maragua 4 Dam has not been limited to a particular volume but a range of capacities from 30 – 120Mm^3 has been analysed.
- Based on the recommendations in Section 3.5.4, the Chania and Irati rivers IFR has been set at 0.3m^3/s and 1.4Q_{95}. The IFR for all other NC rivers is set as Q_{95}.
- Maragua 4 Dam is simulated without Operational Rules.
- The Maragua River Intake is simulated to stop diverting water to Thika Dam when full. Therefore, surplus water is automatically passed downstream to Maragua 4 Dam.

The Options of Water Transfer further investigated are presented in Table 7-13.

Table 7-13: Water Transfer Options further Investigated

Option	Component
1	Maragua 4 Dam with natural inflows only
2	Thika Dam + NC I + Maragua 4 Dam
3	Thika Dam + NC I + S. Mathioya Diversion + Maragua 4 Dam (*The S. Mathioya Diversion outfall is upstream of the NC I intake on Maragua River)*
4	Thika Dam + NC I + NC II + Maragua 4 Dam. (*The NC II outfall is upstream of the NC I intake on Maragua River)*
5	Thika Dam + NC I + S. Mathioya Diversion + Maragua 4 Dam (*The S. Mathioya Diversion outfall is downstream of the NC I intake on Maragua River)*
6	Thika Dam + NC I + NC II + Maragua 4 Dam. (*The NC II outfall is downstream of the NC I intake on Maragua River)*
7	Thika Dam + Irati Diversion to Thika Dam + S. Mathioya Diversion to Maragua 4 Dam + Maragua 4 Dam
8	Thika Dam + Irati Diversion to Thika Dam + NC II + Maragua 4 Dam (*The NC II outfall is downstream of the NC I intake on Maragua River)*
9	Thika Dam + Irati Diversion to Maragua 4 Dam + S. Mathioya Diversion to Maragua 4 Dam + Maragua 4 Dam
10	Thika Dam + Irati Diversion to Maragua 4 Dam + NC II + Maragua 4 Dam (*The NC II outfall is downstream of the NC I intake on Maragua River)*

3.6.1 Operation of Integrated Water System with Maragua 4 Dam

The integrated operation of the Existing System with Northern Collector has already been explained under Section 3.3.2.

The Model has been set to ensure highest priority of water supply to the Existing System and the Northern Collector. Water will first be diverted from Kiama and Kimakia Rivers into the Chania River to meet the demand at Mwagu. Any deficit will then be supplied from Thika Dam.

Upon introduction of NC I, water will first be diverted from Irati and Gikigie Rivers to meet demand at Thika Dam. Any deficit will then be supplied from Maragua River. This means that the diversion on Maragua River will be regulated which has the advantage of transferring surplus water, whenever possible, to Maragua 4 Dam instead of it spilling at Thika Dam. The same principle applies to diversions for NC II which commence with South Mathioya River, thereafter moving north to North Mathioya River.

All diversions except the one on Maragua River are unregulated hence water will continuously be diverted to maximum intake capacity whenever possible irrespective of demand and storage situation at Thika Dam.

Thika Dam has also been assigned higher priority in filling than Maragua 4 Dam. Therefore, in any particular time step, Thika Dam will meet demand and any surplus water in the system will first be used to refill its reservoir. Surplus water will then be used to fill Maragua reservoir.

3.6.2 Alternative Water Transfer Options

Option 1: Maragua 4 Dam with Natural Inflows only

This Option only investigates the impact of augmenting storage within the Existing Water Resource System. The proposed Maragua 4 Dam impounds both the Maragua and Gikigie rivers and will enable water supply by gravity to Nairobi City.

The yield simulation for Maragua 4 Dam was carried out under adopted parameters defined in Section 3.6. For comparison, the analysis was also carried out using IFR of $2Q_{95}$. Table 7-14 gives the Simulated Net Yields for the Dam for different storage capacities.

Table 7-14 : Simulated Net Yields for Option 1

	Yield (m^3/s)	
Component	**Q_{95}**	**$2Q_{95}$**
Maragua 4 Dam		
Capacity		
30Mm^3	1.80	0.90
60Mm^3	2.25	1.37
90Mm^3	2.40	1.50
120Mm^3	2.52	1.62

The Storage and Yield Ratios for the Dam are given in Table 7-14.

Table 7-15: Storage and Yield Ratios for Maragua 4 Dam – Option 1

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.36	1.80	0.70
60	0.73	2.25	0.86
90	1.09	2.40	0.92
120	1.46	2.52	0.97

Notes:

1. *Mean Annual Inflow (MAI) = 2.61m^3/s (82.3Mm^3/year)*
2. *MAI is Net of releases for Downstream users*

Figure 7-7 is a Layout Plan of the Proposed Arrangement under Option 1.

Option 2: NC I to Thika Dam + Maragua 4 Dam

This Option investigates the available yields for Maragua 4 Dam after implementing NC I. The inflows to Maragua 4 Dam are now reduced because of the diversions on Maragua and Gikigie rivers by the NC I.

Table 7-16 : Simulated Net Yields for Option 2

Component	Yield (m^3/s)
Maragua 4 Dam	
Capacity	
$30Mm^3$	0.84
$60Mm^3$	1.12
$90Mm^3$	1.30
$120Mm^3$	1.40

The Storage and Yield Ratios for the Dam are given in Table 7-17.

Table 7-17: Storage and Yield Ratios for Maragua 4 Dam – Option 2

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.63	0.84	0.56
60	1.27	1.12	0.75
90	1.90	1.30	0.87
120	2.54	1.40	0.93

Notes:

1. *Mean Annual Inflow (MAI) = 1.50m^3/s (47.3Mm^3/year)*
2. *MAI is Net of releases for Downstream users*

Figure 7-8 is a Layout Plan of the proposed arrangement under Option 2.

Figure 7-7 : Option 1

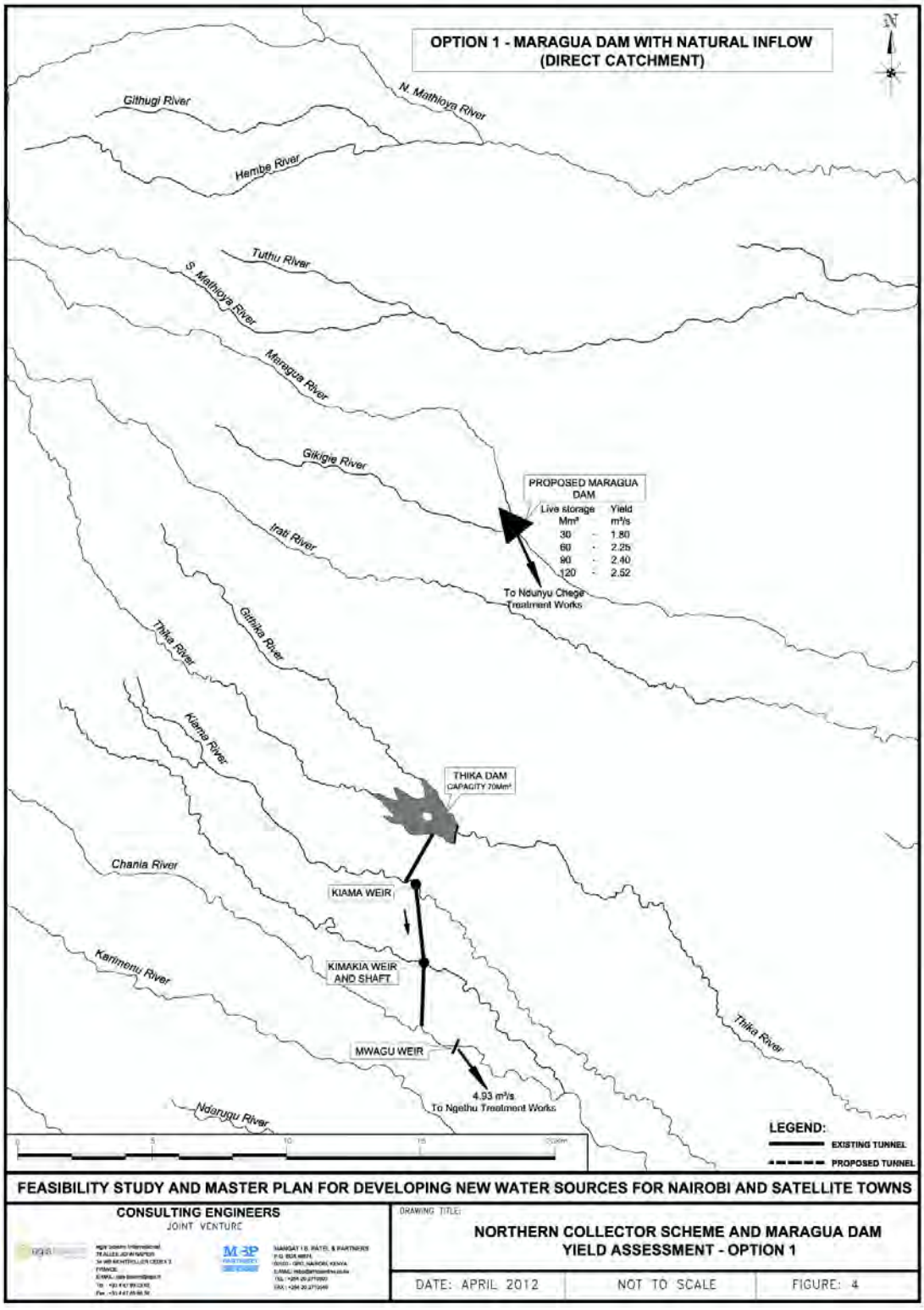
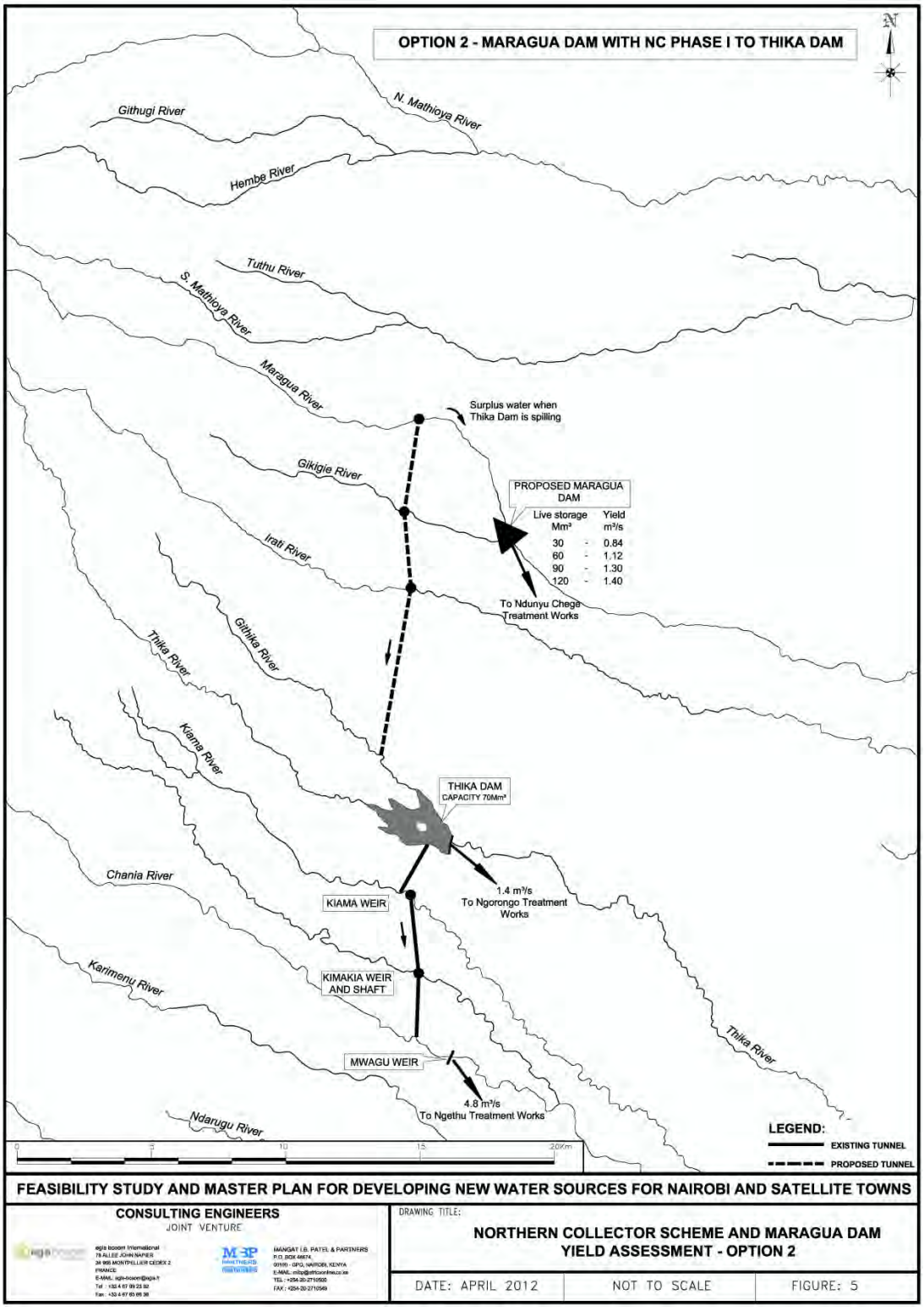


Figure 7-8 : Option 2



Option 3: NC I and S. Mathioya Diversion to Thika Dam + Maragua 4 Dam

This Option analyses the available yields for Maragua 4 Dam after implementing NC I and with an additional diversion from S. Mathioya River.

The outfall of the S. Mathioya Diversion is located upstream of the Maragua Intake for NC I thus enabling sharing of the additional water between Thika and Maragua 4 Dams. Therefore, in situations when Thika Dam is full, surplus water in Maragua River and from S. Mathioya Diversion will flow downstream to Maragua 4 Dam thus increasing its yield.

Table 7-18 : Simulated Net Yields for Option 3

Component	Yield (m^3/s)
Mwagu	4.80
Additional Yield at Thika Dam	2.00
Maragua 4 Dam	
Capacity	
$30Mm^3$	0.93
$60Mm^3$	1.28
$90Mm^3$	1.45
$120Mm^3$	1.70

The Storage and Yield Ratios for the Dam are given in Table 7-19.

Table 7-19: Storage and Yield Ratios for Maragua 4 Dam – Option 3

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.52	0.84	0.56
60	1.04	1.12	0.75
90	1.56	1.30	0.87
120	2.08	1.40	0.93

Notes:
1. Mean Annual Inflow (MAI) = $1.83m^3/s$ ($57.7Mm^3$/year)
2. MAI is Net of releases for Downstream users

Figure 7-9 is a Layout Plan of the Proposed Arrangement under Option 3.

Option 4: NC I and NC II to Thika Dam + Maragua 4 Dam

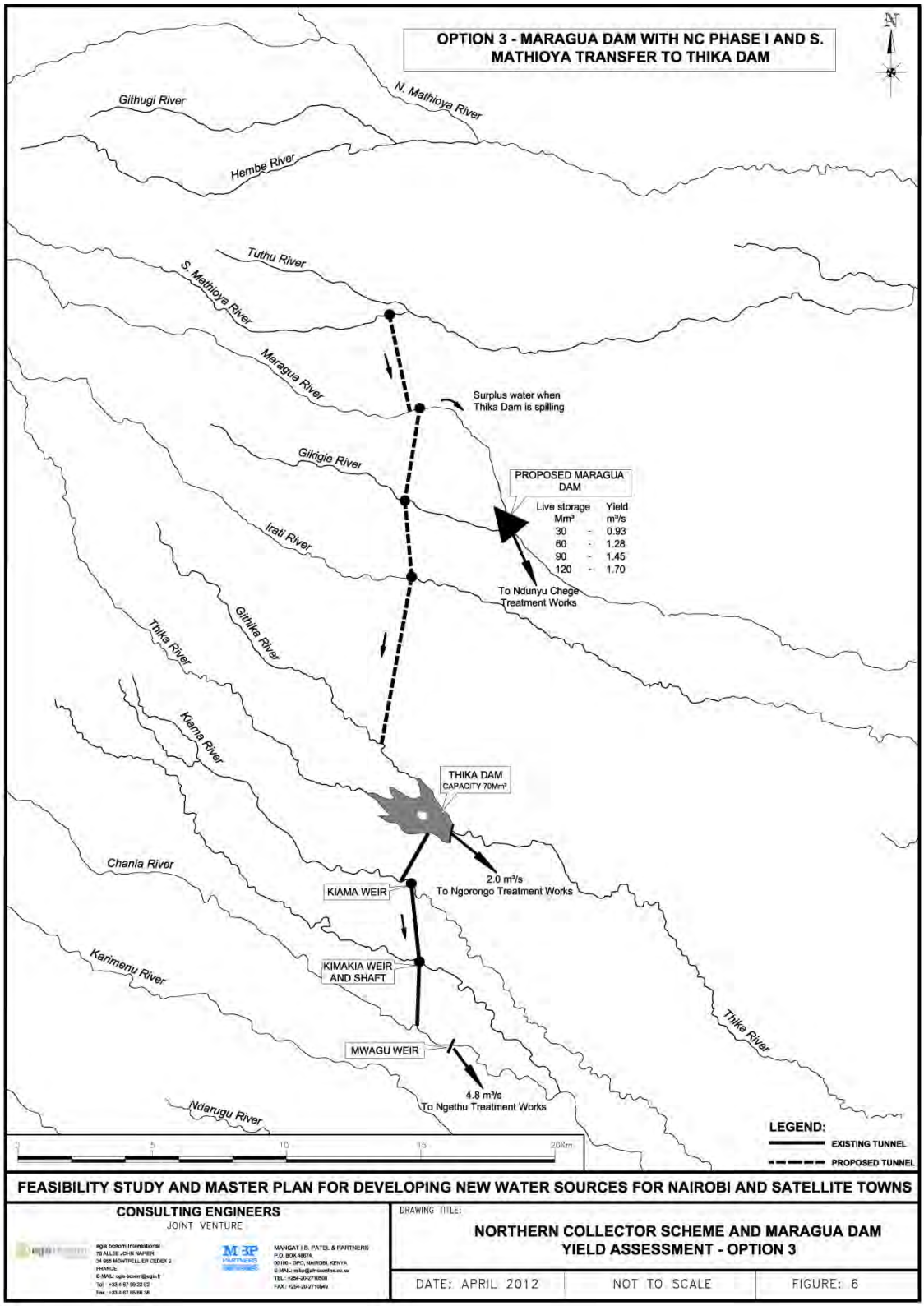
This Option analyses the available yields for Maragua 4 Dam after implementing NC I & NC II.

The outfall of NC II on Maragua River is located upstream of the Maragua Intake for NC I thus enabling sharing of the additional water between Thika and Maragua 4 Dams. Therefore, in situations when Thika Dam is full, surplus water in Maragua River NC II will flow downstream to Maragua 4 Dam.

Table 7-20 : Simulated Net Yields for Option 4

Component	Yield (m^3/s)
Mwagu	4.80
Additional Yield at Thika Dam	3.30
Maragua 4 Dam	
Capacity	
$30Mm^3$	1.02
$60Mm^3$	1.68
$90Mm^3$	2.25
$120Mm^3$	2.64

Figure 7-9 : Option 3



The Storage and Yield Ratios for the Dam are given in Table 7-21.

Table 7-21: Storage and Yield Ratios for Maragua 4 Dam – Option 4

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.31	1.02	0.33
60	0.62	1.68	0.55
90	0.93	2.25	0.73
120	1.24	2.64	0.86

Notes:
1. Mean Annual Inflow (MAI) = $3.07m^3/s$ ($96.8Mm^3$/year)
2. MAI is Net of releases for Downstream users

Figure 7-10 is a Layout Plan of the Proposed Arrangement under Option 4.

Option 5: NC I to Thika Dam + S. Mathioya Diversion to Maragua 4 Dam

This Option is the same as Option 3 but with the S. Mathioya Diversion having its outfall downstream of the NC I intake on Maragua River. Therefore, the additional water from the transfer flows entirely downstream to Maragua 4 Dam.

Table 7-22 : Simulated Net Yields for Option 5

Component	Yield (m^3/s)
Mwagu	4.80
Additional Yield at Thika Dam	1.40
Maragua 4 Dam	
Capacity	
$30Mm^3$	1.18
$60Mm^3$	1.68
$90Mm^3$	1.80
$120Mm^3$	2.00

The Storage and Yield Ratios for the Dam are given in Table 7-23.

Table 7-23: Storage and Yield Ratios for Maragua 4 Dam – Option 5

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.31	1.02	0.33
60	0.62	1.68	0.55
90	0.93	2.25	0.73
120	1.24	2.64	0.86

Notes:
1. Mean Annual Inflow (MAI) = $2.16m^3/s$ ($68.1Mm^3$/year)
2. MAI is Net of releases for Downstream users

Figure 7-11 is a Layout Plan of the Proposed Arrangement under Option 5.

Figure 7-10 : Option 4

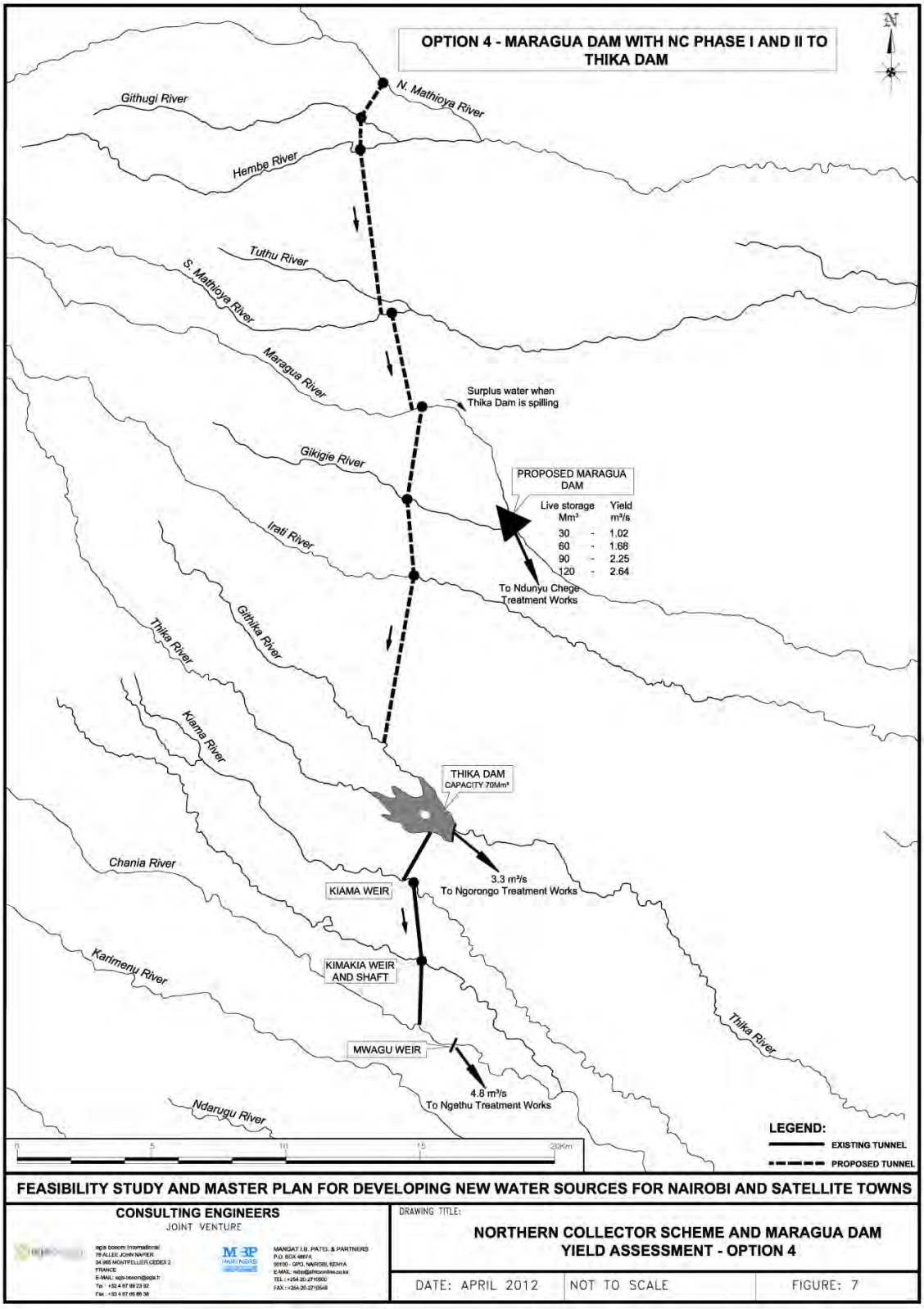
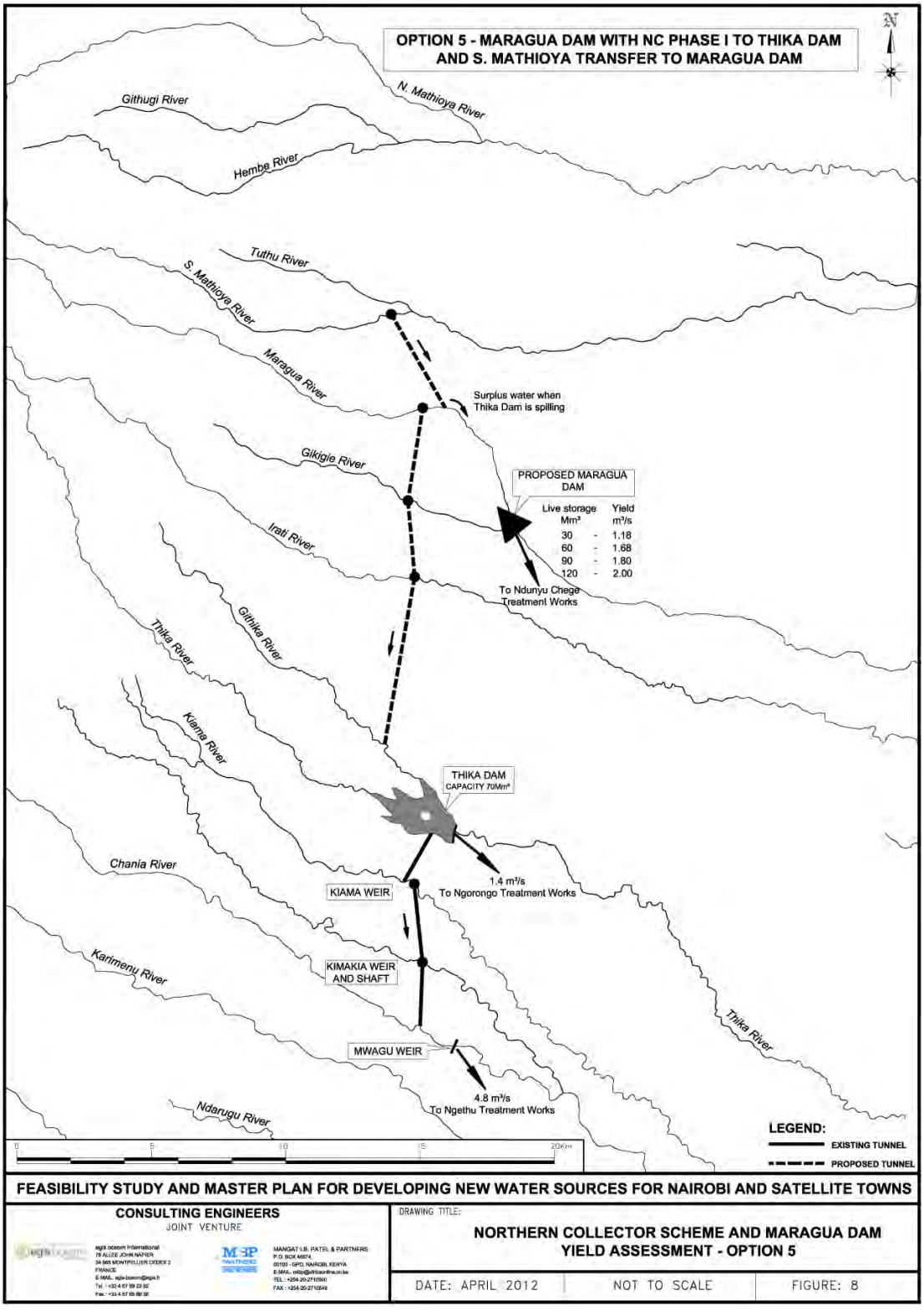


Figure 7-11 : Option 5



Option 6: NC I to Thika Dam + NC II to Maragua 4 Dam

This Option is the same as Option 4 but with the NC II having its outfall downstream of the NC I intake on Maragua River. Therefore, the additional water from the transfer flows entirely downstream to Maragua 4 Dam.

Table 7-24 : Simulated Net Yields for Option 6

Component	Yield (m^3/s)
Mwagu	4.80
Additional Yield at Thika Dam	1.40
Maragua 4 Dam	
Capacity	
$30Mm^3$	2.39
$60Mm^3$	3.30
$90Mm^3$	3.82
$120Mm^3$	4.10

The Storage and Yield Ratios for the Dam are given in Table 7-25.

Table 7-25: Storage and Yield Ratios for Maragua 4 Dam – Option 6

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.20	2.39	0.51
60	0.40	3.30	0.70
90	0.60	3.82	0.81
120	0.81	4.10	0.87

Notes:
1. Mean Annual Inflow (MAI) = $2.16m^3/s$ ($68.1Mm^3$/year)
2. MAI is Net of releases for Downstream users

Figure 7-12 is a Layout Plan of the Proposed Arrangement under Option 6.

Option 7: Irati Diversion to Thika Dam + S. Mathioya Diversion to Maragua 4 Dam

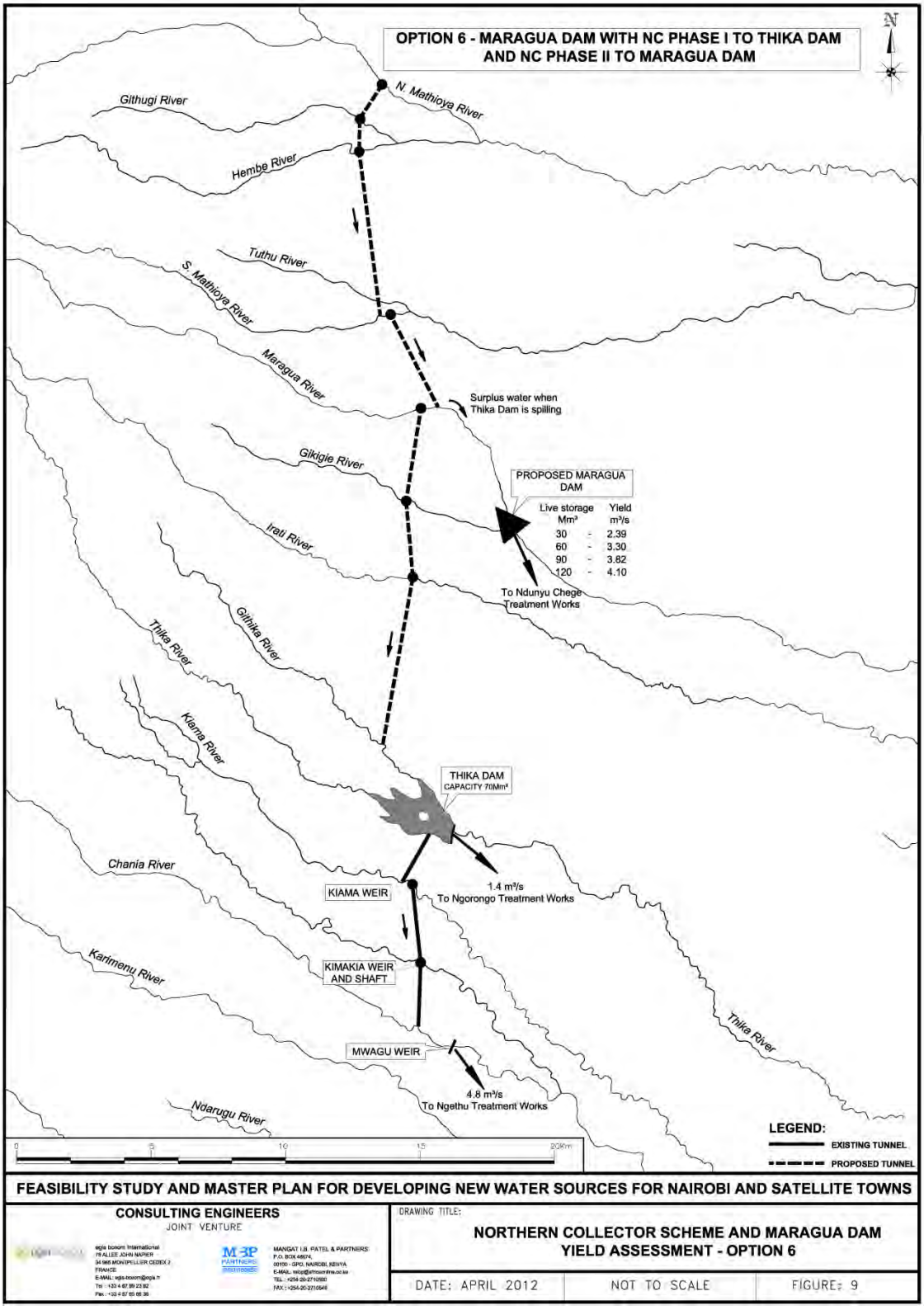
This Option looks at transferring water from Irati River to Thika Dam and from S. Mathioya River to Maragua 4 Dam. This Option is the same as Option 1 for Maragua 4 Dam but with additional inflows from S. Mathioya River.

The Yield Analysis for this Option is given in Table 7-26.

Table 7-26 : Simulated Yields for Option 7

Component	Yield (m^3/s)
Mwagu	4.8
Additional Yield at Thika Dam	0.33
Maragua 4 Dam	
Capacity	
$30Mm^3$	2.10
$60Mm^3$	2.95
$90Mm^3$	3.17
$120Mm^3$	3.29

Figure 7-12 : Option 6



The Storage and Yield Ratios for the Dam are given in Table 7-27.

Table 7-27: Storage and Yield Ratios for Maragua 4 Dam – Option 7

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.28	2.10	0.61
60	0.56	2.95	0.86
90	0.83	3.17	0.92
120	1.11	3.29	0.96

Notes:
1. *Mean Annual Inflow(MAI)=3.44m^3/s(108Mm^3/year)*
2. *MAI is Net of releases for Downstream users*

Figure **7-13** is a Layout Plan of the Proposed Arrangement under Option 7.

Option 8: Irati Diversion to Thika Dam + NC II to Maragua 4 Dam

Building upon Option 7, this alternative includes diversions from N. Mathioya, Githugi and Hembe rivers to the already proposed S. Mathioya transfer thus forming the NC II.

The Yield Analysis for this Option is given in Table 7-28.

Table 7-28 : Simulated Yields for Option 8

Component	Yield (m^3/s)
Mwagu	4.8
Additional Yield at Thika Dam	0.33
Maragua 4 Dam	
Capacity	
30Mm^3	2.10
60Mm^3	2.95
90Mm^3	3.17
120Mm^3	3.29

The Storage and Yield Ratios for the Dam are given in Table 7-29.

Table 7-29: Storage and Yield Ratios for Maragua 4 Dam – Option 8

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.16	3.35	0.55
60	0.31	4.40	0.73
90	0.47	5.15	0.85
120	0.63	5.40	0.89

Notes:
1. *Mean Annual Inflow(MAI) = 6.05m^3/s (191 Mm^3/year)*
2. *MAI is Net of releases for Downstream users*

Figure 7-14 is a Layout Plan of the Proposed Arrangement under Option 8.

Figure 7-13 : Option 7

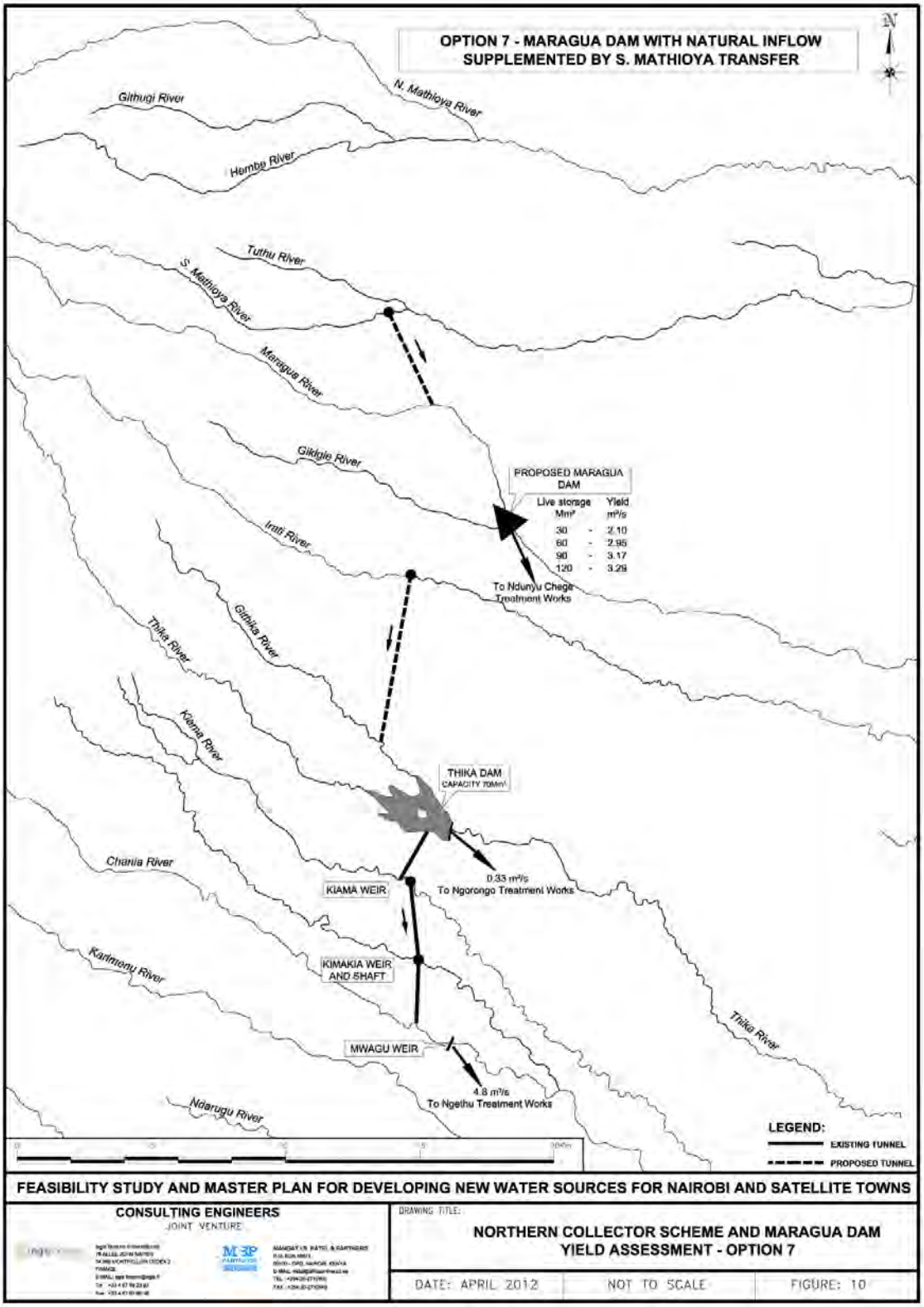
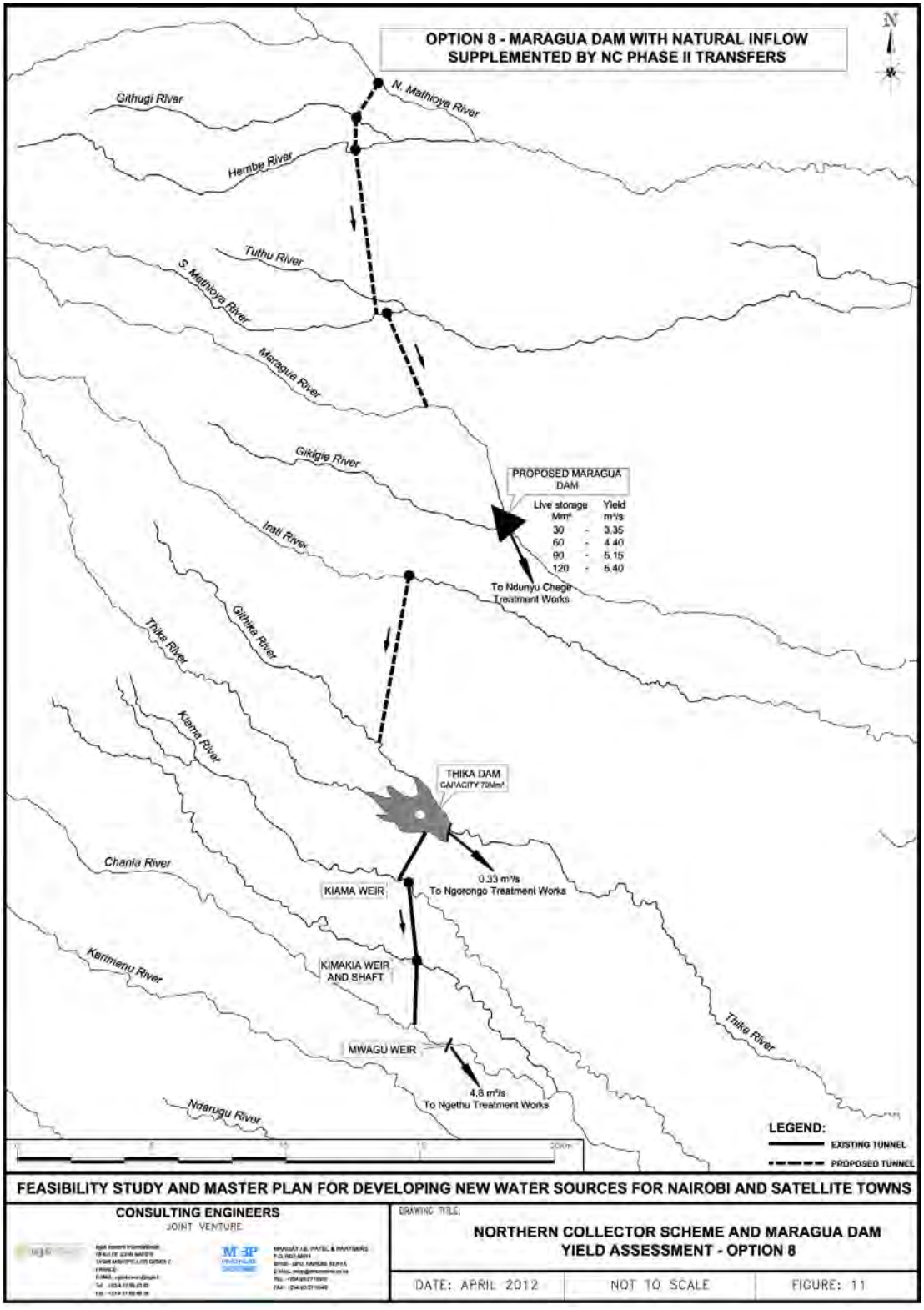


Figure 7-14 : Option 8



Option 9: Thika Dam + Irati and S. Mathioya Diversion to Maragua 4 Dam

This Option analyses the available yields when water is transferred from Irati and S. Mathioya rivers to Maragua 4 Dam. Thika Dam remains as is without augmentation of its inflows.

The Yield Analysis for this Option is given in Table 7-30.

Table 7-30 : Simulated Yields for Option 9

Component	Yield (m^3/s)
Mwagu	4.8
Additional Yield at Thika Dam	-
Maragua 4 Dam	
Capacity	
$30Mm^3$	2.40
$60Mm^3$	3.40
$90Mm^3$	3.75
$120Mm^3$	3.85

The Storage and Yield Ratios for the Dam are given in Table 7-31.

Table 7-31: Storage and Yield Ratios for Maragua 4 Dam – Option 9

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.16	3.35	0.55
60	0.31	4.40	0.73
90	0.47	5.15	0.85
120	0.63	5.40	0.89

Notes:

1. *Mean Annual Inflow (MAI) = 6.05m^3/s(191 Mm^3/year)*
2. *MAI is Net of releases for Downstream users*

Figure 7-15 is a Layout Plan of the Proposed Arrangement under Option 9.

Option 10: Thika Dam + Irati Diversion and NC II to Maragua 4 Dam

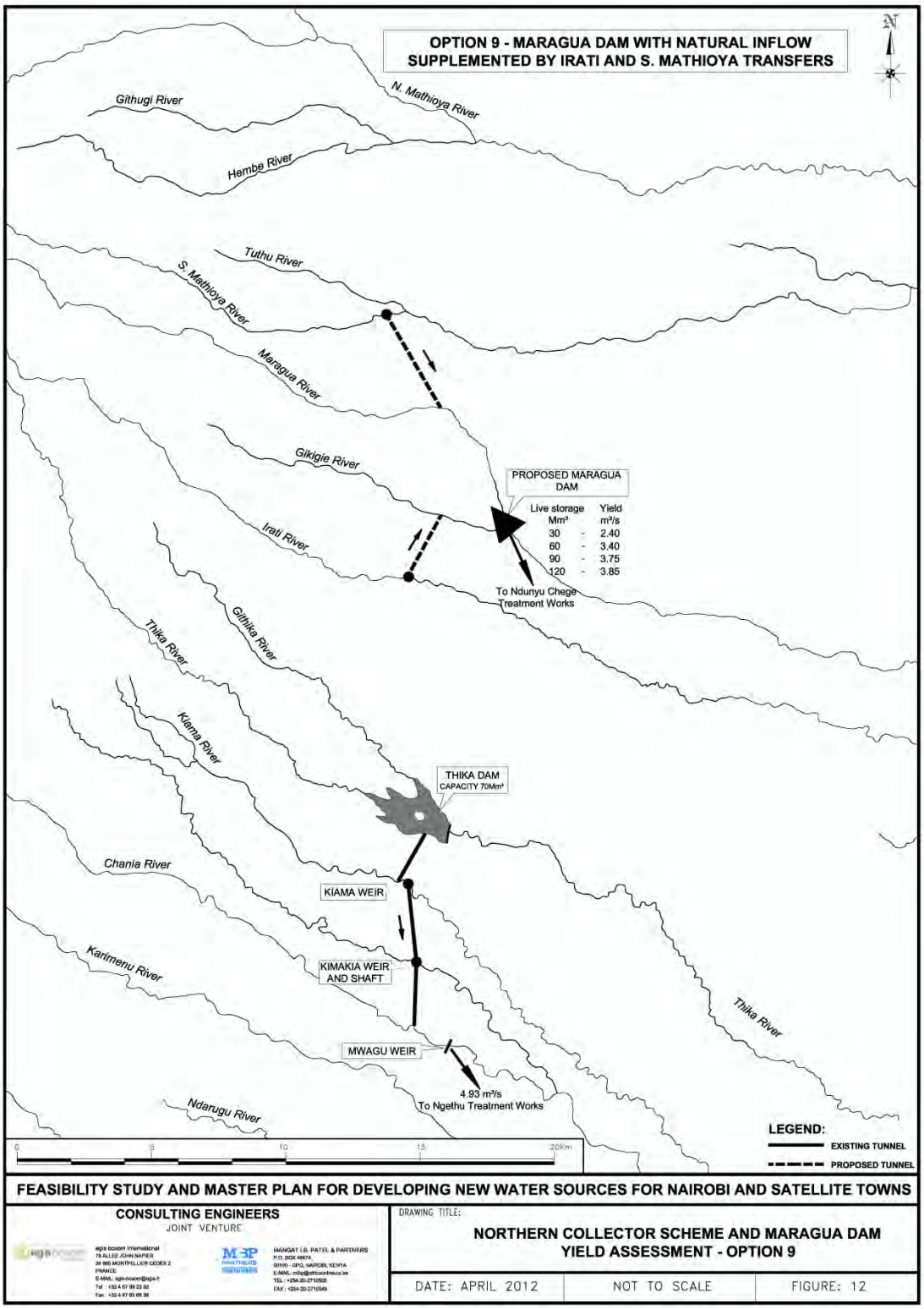
Building upon Option 7, this alternative includes diversions from N. Mathioya, Githugi and Hembe rivers to the already proposed S. Mathioya transfer thus forming the NC II.

The Yield Analysis for this Option is given in Table 7-32.

Table 7-32 : Simulated Yields for Option 10

Component	Yield (m^3/s)
Mwagu	4.8
Additional Yield at Thika Dam	-
Maragua 4 Dam	
Capacity	
$30Mm^3$	3.47
$60Mm^3$	4.68
$90Mm^3$	5.70
$120Mm^3$	6.00

Figure 7-15 : Option 9



The Storage and Yield Ratios for the Dam are given in Table 7-33.

Table 7-33: Storage and Yield Ratios for Maragua 4 Dam – Option 10

Maragua 4 Dam Live Storage, Mm^3	Storage/MAI	90% Reliable Yield, m^3/s	Yield/ MAI
30	0.14	3.47	0.51
60	0.28	4.68	0.69
90	0.42	5.70	0.84
120	0.56	6.00	0.88

Notes:
1. Mean Annual Inflow (MAI) = 6.81m^3/s (215Mm^3/year)

Figure 7-16 is a layout Plan of the Proposed Arrangement under Option 10.

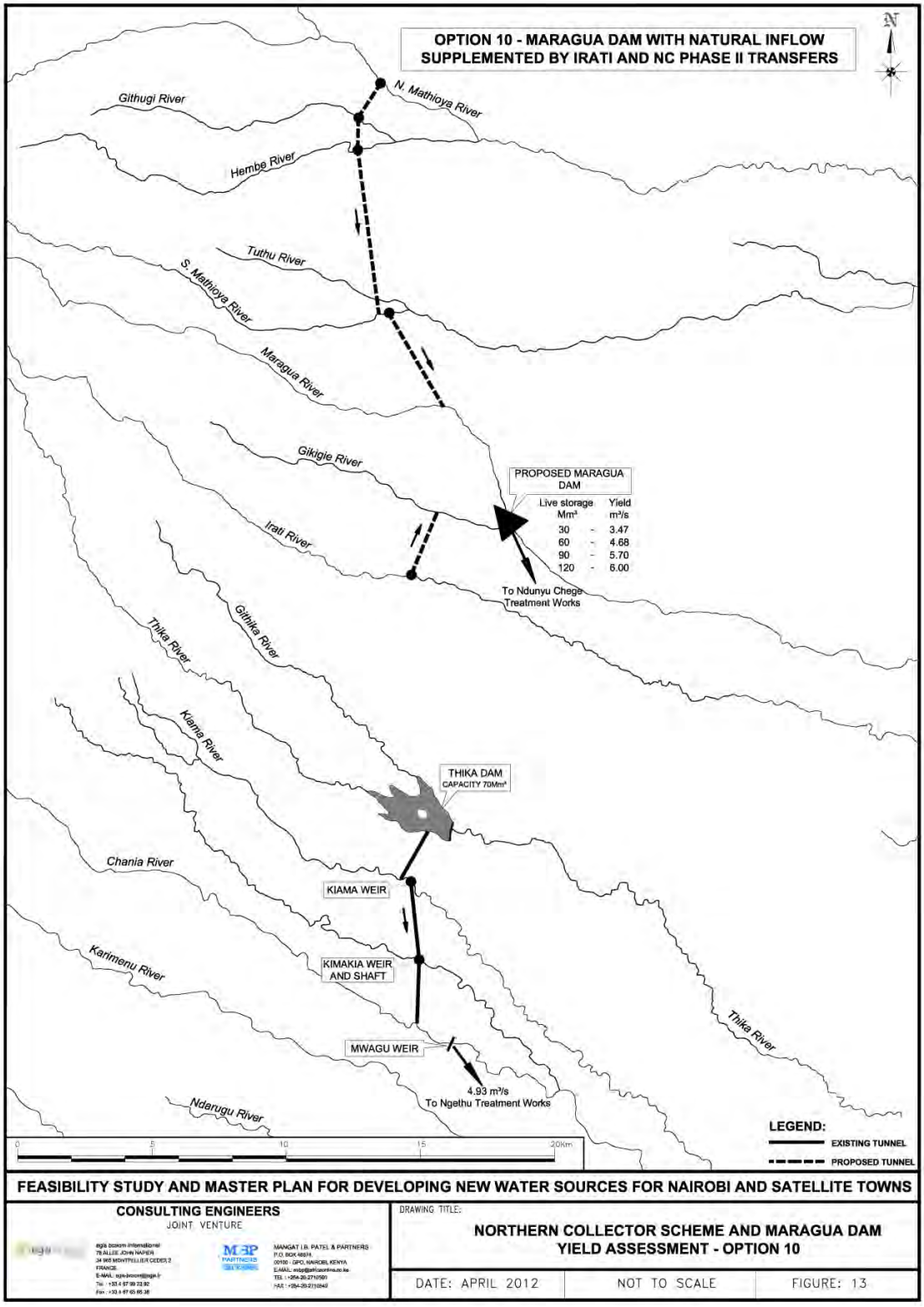
3.6.3 Summary of Yield Analysis

A summary of the Yield Analysis for all the Alternative Options is presented in Table 7-34.

Table 7-34: Summary of Total Additional System Yields (m^3/s) for all Alternative Options

	OPTION									
Component	1	2	3	4	5	6	7	8	9	10
Additional Yield at Thika	0	1.40	2.00	3.30	1.40	1.40	0.33	0.33	0	0
Maragua 4 Dam Yield for Different Storages in Mm^3										
30	1.80	0.84	0.93	1.02	1.18	2.39	2.10	3.35	2.40	3.47
60	2.25	1.12	1.28	1.68	1.68	3.30	2.95	4.40	3.40	4.68
90	2.40	1.30	1.45	2.25	1.80	3.82	3.17	5.15	3.75	5.70
120	2.52	1.40	1.70	2.64	2.00	4.10	3.29	5.40	3.85	6.00
Total Additional System Yield (Additional Yield at Thika Dam + Maragua 4 Dam)										
30	1.8	2.24	2.93	4.32	2.58	3.79	2.43	3.68	2.4	3.47
60	2.25	2.52	3.28	4.98	3.08	4.7	3.28	4.73	3.4	4.68
90	2.4	2.7	3.45	5.55	3.2	5.22	3.5	5.48	3.75	5.7
120	2.52	2.8	3.7	5.94	3.4	5.5	3.62	5.73	3.85	6

Figure 7-16 : Option 10



The Option which gives the maximum System Yield using Maragua 4 Dam storages of 30 and 60Mm^3 is Option 4. For higher storages, Option 10 gives the maximum Yields.

Option 4 comprises of the following components:

- NC I diverting water from Irati, Gikigie and Maragua rivers
- NC II diverting water from S. Mathioya, Hembe, Githugi and N. Mathioya rivers. The Outfall of NC II will be upstream of the Maragua River Intake for NC I to enable sharing of the additional water between Thika and Maragua 4 Dams.
- Maragua 4 Dam

Option 10 comprises of the following components:

- Transfer from Irati River to Gikigie River
- NC II diverting water from S. Mathioya, Hembe, Githugi and N. Mathioya rivers
- Maragua 4 Dam

3.6.4 Conclusion

Different Options of Water Transfer with Maragua 4 Dam incorporated into the System have been investigated using the WEAP model and respective System Yields simulated.

Table 7-34 presents the summary of the Yield Analysis for the 10 Options investigated. From the results, it can be seen that Options 4 and 10 give the maximum yields given particular storage capacities of Maragua 4 Dam. Option 4 maximises System Yields for Maragua 4 Dam storage of 30 and 60Mm^3 whereas Option 10 does so for storages of 90 and 120Mm^3.

However, Option 4 is selected as the preferred Option because of the following:

- Storage at Maragua 4 Dam greater than 90Mm^3 may not be technically and economically feasible.
- The location of Maragua 4 Dam would result in a lesser area of Nairobi City to be supplied by gravity. Therefore, transferring as much water as possible to Thika Dam is recommended to command a larger water demand area without the need for introducing new pumping facilities.

The recommended Option 4 involves construction of the following:

- NC I diverting water from Irati, Gikigie and Maragua rivers.
- NC II diverting water from S. Mathioya, Hembe, Githugi and N. Mathioya rivers. The Outfall of NC II will be upstream of the Maragua River Intake for NC I to enable sharing of the additional water between Thika and Maragua 4 Dams.
- Maragua 4 Dam

The construction of NC II can be done in two phases, with only the diversion from S. Mathioya River implemented earlier followed by the diversions from the other 3 rivers at a later stage.

3.7 Overall System Yield Summary

3.7.1 Existing System

The simulated yields for the Existing System are given in Table 7-35.

Table 7-35: Simulated Yields for Existing System

90% Reliable Yield (m^3/s)	Without Operational Rules at Thika Dam	With Operational Rules at Thika Dam
Thika Dam (Gross)	2.20	-
Mwagu (Chania IFR = 0.158m^3/s)	5.08	4.60

Using an IFR of 0.3m^3/s for Chania River, the simulated yield at Mwagu is 4.93m^3/s.

3.7.2 Northern Collector System

Northern Collector I

Yield analysis was initially carried out using IFR for Chania and Irati rivers of 0.158m^3/s and Q_{95} respectively. In addition, basic Operational Rules for Thika Dam were also incorporated in the simulation. The results for this analysis are presented in Table 7-36.

Table 7-36: Simulated Yields (m^3/s) for the Existing System with NC I

	Without Operational Rules		**With Operational Rules For Thika Dam Only**	
Component	**Q_{95}**	**$2xQ_{95}$**	**Q_{95}**	**$2xQ_{95}$**
Mwagu	4.80	4.80	4.80	4.80
Additional Thika Yield	1.68	0.85	1.23	0.50

Note: Chania IFR = 0.158m^3/s, Irati IFR = Q_{95}

Table 7-37: Simulated NC I System Yields (m^3/s) for Different Combinations of IFR for Chania and Irati Rivers

	Without Operational Rules			***With Operational Rules***		
	Case 1	**Case 2**	**Case 3**	**Case 1**	**Case 2**	**Case 3**
Component	**Chania – 0.3 Irati - Q_{95}**	**Chania – 0.3 Irati – $1.4xQ_{95}$**	**Chania – 0.158 Irati – $1.4xQ_{95}$**	**Chania – 0.3 Irati - Q_{95}**	**Chania – 0.3 Irati – $1.4xQ_{95}$**	**Chania – 0.158 Irati – $1.4xQ_{95}$**
Mwagu	4.80	4.80	4.80	4.80	4.80	4.80
Additional Thika Yield	1.50	1.40	1.54	1.10	0.95	1.08

Northern Collector II

The Model was extended to include the NC II. Results of the analysis are presented in Table 7-38.

Table 7-38: Simulated Yields (m^3/s) for the Existing System with NC I and NC II

Component	Without Operational Rules		With Operational Rules For Thika Dam Only	
	Q_{95}	$2xQ_{95}$	Q_{95}	$2xQ_{95}$
Mwagu	4.80	4.80	4.80	4.80
Additional Thika Yield	3.58	1.66	3.05	0.80

Note: Chania IFR = 0.158m^3/s, Irati IFR = Q_{95}

Similar to NC I, additional simulations were carried out using IFR for Chania and Irati rivers set at 0.3m^3/s and 1.4Q_{95}. Table 7-39 gives the yield results for the above cases.

Table 7-39: Simulated System Yields (m^3/s) for the Existing System with NC I & NC II

	Without Operational Rules			*With Operational Rules*		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Component	Chania – 0.3 Irati - Q_{95}	Chania – 0.3 Irati – 1.4xQ_{95}	Chania – 0.158 Irati – 1.4xQ_{95}	Chania – 0.3 Irati - Q_{95}	Chania – 0.3 Irati – 1.4xQ_{95}	Chania – 0.158 Irati – 1.4xQ_{95}
Mwagu	4.80	4.80	4.80	4.80	4.80	4.80
Additional Thika Yield	3.45	3.30	3.50	2.92	2.80	2.90

3.7.3 Northern Collector System with Maragua 4 Dam

A summary of Yield Analysis for the 10 different Options comprising part and/ or the entire Northern Collector System and Maragua 4 Dam is presented in Table 7-40.

Table 7-40: Summary of Yield Analysis for Additional Options of Water Transfer

Option	Component	Yield (m^3/s)
1	**Thika Dam + Maragua 4 Dam only**	
	Mwagu	4.93
	Additional Yield at Thika	-
	Maragua 4 Dam Capacity	
	30Mm^3	1.80
	60Mm^3	2.25
	90Mm^3	2.40
	120Mm^3	2.52
2	**NC I to Thika Dam + Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	1.40
	Maragua 4 Dam Capacity	
	30Mm^3	0.84
	60Mm^3	1.12
	90Mm^3	1.30
	120Mm^3	1.40
3	**NC I and S. Mathioya Diversion to Thika Dam + Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	2.00
	Maragua 4 Dam Capacity	
	30Mm^3	0.93
	60Mm^3	1.28
	90Mm^3	1.45
	120Mm^3	1.70
4	**NC I and NC II to Thika Dam + Maragua 4 Dam**	

Option	Component	Yield (m^3/s)
	Mwagu	4.80
	Additional Yield at Thika	3.30
	Maragua 4 Dam Capacity	
	$30Mm^3$	1.02
	$60Mm^3$	1.68
	$90Mm^3$	2.25
	$120Mm^3$	2.64
5	**NC I to Thika Dam + S. Mathioya Diversion to Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	1.40
	Maragua 4 Dam Capacity	
	$30Mm^3$	1.18
	$60Mm^3$	1.68
	$90Mm^3$	1.80
	$120Mm^3$	2.00
6	**NC I to Thika Dam + NC II to Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	1.40
	Maragua 4 Dam Capacity	
	$30Mm^3$	2.39
	$60Mm^3$	3.30
	$90Mm^3$	3.82
	$120Mm^3$	4.10
7	**Irati Diversion to Thika Dam + S. Mathioya Diversion to Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	0.33
	Maragua 4 Dam Capacity	
	$30Mm^3$	2.10
	$60Mm^3$	2.95
	$90Mm^3$	3.17
	$120Mm^3$	3.29
8	**Irati Diversion to Thika Dam + NC II to Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	0.33
	Maragua 4 Dam Capacity	
	$30Mm^3$	3.35
	$60Mm^3$	4.40
	$90Mm^3$	5.15
	$120Mm^3$	5.40
9	**Thika Dam + Irati and S. Mathioya Diversion to Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	-
	Maragua 4 Dam Capacity	
	$30Mm^3$	2.40
	$60Mm^3$	3.40
	$90Mm^3$	3.75
	$120Mm^3$	3.85
10	**Thika Dam + Irati and S. Mathioya Diversion to Maragua 4 Dam**	
	Mwagu	4.80
	Additional Yield at Thika	-
	Maragua 4 Dam Capacity	
	$30Mm^3$	2.40
	$60Mm^3$	3.40
	$90Mm^3$	3.75
	$120Mm^3$	3.85

3.8 Conclusions and Recommendations

3.8.1 Compensation Flows

System Yields have proven to be sensitive to IFR. The Yield Analysis has been carried out with set IFR values for each of the rivers of interest. Therefore, any significant upward change to the IFRs will have an inversely proportional effect on the System Yields.

Therefore, proper management of the water resources and constant involvement of the stakeholders within the catchments is irrefutably paramount. Any significant abstractions upstream of the proposed intakes will result in the System Yields being negatively impacted. Furthermore, due to the abstractions by the Northern Collector System, abstractions immediately downstream will be limited.

3.8.2 Controls at Intakes

All proposed intakes, except the one on Maragua River, have been modelled as gravity transfers with no control on their diversion capacity. Therefore, there will be periods during average and wet years when spill will occur at Thika Dam due to overwhelming inflows into the reservoir from higher natural flows in Thika River and inflows from the NC. The Maragua River intake has been modelled as a controlled structure thus limiting water transfer from the river when Thika Dam is full.

Ideally, the Water Resource System should be operated in a manner that prevents unnecessary inter-basin water transfers. Therefore, it is recommended to provide control gates at all the river diversions for NC I which will operate synchronously with the storage level in Thika Dam. The additional inflows from NC II will be shared with Maragua 4 Dam, therefore, the Maragua Intake control will automatically pass any surplus water downstream to Maragua 4 Dam. Controls would also be required on the intakes for NC II which could be synchronised with storage at both Thika and Maragua 4 Dams, thus preventing unnecessary water transfers from the NC II rivers when either or both dams are full.

3.8.3 Reservoir Operating Rules

All Municipal reservoirs are normally operated conservatively in Kenya especially when faced with even the slightest indication of water scarcity. The same still applies to Thika Dam and will do so to Maragua 4 Dam when in operation.

However, the model simulation at this stage has not considered any form of rules in effect in determining the maximum yields at the desired reliability from the dams. The maximum yields abstractable from the dams without any operational rules in place have been obtained and adopted. This is purely for establishing the infrastructure capacity for engineering design and allows the design and eventual construction of infrastructure with adequate capacity to utilise the maximum yields when available. During relatively drier periods, the infrastructure will operate under capacity.

The Northern Collector System will extensively alter the operating regime of Thika reservoir. Therefore, new operational rules for Thika Dam will be required to ensure the maximum yield is achieved during average and wet years whilst appropriate constraints are effected during the dry periods. The same will have to be done for Maragua 4 Dam.

During average/ wet years, yields at Mwagu and Thika Dam can be maintained at 90% reliability. However during relatively drier periods, the yields reduce significantly if the same reliability is to be maintained. This shows that a water rationing program will have to be implemented in this period to 'stretch' the supply period of the stored water as long as possible. On the other hand, the maximum yield could be supplied but with the risk of running the reservoirs dry in a shorter period.

Therefore, it should be noted with the introduction of reservoir operating rules, that risk and severity of failures in water supply will be reduced but its frequency will increase. This is as a result of the water rationing mentioned earlier, objective of which is to maximise the period of supply rather than maintaining the same volume of supply which would last shorter. Therefore, the reliability of water supply will inevitably be reduced in the drier periods.

Reference is made to Case 2 in Table 7-37 and Table 7-39 for comparison of the effect of Operational Rules on yields at Thika Dam.

3.8.4 Additional Storage

It has been established in Section 3.5.5 that additional storage is definitely necessary to effectively utilise the additional inflows from the NC System at Thika Dam.

Ideally, provision of storage upstream of the proposed intakes for NC would be recommended. However, this is not feasible at this stage due to lack of adequate technical and economic assessment which was beyond the scope of the present Study. The proposed Maragua 4 Dam was recommended as a potential candidate for additional storage by Howard Humphreys. This Study has also adopted this recommendation and incorporated it in the Yield Analysis.

Based on the results presented in Section 3.6.2 for various Options, the most optimal storage at Maragua 4 Dam with the construction of Northern Collector scheme Phase I and II to Thika reservoir will be approximately 90 Mm^3. If Phase II of the collector is diverted into Maragua 4 Dam, then storage of capacity more than 120 Mm^3 will have to be provided.

The storage volumes quoted are theoretical and further detailed technical, economic and financial studies will have to be carried out to determine whether the larger storage volumes quoted can be realised. The stage of construction of Maragua 4 Dam within the collector scheme development can only be best determined if the storage to be provided is ascertained.

3.8.5 Outputs - WEAP Water Balance Modelling

The output of the WEAP Water Balance Model for various simulated conditions are given in **Appendix 7.4**.

4 Multicriteria Analysis and Review of Scenarios

4.1 Introduction

Under the Water Resources Options Review Report, a Multicriteria Analysis to identify the most suitable Development Strategy from a total of six development scenarios was carried out. The results of the analysis gave Scenario 2 and 3A a very close ranking. At that stage, Scenario 2 ranked slightly better and was therefore adopted as the best development option for water supply to Nairobi.

Subsequently, based on results of the Extended Water Balance Modelling discussed in section 3 above, the Multi-Criteria Analysis has been re-done specifically for Scenario 2 and 3A in order to rank the two scenarios against the objectives of the development strategy. The following criteria using four key sustainability issues has been used to compare the two scenarios:

- **Natural Resources (Mandatory Criteria)**: essentially mandatory water quantity indicators on the security of the resource for Nairobi WS, the reliability of the resource, the coverage of the water demand of Nairobi and Satellite Towns, impact on downstream flows and competition with alternative downstream/upstream uses of water.
- **Economic Sustainability**: scenarios are compared through their respective indicators of least cost analysis: ***Average Incremental Economic Cost of water (AIEC)***. The AIEC is the present value of the cost of a scenario divided by the present value of water outputs that the scenario enables over the period 2011-2035. ***Present Value of Economic Costs (PVEC),*** an indicator of the scale of the capital investment costs*;* ***Present Value of Operation and Maintenance Costs (PVO&M)*****,** a measure of the relative cost of operating the system over its life.
- **Technical Sustainability:** scenarios are compared based on the construction and operational techniques required, ease for further development, number of sources to be developed and the use and build upon of existing infrastructure and resources. The overall result demonstrates the ease in the implementation and operation of the water supply systems.
- **Environment Sustainability**: scenarios are compared against their downstream impact of water quantity releases on environment, the impact they have on water quality issues for upstream land use; and impacts on appropriate management of downstream ecosystems during the construction and operation stages.
- **Social Sustainability:** Scenarios are compared against their impact on access to water, i.e. equity of access to water for upstream and downstream water users and stakeholders. Scenarios leading to specific water uses are ranked low, and scenarios maintaining access water are favoured. Impact on resettlement and land losses is an important criteria which has been evaluated. The socio-economic benefits which the local communities will accrue from the construction and operation of the infrastructure have also been evaluated

The analysis has been carried out in three steps:

First Step – Natural Resources (Mandatory Criteria):

The two scenarios are designed to meet the quantity of water supply required to meet the projected year 2035 water demand for Nairobi City and therefore this is the first criteria to be assessed.

The other criteria in this section are: (i) ensuring sufficient security on the water sources for downstream environmental flows and other water demands, (ii) the source water quality, (iii) the security and reliability of the resources, (iv) optimisation of the resource to maximise on its use, and (v) diversity of the resources which have been considered as mandatory criteria. The eight aspects are scored as either poor, medium or good against, and judged whether they meet the mandatory criteria.

Second Step: Least Cost Analysis

The cost of developing each scenario is compared through the least cost analysis applying the three criteria mentioned above: AIEC, PVEC and PVO&M, have been calculated over the 2011-2035 period.

Third Step: Multi-Criteria Analysis on Other Criteria

The scenarios have then been compared though a Multicriteria analysis against secondary indicators along with the four main sustainability issues which include: technical, environmental and social indicators.

4.2 Weighting of Comparison Criteria

All criteria do not have the same importance for the ranking and are given a weighting according to their importance to the assessment.

Table 7.41 below presents the adopted weights for each of the criteria factors. Overall the natural resources aspects have been accorded 30% weighting, economic aspects 30% weighting, technical aspects 15% weighting, environment 15% weighting and social 10% weighting.

Within each criteria, the sub-criteria have been weighted according to their relative importance / impacts within the main criteria.

Table 7-41: Multi-Criteria Analysis – Weighting of Criterion

Sustainability Issue		Headline Criteria	Sub-criteria	Weighting %	
A. Natural Resources					
A-1	Resources	Water Quantity	Meeting Forecast year 2035 Water Demand	10%	
A-2	"	"	Downstream Water Demands	5%	
A-3	"	"	Environmental Flow Requirements	5%	
A-4	"	Water Quality	Source Water Quality	4%	
A-5	"	Water Quantity	Security of the Resource	3%	
A-6	"	"	Reliability of the Resource	1%	
A-7	"	"	Optimization of the Resource	1%	
A-8	"	"	Diversity of the Resource	1%	30%
B. Economic					
B-2	Economic	"	Average Incremental Economic Cost (AIEC)	10%	
B-1	"	New Infrastructure	Present Value of Economic Costs (PVEC)	10%	
B-3	"	Operation	Present Value of O&M costs (PVO&M)	10%	30%
C. Technical					
C-1	Technical	New Infrastrucutre	Construction aspects	5%	
C-2	"	"	Operational aspects	3%	
C-3	"	"	Ease in Further Development	3%	
C-4	"	"	No. of additional Independent Water Sources	2%	
C-5	"	Existing Infrastructure	Utilization of Existing Infrastructure	2%	15%
D. Environment					
D-1	Environment	Water Quantity & Quality	Downstream Impacts	5%	
D-2	"	"	Upstream Impacts	5%	
D-3	"	New Infrastructure	Construction Impacts	3%	
D-4	"	"	Operational Impacts	2%	15%
E. Social					
E-1	Social	Access	Water access	5%	
E-2	"	Amenity	Resettlement / Land losses	3%	
E-3	"	Amenity	Socio-Economic Benefits to the Local Communities	2%	10%
TOTAL				**100%**	

4.3 Ranking of Scenarios

The two scenarios have been assessed against the multicriteria matrix described above. The main points about the assessment are discussed below, with the results of the weighting criteria and the final weighted score and ranking of the two scenarios being discussed in section 4.4.

The scores given for each sub-criteria range from 0 to 1 with: 0 (for poor score), 0.5 (for medium or fair score) and (1 for satisfactory or good score). Intermediate scores of 0.25 (for weak score) and 0.75 (for fairly good score) have also been introduced for cases where it is difficult to allocate the major scores.

A. Natural Resources (Mandatory) Criteria (First step)

✓ **Meeting Water Demand up to year 20135:**
The scenarios studied meet the quantity of water supply to meet the projected 2035 demand for Nairobi City. However, Scenario 2 meets the year 2035 water demand by more than 10% and therefore scores satisfactory or good against Scenario 3A which meets the demand by between 5 to 10% of the projected water demand.

✓ **Downstream water demands and environmental flow requirements:**
The two scenarios are considered to score equally (satisfactory/good) for allowing sufficient water for downstream environmental flows and to meet anticipated future urban and rural water demands. This aspect was part of the design standard for water abstraction, therefore maintaining minimum flows was ensured in the planning of all water resources.

✓ **Source water quality:**
The source water quality sub-criteria has been assessed with regard to the ease in treatment of the water and the final water quality anticipated from the sources. Scenario 2 gets a medium score compared to Scenario 3A which scores fairly good. This is because the source water quality for Scenario 2 is expected to be poorer because of the full utilisation of Ndarugu 1 Dam and the contribution by Chania-Komu transfer from which the water quality is relatively worse compared to the water quality expected at Maragua 4 Dam.

✓ **Security of the water resource:**
Scenario 3A is considered to have greater security as it has Maragua 4 Dam compared to Scenario 2 which alternatively is to be served by the Chania-Komu transfer which is a run-of-river scheme. Storage provides additional security in periods of extreme droughts.

✓ **Reliability of the water resource:**
The two scenarios score the same with regard reliability of the resource based on the number of additional independent sources to be mobilised. All sources are designed to operate at 90% reliability (9 out of every 10 years, full supply is guaranteed). In this sub-criteria, it is considered the more the sources the higher the reliability.

✓ **Optimization of the resource:**
This sub-criteria is assessed based on whether the sources are interlinked to operate as a system or not. This is with regard to the existing Thika system and the proposed Northern Collector and Maragua system.

Where sources are interlinked, it is expected that the sources will operate optimally. Scenario 3A gets a fairly good score compared to Scenario 2 which gets medium score.

✓ **Diversity of the water resource**:

This relates to the risk of the supply to long term or extended change through dry years and climate change. Other alternative complementary sources such as groundwater, rainwater collection, wastewater recycling, etc. have been used in the weighting this sub-criteria.

The two scenarios score the same (satisfactory/good) mainly because of the groundwater contribution from the Kiunyu and Ruiru Wellfields in addition to the anticipated groundwater development within the city.

B. Economic Least Cost analysis (Second step)

Details of the economic least cost analysis of the two scenarios are discussed in the Preliminary Design Report Version 02 (June 2012) and in the Chapter 8 of this report.

Scenario 3A scores best (satisfactory/good) with an Average Incremental Economic Cost (AIEC) value of US$0.63/$m^3$, 15% less compared with Scenario 2 which has an AIEC value of US$0.74/$m^3$.

The Present Value of Economic Costs (PVEC) which includes the initial capital investment costs, annual fixed and annual variable operation and maintenance costs shows that Scenario 3A ranks the highest (satisfactory/good) with the lowest PVEC of 669.5mUS$ compared to Scenario 2 which has a PVEC of 831.5mUS$.

The Present Value of Operation and Maintenance Costs (PVO&M), included to allow for the importance of the future pumping costs which affects financial sustainability and the magnitude of water tariffs, shows that Scenario 3A ranks highest (satisfactory/good) as it has the lowest PVO&M of 198.0mUS$ compared to Scenario 2 which has a PVO&M of 307.8mUS$.

C. Third Step - Multicriteria analysis of other criteria

The assessment of the three remaining aspects completes the multicriteria analysis. Pertinent comments are included below.

- **Technical Aspects.** Two criteria are considered: flexibility in further development, and the number of new water sources to be developed.
    - **Construction aspects.** The two scenarios are compared on the construction techniques required in the implementation of the various schemes and on the degree of speciality in the techniques required. The two scenarios will comprise of similar works comprising of dams, tunnels, pipelines, treatment facilities, etc. and therefore score the same (medium or fair score).
    - **Operational aspects.** The two scenarios are compared on the operational techniques required in the operation of the various components and the degree of speciality of these techniques.

      More operational difficulties are expected in Scenario 3A where there is Maragua 4 Dam and it is expected that the diversions from S. Mathioya River transfer and Northern Collector Phase II Rivers will be shared between Thika Dam and Maragua 4 Dam. This will require precise operations to ensure that the system is well utilised.

      It is with this in mind that Scenario 2 scores highest (good) compared to Scenario 3A which gets a fairly good score.

- **Ease in further development.** This sub-criteria compares the two scenarios on whether the resource can be easily developed in future (after year 2035). The two scenarios are also compared in terms of flexibility in terms of redevelopment (before year 2035).

  It is felt that if Scenario 2 is developed as proposed, especially with regard to the Northern Collector system, it will be much more difficult and costlier to further develop the scheme in future. Scenario 3A is expected to respond well with regard to changing water demand dynamics in Nairobi. Therefore Scenario 2 gets a medium score compared to Scenario 3A which gets a fairly good score.

- **Number of new water resources to be developed.** A scenario which has more proposed sources compared to the other scores poorer. This has been considered in terms of the operation and maintenance requirements of the various sources. The two scenarios will comprise of the same number of new water sources and therefore both score the same (fairly good score)

- **Utilisation of existing infrastructure.** The two scenarios are compared in the use of existing infrastructure and resources. Both scenarios equally utilise the existing Thika system and therefore score the same (medium score).

- **Environment Considerations:** the four selected criteria include water quantity, water quality and construction and operational impacts.

  - **Downstream impact (water quantity and quality):** impact of water quantity downstream on the environment: water flow patterns and water and land use. Scenario 2 scores poorer (medium score) compared to Scenario 3A (fairly good). This is because the latter comprises of more storage compared to Scenario 2 which utilises more of run-off-river intakes. It is expected that provision storage will sustain the downstream water demands.

  - **Upstream impact (water quality and quantity)**: impact on upstream land use, water quality, erosion, nutrients, pesticides, and runoff. The provision of storage provides upstream impacts. It is with this regard that Scenario 2 scores better (fairly good score) than Scenario 3A (medium score).

  - **Construction impacts**: Impact on and appropriate management of ecosystems during construction stages. The construction of dams is expected to result to more impacts and therefore Scenario 3A which comprises of two dams scores poorer with a medium score.

  - **Operational impacts**: Impact on and appropriate management of downstream ecosystems during operation stages. If the two scenarios are operated as desired, same impacts will result from the operational point of view. Both scenarios get a fair score with this respect.

- **Social Criteria:** the criteria applies to resettlement and compensation issues and land lost for dam storage, pipelines, treatment facilities etc. Also issues relating to water access and socio-economic benefits are also assessed.

  - **Water Access:** equity of access to water and impact on downstream domestic and commercial users. Scenarios which allow only a specific use of water, excluding other water uses downstream or upstream are ranked poor. When several sectors have access to the water sources, the scenario is ranked medium. If there is no restriction on alternative water sources the scenario is ranked good. Scenario 2

scores poorer (weak score) compared to Scenario 3A (fairly good score) because it is expected that the provision of storage at Maragua 4 Dam site will sustain the downstream demands.

- **Resettlement/land losses:** Scenario 2 is rated as having manageable issues and gets a fairly good score, while Scenario 3A is rated as having a greater risk of potential significant issues and therefore gets a medium score. This is because of the construction of Maragua 4 Dam which is associated with land loss necessitating resettlement and compensation.

4.4 Results of the Analysis

The following tables present the results of the Multicriteria Analysis. Table 7.43 shows the weighting criteria and the allocation of weightings while Table 7.44 presents the final weighted score and the ranking of the two Scenarios.

Comparison of each Water Source Development Scenario shows Overall Scenario 3A with a score of 78% higher by 19% than Scenario 2 which scores 59%. **Therefore, Scenario 3A has been found to be the most advantageous development plan for mobilising new water sources for Nairobi City.**

4.5 Selected Scenario - Scenario 3A

This review of Scenarios has indicated that Scenario 3A ranks higher than Scenario 2 due to the following main reasons:

- Additional storage provided in Phase III with the construction of Maragua 4 Dam
- Water supply from Maragua 4 Dam to Nairobi is by gravity
- Chania-Komu Transfer to Ndarugu 1 Dam is not required to meet the year 2035 water demand for Nairobi (under Scenario 2 this transfer would be required and as supply from Ndarugu 1 Dam is by pumping, this option will have higher operations costs).

A list of sources, capacity and year of implementation based on the mobilisation plan for Scenario 3A is given in Table 7-42.

Table 7-42: Proposed Future Water Sources for Nairobi City

Phase	Year Required	Source	Yield, m^3/d
Phase I	2014 & 2015	Wellfields in Kiunyu and Ruiru	64,800
Phase II	2016	Northern Collector Tunnel Phase I diverting Irati, Gikigie, Maragua Rivers to Thika Dam	120,960
Phase III	2021	Maragua 4 Dam ($30Mm^3$) with S. Mathioya River Transfer to Maragua and Thika Dam	132,192
Phase IV	2026	Northern Collector Phase II diverting Githugi, Hembe and N. Mathioya Rivers to Maragua and Thika Dam	120,096
Phase V	2030	Ndarugu 1 Dam ($300Mm^3$)	216,000
		Total Additional Yield, m^3/d	**654,048**

The main features regarding the Implementation Schedule for the two Proposed Scenarios are illustrated by Table 7-45, Figure 7-17 and Figure 7-18.

The schematics of Scenario 2 and Scenario 3A are given in Figures 7-19 and 7-20.

Table 7-43: Multicriteria Analysis - Weighting Criteria / Allocation of Weightings

Sustainability issue		Headline Criteria	Sub-criteria	Description	(0) Poor	(0.5) Medium	(1) Good	Scenario 2	Scenario 3A
A. Natural Resources (Mandatory Criteria)								**Score**	
A-1	Natural Resources	Water Quantity	Forecast year 2035 Water Demand	Quantity of water supply enough to meet year 2035 water demand for Nairobi City	Does Not meet year 2035 water demand	Between 5 to 10% of year 2035 water demand	More than 10% of year 2035 water demand	**1.00**	**0.75**
A-2	Natural Resources	Water Quantity	Downstream Water Demands	Water left for Downstream Users meets the Downstream Rural and Urban water demands with a Factor of Safety (FoS)	Does not meet the downstream water demands (FoS < 1.0)	Just meets the downstream water demands (1.0 < FoS < 1.2)	Meets the downstream water demands (FoS >1.2)	**1.00**	**1.00**
A-3	Natural Resources	Water Quantity	Environmental Flow Requirements	Water left downstream maintains Environmental Flows	Survival (10%)	Satisfactory (70%)	Good (96% of minimum flow)	**0.50**	**0.50**
A-4	Natural Resources	Water Quality	Source Water Quality	Source water quality in relation to treatment requirements and final water quality	Poor Quality	Satisfactory Quality	Good Quality	**0.50**	**0.75**
A-5	Natural Resources	Water Quantity	Security of the Resource	Risk of water supply option to long term or extended changes in dry years, climate change etc	Run-off the river source	Run-off the river source with storage	Run-off the river source fully supported by storage	**0.25**	**0.50**
A-6	Natural Resources	Water Quantity	Reliability of the Resource	Number of additional and independent water sources	Few sources	Average number	Many sources	**0.50**	**0.50**
A-7	Natural Resources	Water Quantity	Optimization of the Resource	Sources interlinked to operate as a System and able to augment one another (Maragua and Thika System)	Sources operate independently	Sources partly operate together	Sources fully operate as a system	**0.50**	**0.75**
A-8	Natural Resources	Water Quantity	Diversity of the Resource	Share of alternative water sources e.g. groundwater, roof catchment, wastewater recyling etc. to surface water sources	Below 5% of year 2035 total water demand	Between 5 to 10% of year 2035 total water demand	More than 10% of year 2035 total water demand	**1.00**	**1.00**
							Average Score - Mandatory Criteria	**0.61**	**0.71**
								Consider	**Consider**
B. Economic (Least Cost Analysis (5% discount rate))									
B-1	Economic	New Infrastructure	Average Incremental Economic Cost (AIEC)	Normalised discounted Average Economic Cost / m3 (Capex and O&M) of the proposed scenario over the projected life of the infrastructure	AIEC > 0.75 USD/m3	0.65 USD/m3 < AIEC < 0.75 USD/m3	AIEC < 0.65 USD/m3	**0.50**	**1.00**
B-2	Economic	New Infrastructure	Present Value of Economic Costs (PVEC)	Total Present Value of Capital Costs and Operation and Maintenance Costs	PVEC > 900 MUSD	800 MUSD < PVEC < 900 MUSD	PVEC < 800 MUSD	**0.75**	**1.00**
B-3	Economic	Operation & Maintenance	Present Value of O&M cost (PVO&M)	Net Present Value of Operation and Maintenance Costs over the projected life of the infrastructure	PVO&M > 200 MUSD	150 MUSD < PVO&M < 200 MUSD	PVO&M < 150 MUSD	**0.00**	**1.00**
C. Technical									
C-1	Technical	New Infrastructure	Construction aspects	Construction Techniques required	Specialized	Partly Specialized	Fully Specialized	**0.50**	**0.50**
C-2	Technical	New Infrastructure	Operational aspects	Operational Techniques needed	Specialized	Partly Specialized	Fully Specialized	**1.00**	**0.75**
C-3	Technical	New Infrastructure	Ease in Further Development	Allows for further development of the sources	Does not allow	Partially allows	Fully allows	**0.50**	**0.75**
C-4	Technical	New Infrastructure	No. of additional Independent Water Sources	Number of new water sources which need to be developed	Many sources	Average number	Few sources	**0.75**	**0.75**
C-5	Technical	Existing Infrastructure	Utilization of Existing Infrastructure	Use and build upon Existing infrastructure & resources	All new infrastructure	Some use existing	Most existing	**0.50**	**0.50**
D. Environment									
D-1	Environment	Water Quantity and Quality	Downstream Impacts	Impacts on Environments Downstream; water flow patterns, downstream water and land use from reduced environmental flows	Significant Impacts	Some Impacts	No change	**0.50**	**0.75**
D-2	Environment	Water Quantity and Quality	Upstream Impacts	Impacts on Upstream Land Use on water quality; runoff & erosion, nutrients/pesticides runoff, change in wood cover and land use.	Significant Issues	Manageable Issues	No Issues	**0.75**	**0.50**
D-3	Environment	New Infrastructure	Construction Impacts	Environmental impacts from construction, including Diversion Weirs, Dams, Water Treatment works and Transmission Systems	Significant Impacts	Some Impacts	Minimal Impacts	**0.75**	**0.50**
D-4	Environment	New Infrastructure	Operational Impacts	Environmemtal impacts from operation, including managememt of intake sites, aquatic fauna abd riverine ecosystems, incl impacts on protected areas and vulnerable species.	Significant Impacts	Some Impacts	Minimal Impacts	**1.00**	**1.00**
E. Social									
E-1	Social	Access	Water access	Equity of access to water, impact on upstream and downstream domestic, commercial, and stakeholders	Specific water supply use only	Several sectors have access	All sectors can use	**0.25**	**0.75**
E-2	Social	Amenity	Resettlement / Land losses	Population to be resettled and total land losses from dam storage reservoirs, WTW, etc.	Significant resettlement and land losses	Manageable resettlement / Land losses	No resettlement / land losses	**0.75**	**0.50**
E-3	Social	Amenity	Socio-Economic Benefits to the Local Communities	Improvement of the Socio-Economic infrastructure, job creation etc	Lowest contribution	Medium contribution	High contribution	**0.50**	**0.75**
							Average Score - Other Criteria	**0.61**	**0.71**

Table 7-44: Multicriteria Analysis - Ranking of Scenarios 2 and 3A

Multicriteria Analysis - Weighting of Criterias and Ranking of Scenarios

Sustainability Issue		Headline Criteria	Sub-criteria	Weighting		Scenario 2	Scenario 3A
				%			
A. Natural Resources							
A-1	Resources	Water Quantity	Meeting Forecast year 2035 Water Demand	10%		0,10	0,08
A-2	"	"	Downstream Water Demands	5%		0,05	0,05
A-3	"	"	Environmental Flow Requirements	5%		0,03	0,03
A-4	"	Water Quality	Source Water Quality	4%		0,02	0,03
A-5	"	Water Quantity	Security of the Resource	3%		0,01	0,02
A-6	"	"	Reliability of the Resource	1%		0,01	0,01
A-7	"	"	Optimization of the Resource	1%		0,01	0,01
A-8	"	"	Diversity of the Resource	1%	30%	0,01	0,01
B. Economic							
B-2	Economic	"	Average Incremental Economic Cost (AIEC)	10%		0,05	0,10
B-1	"	New Infrastructure	Present Value of Economic Costs (PVEC)	10%		0,08	0,10
B-3	"	Operation	Present Value of O&M costs (PVO&M)	10%	30%	0,00	0,10
C. Technical							
C-1	Technical	New Infrastrucutre	Construction aspects	5%		0,03	0,03
C-2	"	"	Operational aspects	3%		0,03	0,02
C-3	"	"	Ease in Further Development	3%		0,02	0,02
C-4	"	"	No. of additional Independent Water Sources	2%		0,02	0,02
C-5	"	Existing Infrastructure	Utilization of Existing Infrastructure	2%	15%	0,01	0,01
D. Environment							
D-1	Environment	Water Quantity & Quality	Downstream Impacts	5%		0,03	0,04
D-2	"	"	Upstream Impacts	5%		0,04	0,03
D-3	"	New Infrastructure	Construction Impacts	3%		0,02	0,02
D-4	"	"	Operational Impacts	2%	15%	0,02	0,02
E. Social							
E-1	Social	Access	Water access	5%		0,01	0,04
E-2	"	Amenity	Resettlement / Land losses	3%		0,02	0,02
E-3	"	Amenity	Socio-Economic Benefits to the Local Communities	2%	10%	0,01	0,02
TOTAL				**100%**		**59%**	**78%**

Table 7-45: Selected Scenarios

NAIROBI WATER SUPPLY MASTER PLAN
Selected Scenarios for Mobilisation of New Water Sources

Water Demand for Nairobi City (based on Medium Population Growth Rate, including Physical Water Losses)

YEAR			*2010*	*2015*	*2017*	*2020*	*2025*	*2030*	*2035*
Population Projections (Nairobi City)			3 257 615	3 850 370	4 107 466	4 517 800	5 237 368	6 086 401	7 063 903
TOTAL Net Water Demand (m^3/day)			378 500	451 100	480 100	533 600	639 900	746 200	883 000
Physical Water Losses (%)			53%	44%	40%	37%	37%	37%	37%
TOTAL Water Demand (m^3/day)			578 700	649 600	671 100	728 400	873 500	1 018 600	1 205 300
			Data Sources:						
			MWI Guidelines, 2009 Census and Consultant's analyses						
			2009 Population is 3,138,366 according to Census						
Available Water Resources (m^3/day):									
Kikuyu springs			4 800	4 800	4 800	4 800	4 800	4 800	4 800
Ruiru Dam			21 700	21 700	21 700	21 700	21 700	21 700	21 700
Sasumua Dam			56 200	56 200	56 200	56 200	56 200	56 200	56 200
Thika / Chania / Ngethu System			414 700	414 700	414 700	414 700	414 700	414 700	414 700
Groundwater Sources (assumed to increase by 1,000m^3/day per year)			45 000	50 000	52 000	55 000	60 000	65 000	70 000
Total Available Water Resources (m^3/day):			**542 400**	**547 400**	**549 400**	**552 400**	**557 400**	**562 400**	**567 400**
Expected Water Deficit (m^3/day):			-36 300	-102 200	-121 700	-176 000	-316 100	-456 200	-637 900
Expected Water Deficit (m^3/s):			-0,42	-1,18	-1,41	-2,04	-3,66	-5,28	-7,38
Additional Water Resources based on Alternative Mobilisations Schemes:	**Capacity / Yield**								
(2) Wellfields + NC I + NC II to Thika Dam + Ndarugu Dam + Chania-Komu Transfer			*2010*	*2015*	*2017*	*2020*	*2025*	*2030*	*2035*
Transmission to Kabete Reservoirs via Ngorongo T. Works (1.4 + 1.9m^3/s)	m^3/s	m^3/d							
Wellfield in Kiunyu (2014)	0,40	34 560		34 560	34 560	34 560	34 560	34 560	34 560
Wellfield in Ruiru (2015)	0,35	30 240		30 240	30 240	30 240	30 240	30 240	30 240
Northern Collector Tunnel Phase I to Thika Dam (2016)	1,40	120 960			120 960	120 960	120 960	120 960	120 960
Northern Collector Tunnel Phase II to Thika Dam (2020)	1,90	164 160					164 160	164 160	164 160
Ndarugu Dam (300Mm^3) with Natural Inflow (2027)	2,50	216 000						216 000	216 000
Ndarugu Dam + Chania-Komu Transfer (2033)	2,10	181 440							181 440
Remaining surplus / deficit (m^3/day):			-36 300	-37 400	64 060	9 760	33 820	109 720	109 460
(3a) Wellfields + NC I + S. Mathioya Transfer to Thika Dam + Maragua Dam + NC II + Ndarugu Dam			*2010*	*2015*	*2017*	*2020*	*2025*	*2030*	*2035*
Transmission to Kabete Reservoirs via Ngorongo T. Works (1.4 + 1.3m^3/s), the rest to Gigiri	m^3/s	m^3/d							
Wellfield in Kiunyu (2014)	0,40	34 560		34 560	34 560	34 560	34 560	34 560	34 560
Wellfield in Ruiru (2015)	0,35	30 240		30 240	30 240	30 240	30 240	30 240	30 240
Northern Collector Tunnel Phase I to Thika Dam (2016)	1,40	120 960			120 960	120 960	120 960	120 960	120 960
S. Mathioya Transfer to Thika Dam (2020)	0,60	51 840					51 840	51 840	51 840
Maragua Dam (30Mm^3) (2020)	0,93	80 352					80 352	80 352	80 352
Northern Collector Tunnel Phase II to Thika Dam (2026)	1,39	120 096						120 096	120 096
Ndarugu Dam (300Mm^3) with Natural Inflow (2029)	2,50	216 000						216 000	216 000
Remaining surplus / deficit (m^3/day):			-36 300	-37 400	64 060	9 760	1 852	197 848	16 148
Legend:	*(2016) facilities start operating*			*-120 000*	***Deficit***		*120 000*	***Surplus***	

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Figure 7-17: Scenario 2 Implementation Schedule

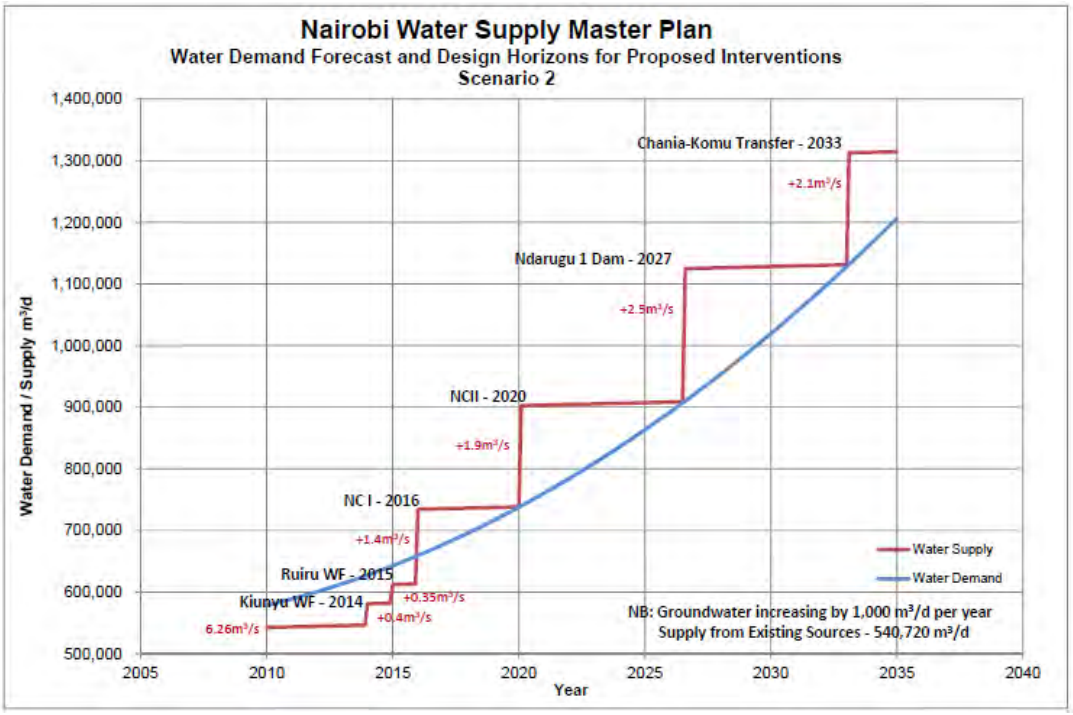


Figure 7-18: Scenario 3A Implementation Schedule

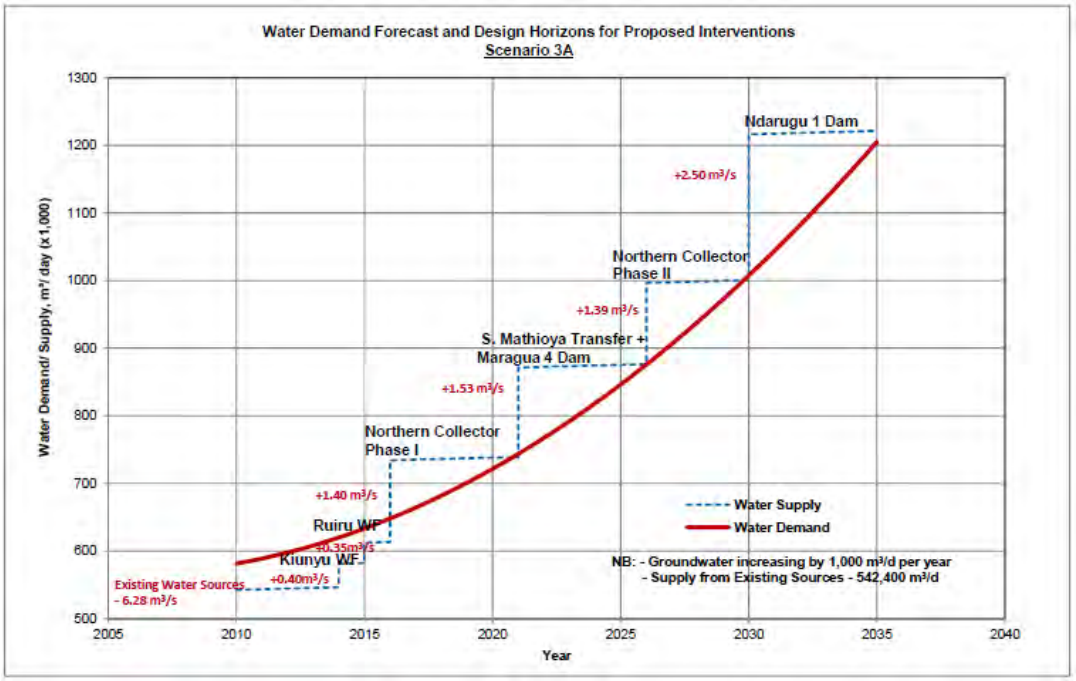


Figure 7-19: Schematic of Scenario 2

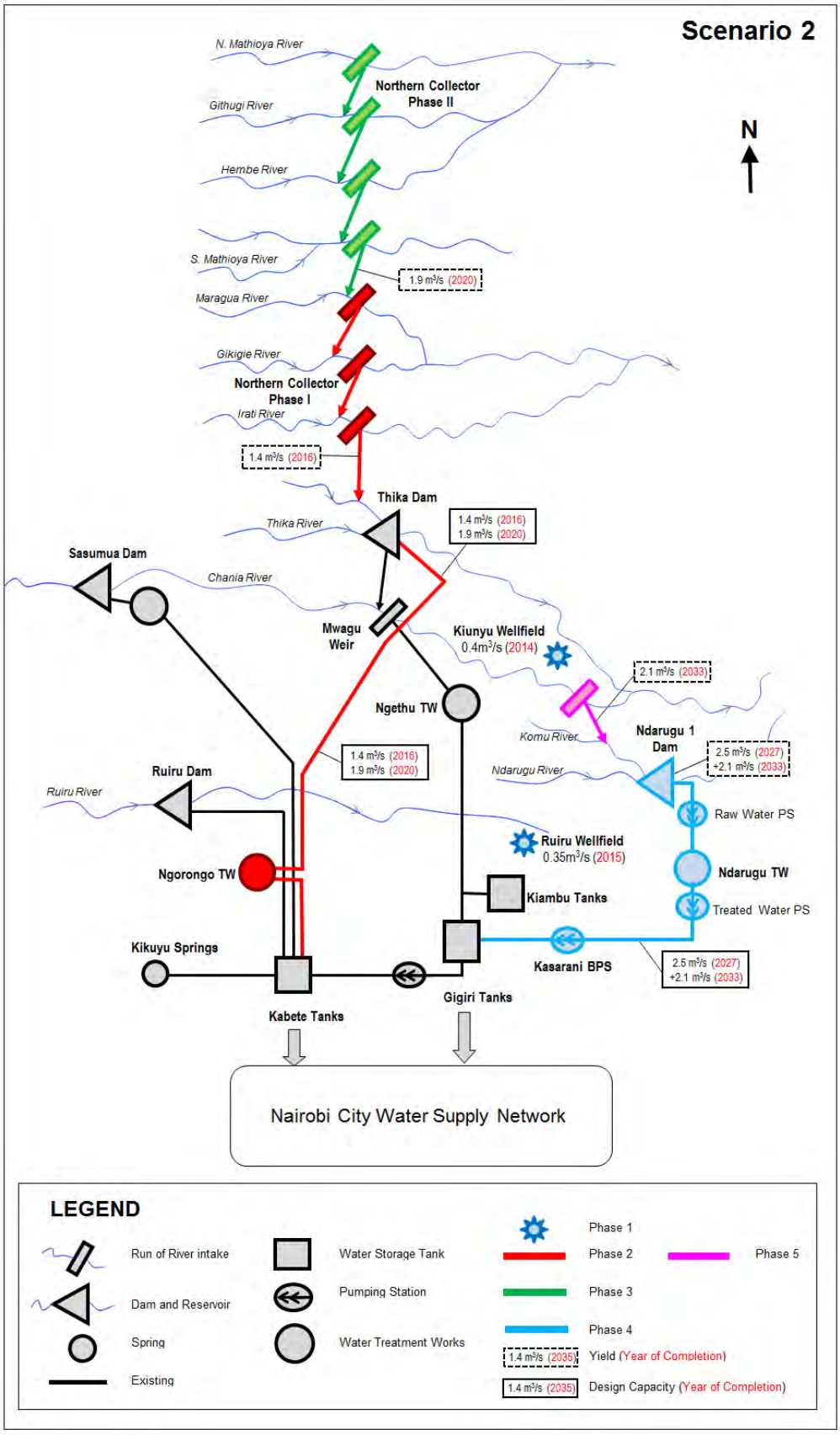
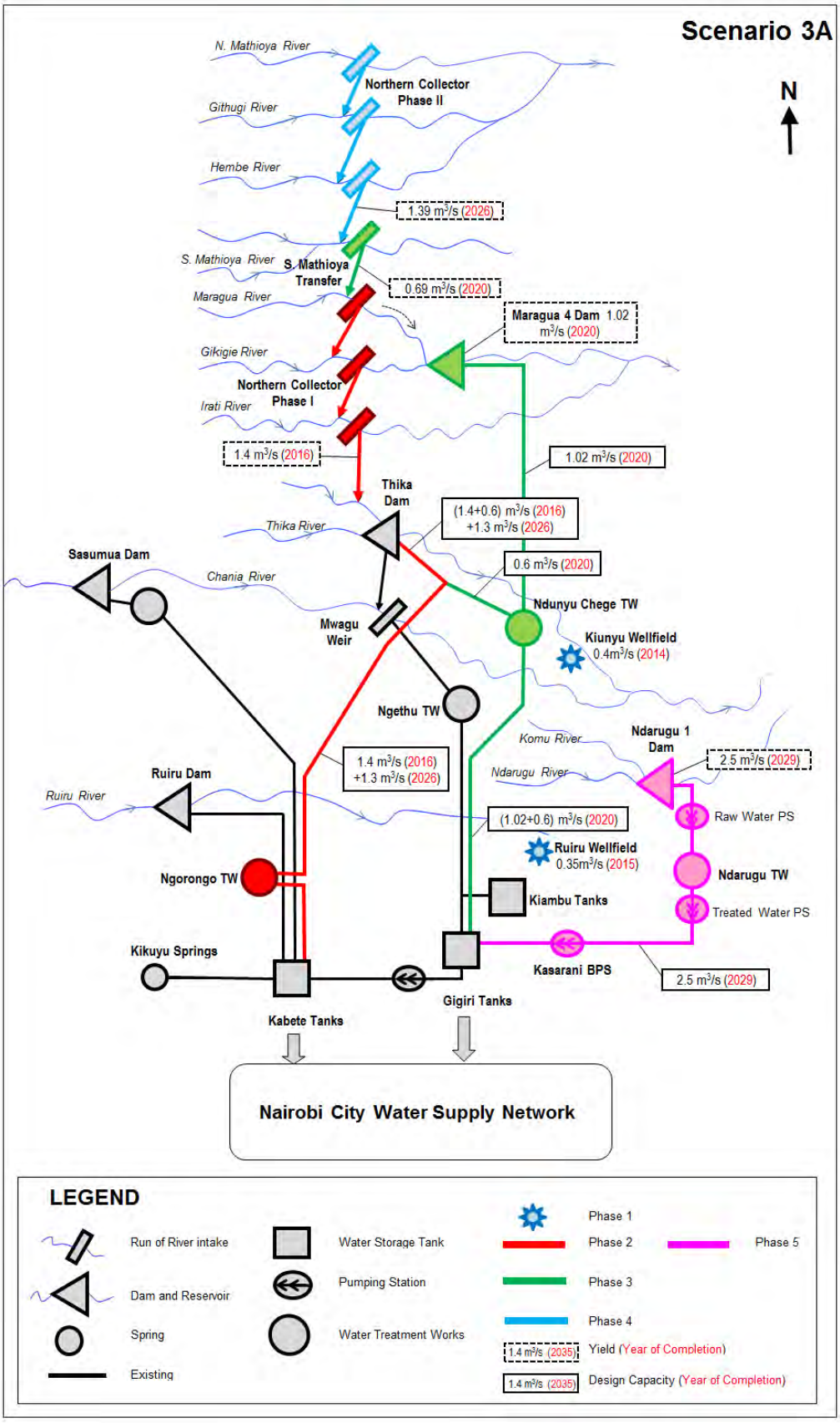


Figure 7-20: Schematic of Scenario 3A



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Chapter 8 - Preliminary Design of Northern Collector Phase I Project

1 Introduction

This Chapter outlines the Preliminary Design of the Northern Collector Phase I Project which was submitted as a separate detailed Preliminary Design Report – Northern Collector Phase I Project, Version 02 dated June 2012.

The components described under this Chapter are:

i) Wellfields Development (Feasibility Design);
ii) Northern Collector (Phase I) Tunnel and Related Works;
iii) Water Treatment Facilities;
iv) Raw Water and Treated Water Transmission Mains;
v) Environmental Evaluation;
vi) Project Costs and Implementation Schedule;
vii) Financial Analysis and
viii) Economic Analysis

2 Wellfields Development

The review of groundwater resources completed in June 2011 proposes an estimate of the groundwater balance. The portion that infiltrates to the groundwater is put at 6% or 370 MCM/yr, a rather conservative coefficient. Based on previous studies the aquifer outflow by drainage to rivers is estimated at 335 MCM/yr. As highlighted by Albert Tuinhof (WB, Water Expert Team's mission, April 2012), a sensitive analysis of groundwater balance will show that the uncertainty in the values of direct infiltration and drainage to river is larger than the three other components including the 44 MCM/yr groundwater abstraction.

Although the water balance lacks accuracy, the main conclusion of the review of groundwater resources (June 2011) is that the current groundwater abstraction is only a limited fraction of the recharge and drainage. This leads to the conclusion that further groundwater development is still possible. This review recommends that the abstraction can be increased by 2-3 times (90 to 125 MCM/yr), such volumes are below the total groundwater flow transmitting through the aquifer. An accurate figure for the groundwater resource available for abstraction will not be proposed until an accurate groundwater balance is established though a mathematical groundwater flow model and in close cooperation with authority in charge of the management of the surface water resource, as such groundwater development will:

- Locally impact the water levels and should then be initiated in sectors where drawdowns will be acceptable;
- Partially increase the infiltration (direct infiltration of precipitation and local drainage from the rivers to the aquifer) because of the lowering of the piezometric levels;

- Globally reduce the drainage to rivers and then reduce the rivers' baseflow, as the increase of infiltration will not compensate 100% of the abstraction.

For the present stage of the Master Plan, the development of a limited part of the groundwater resource only is considered, for less than 70,000 m^3/day (or 25 MCM/yr).

This Section outlines the Feasibility Design for the two Wellfield Schemes proposed as part of the short-term development plan for the mobilisation of new water sources for Nairobi City. It must be noted that the related schemes are not detailed at the Preliminary Design level adopted by other components because the implementation of the proposed two well-fields cannot be done without additional field investigations and implementation of test holes to confirm potential, location and characteristics of proposed wells and related equipment.

2.1 Location and Extension of Wellfields

2.1.1 Kiunyu Wellfields

The upper part of the Thika River, before the junction with Chania River, drains the basaltic part of the aquifer body. The basalts here belong to the Simbara Series laid in the Miocene and therefore lie on the sub-Miocene erosional surface. The series is quite thick, reaching up to 900 m; its thickness in the immediate area is not known, but could be at least 300 m, given that the dissected valleys are quite deep. Its lithologic character consists of porphyritic basalts and basaltic agglomerates, but also includes flow-brecciated lavas, or "autobreccia". Where the agglomerates occur, they tend to be deeply dissected, hence the ridge-and-valley feature common in the area. The agglomeratization and brecciation are important features for groundwater occurrence. The Simbara basalts are overlain intermittently by non-porhyritic lavas that have been variously named Laikipian basalts.

The Kiunyu sector is characterised with small sharp valleys for each of the tributaries of the Thika River. Between the valleys, the hills can be up to 150 m high. The static water levels are certainly very close to the river bed elevation: a well-field will preferably be developed in the valleys, in order to limit the depth of the static water level. Valleys of the small rivers in the sector (as Gatwariga River) seem to be poorly interesting in terms of available space for a well-field development. The largest valley is the Thika valley. It appears to be rather large (at least 200 to 300 m on both sides of the river) and flat, accessible for standard drilling machine in the sector of Naaro, 6 km NNW of Kiunyu. Boreholes can be distributed in the valley, east of the bridge. In this sector and upstream, the pollution pressure seems to be limited to extensive agriculture, and small coffee factories (see Figure 8.1 for proposed site).

There are no boreholes in proximity to the proposed Kiunyu Wellfield. However, some boreholes located a few kilometres from here have been traced and their data used to estimate likely conditions of upper levels at Kiunyu.

Table 8-1: Boreholes Data in Kiunyu Sector

	Location	Total Depth (m)	SWL (m)	Aquifer	W R	Q (m^3/h)	Q (m^3/d)	S (m)	Logan's T, m^2/d	AWI (r, m)
C-4744	6km/256°	130	66	Contact- pyroclastics on basalt	28	2.9	70.6	78	1.1	53
C-2008	12km/349°	216	16	Contact- pyroclastics on basalt	16	1.1	25.9	183	0.2	184
C-3172	6km/220°	110	104	Basalt	46	6.5	157.0	45.7	4.2	42
C-928	8.5km/183°	137	64, 131	Contact and basalt	85	8.4	201.6			

Two of the boreholes, C-4744 and C-2008 have aquifers at the pyroclastics/ basalt contact, hence their characteristics are not important for the proposed well-field. The other two, C-3172 and C-928 have aquifers from within the basalt that is the target aquifer.

The data shows that borehole yield is better in the basalt aquifer than the contact aquifer atop the basalt. However, the yields are still extremely low. Given that one of the boreholes was drilled to 216 m with no aquifer struck in the basalt, the location of the exploratory boreholes will have to be based on sound investigations and the depths may be greater than 250 m.

This data also indicates that the Wellfield may not necessarily be confined to the proposed site, but may extend up or down the valley. Having made this fact clear, it can therefore be stated that a 1 kilometre stretch of the valley below the bridge was inspected and found to have a terrace on either side of the river channel that can be used to locate the boreholes.

The terrace along the river valley lies at roughly an elevation of 1580 metres. The ascent to the valley top above is steep – rising to 1680 metres in 400 metres (1:25).

2.1.2 Ruiru Wellfield

A potential site of large yielding potential areas upstream from the main cities' pollution and located to the west and north-west of Nairobi was identified beneath Middle Trachyte Series in north of Kiambu, NW of Ruiru area. Boreholes can be distributed on Kamiti river valley at Kianjibbi estate, about the dam area (see Figure 8.1 for proposed site).

In this sector, the pollution pressure seems to be mainly due to agriculture (large coffee plantations) and coffee factories. Upstream, this pressure seems to be reduced but some entropic pollution is expected from the Githunguri sub-urban area. The upper levels of the aquifer series should be sealed to prevent large mixing of local groundwater certainly contaminated with pesticides.

A study of the borehole distribution shows (see Figure 8-1) that the best performing boreholes are those located along the Kamiti River and Mukuyu valleys (C-2321, C-2728, C2913, C-4033, C-6093).

Table 8-2: Boreholes Data in Ruiru Sector

B/hole	Location	TD,m	WS,m	Aquifer	WR	Q, m^3/hr	$Q/m^3/d$	S, m	Logan's T, m^2/d	AWI (r, m)
C-1513	0.9km/139°	65	55	Kerichwatuff	14	3.66	87.84	-		
C-1815	2.8km/204°	206	138,192, 206	Various contacts	50	2.28	54.72	75.3	0.9	57
C-2321	1.4km/239°	192	38,85,176	Trachyte/ phonolite contact	38	7.92	190.08	4.8	48.3	34
C-2728	12.7km/167°	155	143	Trachyte/ phonolite contact	15	19.1	458.4	36.6	15.3	48
C-2913	3.1km/257°	119	96	Trachyte/ phonolite contact	46	6.36	152.64	9.1	20.5	42
C-4033	3.6km/136°	206	-	Trachytes/ UAS	49	30.9	741.6	28.9	31.3	46
C-6093	2.8km/065°	150	70, 110, 126	Trachyte/ phonolite contact	33	19.8	475.2	2.4	241.56	31

The site will generally lie on the 1600 metre contour, more or less 10 metres.

A provision should be made in the pipeline estimates for moving the wellfield up to 2 kilometres downstream from the current site in any case the wells will be distributed over at least 1.4 kilometre stretch (see green outline on map in **Figure 8-1** on **page 8-5**).

2.1 Preliminary Investigations

Well-fields development cannot be planned before the resource availability and the local hydrogeological context is verified. Since little is known about the thickness and detailed lithology beneath the two possible sites for regional groundwater development or about

presence or absence of deeper aquifers, it is clear that a regional understanding of these should be the first priority of an investigation program. A second objective would be the delineation of precise drilling targets.

2.1.1 Geological Issues

The geological investigations should address four major issues: delineation of the outcrops of the volcanic rocks (specifically extension of the basalts, the most highly productive formations), determination of sediments and faults in deep Athi series volcanic rocks, major tectonic events in the basement below the Athi series, determination of basement morphology including overlying palaeo-channels.

One of the key objectives of the geological investigation requires the recognition of the overall thickness of the Athi series, i.e. that depth penetration to 800 m+ be achieved and that stratigraphic and structural detail be determined to 800 m+. Only the seismic reflection technique can meet these criteria on a regional scale. To these ends it is recommended to make a series of geophysical sections which cuts from the north-west to the south-east of Athi River Basin. For costing purposes, 40 km of survey lines are proposed, consistent with the NGWB extension, for a total cost of 1,300,000 US$.

Another issue is to re-define the geological map in order to better understand the direct recharge of the aquifer. This could be done with the existing geological map, validated with satellite imagery sensible to the geological structures (radar imagery band C like the ASAR tool from ENVISAT) and a series (about 20, for an estimated cost of 60,000 US$) of short destructive drillings for lithological validation.

2.1.2 Piezometry and Groundwater Balance

The piezometry of the NGWB can be precisely known around Nairobi itself, due to the large number of wells in this area. Outside this well known area, the number of wells is limited. It is nearly null at the borders of the system. The 20 small recognition holes drilled for geological purpose will also be located according to the needs in terms of piezometry. After drilling, they will be equipped with 4” PVC casing and screen and developed in order to be used as piezometers. Such transformation of the holes will add about 35 US$/m to the borehole cost, i.e. a total amount of 60,000 US$ for works.

The precise elevation will be measured for the 20 new piezometers, as well as for the 15 monitoring wells of Water Resources Management Authority (WRMA) monitoring network, and for a selection of some 40 ideally located existing wells. This exact elevation, associated with at least 6 piezometric campaigns during one full hydrologic year, will allow the elaboration of a piezometric map in a pseudo steady-state situation. Estimated cost for these actions is 50,000 US$.

The piezometric map, in conjunction with the aquifer geometry, the geology, the land use, the river drainage, the estimated abstraction and the rainfall, will allow the construction of a simple groundwater flow model. This model will be used to validate the overall groundwater balance and to evaluate the feasibility of the planned abstraction beneath the (revised) planned sites in terms of resource availability and impact on the water levels. The estimated cost for such model construction and use is 120,000 US$.

Figure 8-1: Boreholes Distribution around Ruiru Wellfield Site

2.1.3 Pilot Holes

Beneath each of the potential well-field site, two (2) pilot holes should be drilled up to the targeted depth, equipped and pump tests carried out. Such tests should be able to confirm: the geological hypothesis (lithology and depth of the targeted aquifer layers); and the assumptions in terms of maximum production per site with an estimate of the local aquifer transmissivity. Such pilot holes are indispensable for a correct estimate of the well-field design, production and cost.

A provision of four (4) additional pilot holes, two per target, should be done in case the hypothesis in terms of geology or aquifer parameters are not verified and new sites should be tested.

The provisional budget for deep pilot hole (up to 600 m) is given in Section 2.5.2. This budget covers a pilot hole equipped in steel instead of stainless steel for production boreholes. The advantage will be a very competitive cost for the pilot holes, with a total provision of 550,000 US$ for works. Such wells will then not be converted in production wells, but would probably be used as piezometers for the well-fields.

For shorter pilot holes (i.e. for the basalt well-field), the unit price per meter of borehole can be reduced: it moves from 230 US$/m to 200 US$/m. The budget for four (4) pilot holes 250 m deep is then 200,000 US$ for works.

2.2 Kiunyu Wells Design

The tentative pre-design below is based on general consideration. The final design options for wells construction and well-field arrangement will only be selected after the preliminary investigations are conduced.

2.2.1 Expected Production

This sector close to the Thika River before the junction with Chania River is the basaltic part of the aquifer body. The expected production for the whole well-field was estimated to some 35,000 m^3/day based on the direct infiltration in basalts upstream the Kiunyu village.

Considering a well-field of up to 25 boreholes including spare ones (maximum number of boreholes in a well-field is usually consider to be 25 due to operational constraints), individual production per borehole should be close to 75 m^3/h.

In basalts, high yielding boreholes can usually be drilled and these 75 m^3/h is a reasonable target (much larger yield are still possible). It should therefore be noted that no boreholes are reported there to validate this figure and the individual production should be adjusted after preliminary investigations of the productive levels.

2.2.2 Hydraulic Constraints and Wells Diameters

For individual yield from 70 to 180 m^3/h with limited drawdown, an 8'' submersible pump should be used. Then, the pumping chamber should be in diameter 9 $^5/_8$", unless the preliminary investigations demonstrated that more than 180 m^3/h can be extracted per well. Drilling of this first section (equipped with blind casing) of the borehole should be 12 ¼" diameter.

For a production up to 120 m^3/h, ID (internal diameter) of the screens should be as large as 170 mm to preserve an ascendant velocity smaller than 1.5 m/s, i.e. screen and plain tube should be at least $6^5/_8$" (for larger individual production, a different design should be defined).This $6^5/_8$" is possible after a 9 $^5/_8$" casing when drilling of the second section is 8

½".If the second part of the borehole is kept open-hole, this 8 ½" will allow a production up to a maximum of 180 m^3/h.

2.2.3 Casing, Tube and Screen Materials

In order to preserve a high water quality, the upper part of the borehole will be sealed. This sealed section can be used as pumping chamber. It should then be deep enough for the pump to be kept below the water table when the drawdown is maximum, but short enough to limit the sealing of potentially productive levels. It can be anticipated that about 75 to 125 m can be sealed, and potentially up to 150 if some 250 m of productive basalt are considered. For this sealing to be perfectly efficient, cement sealing will be set up by pressure from the bottom. Casing should then be stainless steel in order to ensure collapse strength large enough to stand the sealing pressure and to ensure a good resistance to corrosion.

Tubes and screens can be PVC as the diameter and depth are limited. Limitation of PVC is the small open area (usually from 5 to 7% only), but this should not be a problem in fractured basalts if the productive fractures are well distributed in depth. In case the productive levels are thin, stainless steel screen continuous wire type, with large open area (more than 25%), can be associated to PVC plain tube. If the productive part of the well is well stabilised, keeping this part open-hole can also be an option. Nature of the basalts and stability of the open-hole will be analysed after preliminary investigations. See drawing in Appendix 8.1 for a tentative log of a typical well.

2.2.4 Wellfield Arrangement

Spacing between boreholes is fixed knowing the cumulative drawdown in one well caused by the other wells in the well-field. It is function of the aquifer transmissivity and the pumping yield. Spacing between wells will be updated when the local transmissivity will be known. For operational reasons, it should be smaller than 1000 m. When hydrogeological conditions are very good, it can be limited to 50 or 100 m. Furthermore, as has been indicated, good yields will require proper location of the boreholes to take advantage of fractured zones in the rather massive basalt. Any design elements from this information is therefore extremely rudimentary and only indicative.

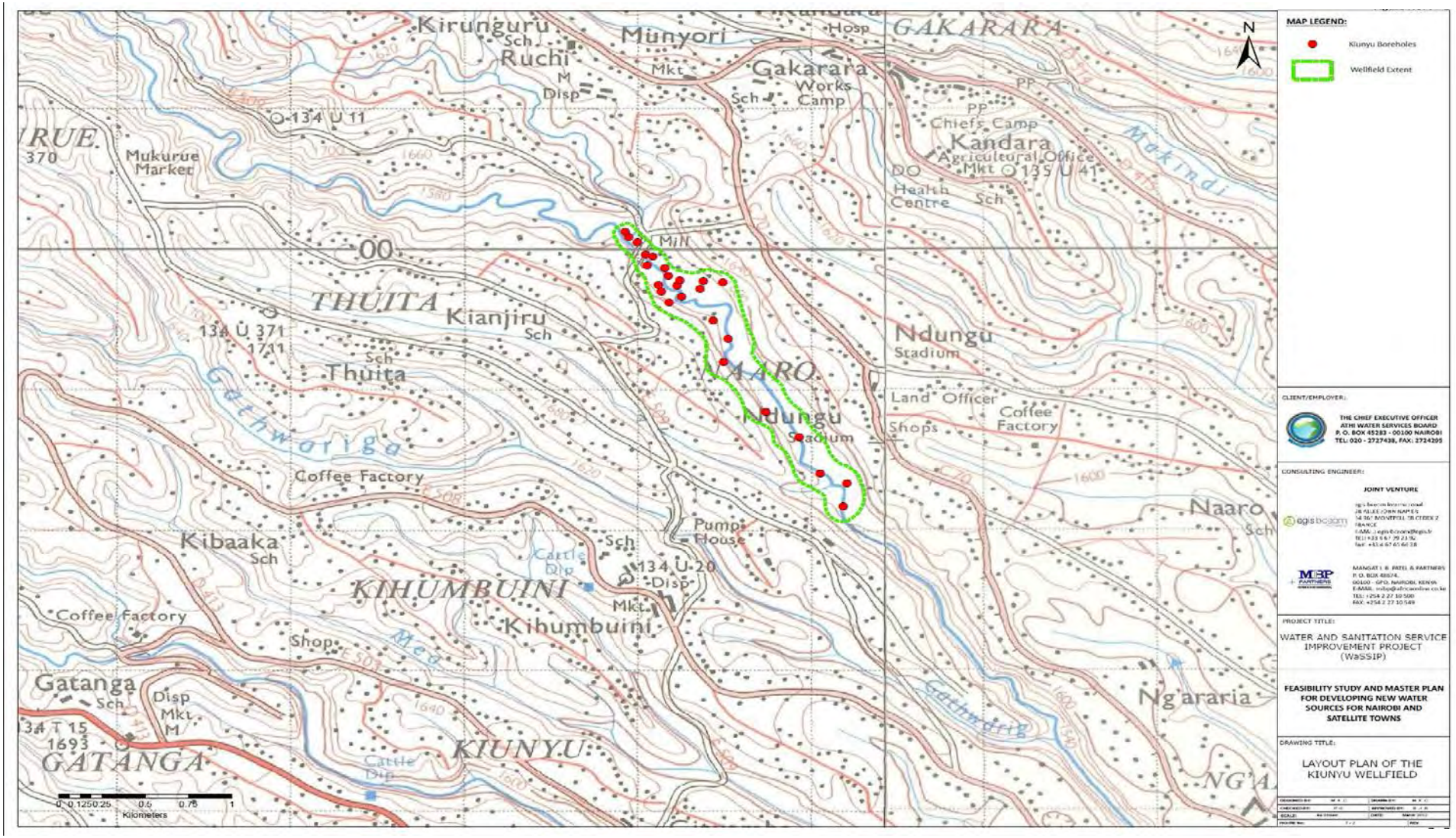
The data in Table 8.1 illustrates that the radius of influence of wells (radius of cone of depression) drilled in the basalt may be as little as 40 metres (cf. C-3172, Table 1). This means that any two boreholes at least 80 metres apart should not interfere with each other.

The landform of the valley is such that one borehole can be located on either side of the river channel and the 80 m minimum distance will be achieved. On a purely mathematical basis therefore, it is possible to have 25 boreholes within 1 kilometer stretch of the valley below the bridge. See **Figure 8.2** on **page 8-8** for Layout Plan of the Kiunyu Wellfield.

It should be borne in mind though that this is not a homogeneous sediment aquifer of considerable extent, but a fractured basalt aquifer is the target. As such this even distribution is not practical – the well-field may extend for longer than 1 kilometre. Drawing section for a tentative log of a typical well is given in **Appendix 8.1**.

The drawings showing the transmission pipeline route from Kiunyu Wellfield to Gigiri Reservoir and its longitudinal profile are given in **Appendix 8.2**.

Figure 8-2: Layout Plan of the Kiunyu Wellfield



2.3 Ruiru Wells Design

The tentative pre-design below is based on general consideration. The final design options for wells construction and well-field arrangement will only be selected after the preliminary investigations are conduced.

2.3.1 Expected Production

The geometry of the Tertiary rocks indicates that these thicken from east to west. Between Nairobi city and Limuru, thickness of the Tertiary rocks increases rapidly and may exceed 1200 m thick near the scarp. This suggests that untapped aquifers could include deep Athi series sediments located to the west and north-west of Nairobi. All these volcanic series are part of the NGWB. This Middle Trachyte Series comprises what Gevaerts named the Upper Athi and Middle Athi Series; it is not certain that the Lower Athi Series may occur here, but certainly this area marks the northern boundary of the Kapiti Phonolite series.

The expected production at this site was estimated to some 30,000 m^3/day based on the direct infiltration upstream this sector. Considering a well-field of up to 15 boreholes (maximum number of boreholes in a well-field is usually considered to be 25 due to operational constraints), individual production per borehole should be close to 100 m^3/h.

The individual borehole production in the outcropping Middle Trachyte Series is usually not compatible with this targeted yield: existing boreholes in this sector are rather short (100 to 200 m, see Table 8-2 on page 8-3) and none produce more than 30 m^3/h (see Table 8-2). Therefore it is very probable to get improved yield with deep and large boreholes. It is therefore expected to benefit from the whole thickness of deposits, certainly 400 to 600 m deep there.

It should therefore be noted that no existing boreholes are reported there to validate these figures (100 m^3/h yielding, 400 to 600 m deep) and the individual production should be adjusted after preliminary investigations.

2.3.2 Hydraulic Constraints and Wells Diameters

For individual yield from 70 to 180 m^3/h with important (from 150 m and over) drawdown, a 10'' submersible pump should be used. Then, the pumping chamber should be in diameter 13 $^3/_8$". Drilling of this first section (equipped with blind casing) of the borehole should be 17 ½" diameter.

For a production up to 120 m^3/h, ID (internal diameter) of the screens should be as large as 170 mm to preserve an ascendant velocity smaller than 1.5 m/s, i.e. screen and plain tube should be at least $6^5/_8$" (for larger individual production, a different design should be defined).

This $6^5/_8$" is possible after a 13 $^3/_8$" casing when drilling of the second section is 10". As the boreholes will be rather deep, the lower part of the tube and screen will be 4 ½" diameter, in order to allow large collapse pressure. Up to 50 m^3/h will be allowed in this 4 ½" section, the rest of the yield will come from the $6^5/_8$" section above.

See Appendix 8.1 for a tentative log of a typical well.

2.3.3 Casing, Tube and Screen Materials

In order to preserve a high water quality, the upper part of the borehole will be sealed. This sealed section can be used as pumping chamber. It should then be deep enough for the pump to be kept below the water table when the drawdown is maximum. It can be

anticipated that about 150 to 250 m can be sealed, if some 500 m of productive Athi series are considered. For this sealing to be perfectly efficient, cement sealing will be set up by pressure from the bottom. Casing should then be stainless steel in order to ensure collapse strength large enough to stand the sealing pressure and to ensure a good resistance to corrosion.

Tubes and screens should be stainless steel, as the final depth and the corresponding collapse pressure are important.

2.3.4 Wellfield Arrangement

The radius of the well influence varies between 30 and 60 metres on average (median 45 m); therefore the minimum distance from one well to the other should be 90 metres to avoid interference. In this regard, 30 boreholes will require a linear distance of 2.6 kilometres between them, or a minimum of 1.4 kilometres with one borehole on either side of the valley.

This will require a minimum of 35 acres of land if the whole well-field is to be fenced off; however, if individual well sites are fenced off, only 1/8th of an acre is required per site so 4 acres will be needed. Given the complexity of security operations for individual sites, it were better that the whole Wellfield (at least 35 acres) is acquired. Allowing for pipeline routes etc., up to 50 acres will be required. See Figure 8.1 for Layout Plan of the Ruiru Wellfield.

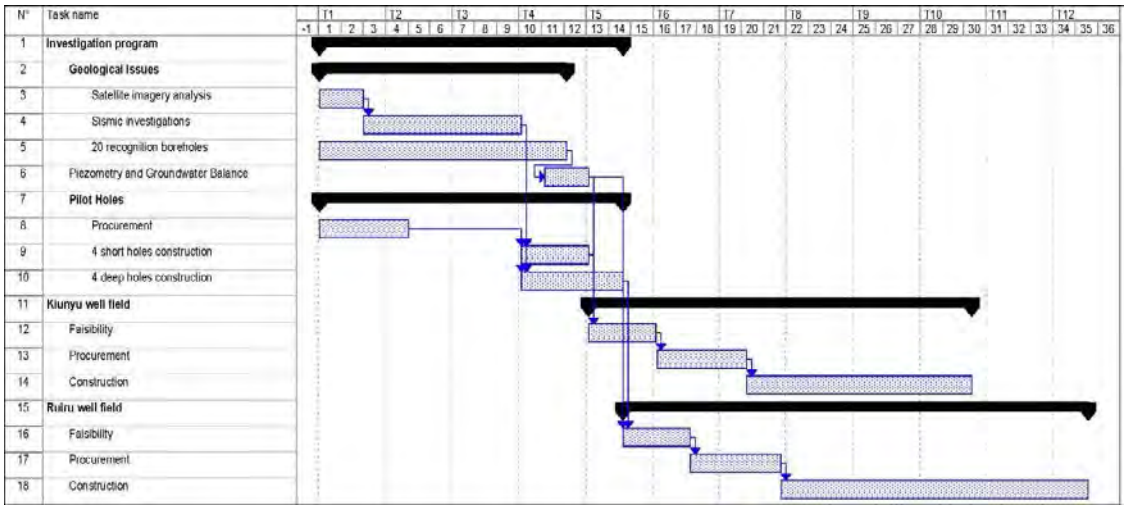
The Drawings showing the transmission pipeline route from Ruiru Wellfield to Gigiri Reservoir and its longitudinal profile are given in **Appendix 8.2**.

2.4 Construction Program

2.4.1 Additional Investigations and Construction Schedule

The Well-fields development is a 3-years program as detailed in the planning below.

Figure 8-3: Investigations and Construction Schedule



2.4.2 Investigations and Construction Costs

The detailed costs for drilling operations (drilling deep investigation boreholes, drilling the Kiunyu boreholes, drilling the Ruiru boreholes) are given in **Appendix 8.3**.

The overall costs, including consultancy services, are summarised in the tables below.

a) Investigation Program

Table 8-3: Tentative Budget for the Investigation Program for Well-field Development

Items		Tentative Amounts (1,000 US$)
Geological investigations	Geophysical prospection (sismic)	1,300
	Seismic works supervision	100
	Recognition drillings	75
	Works supervision	10
	Satellite imagery	40
	Consultancy Services	65
Hydrogeological investigations	Piezometers construction	60
	Works supervision	10
	Topo-survey and piezometry	50
	Consultancy services (groundwater flow model)	120
Pilot holes	Drilling Works deep boreholes	550
	Drilling Works standard boreholes	200
	Work supervision	100
Consultancy Services	Summary, feasibility	100
Miscellaneous		300
	Total	**3,080**

b) Drilling and Wells Equipment

Table 8-4: Provisional Budget for the Two Wellfields (Drilling only)

Items	Tentative Amounts (1,000 US$)		
	Ruiru	Kiunyu	Total
Mobilisation, Site Shifting, Demobilisation	160	140	300
Well construction	4,210	2,300	6,510
Pumping tests	180	290	470
Consultancy services for drilling operation			720
Total			**8,000**

c) Treatment Facilities, Storage and Transmission Mains

Table 8-5: Treatment and Transmission Facilities

Items	Estimated Amounts (1 000 US $)		
	Ruiru Wellfield	Kiunyu Wellfield	Total
Pump Houses	108	104	212
Manifold Pipe System	3,392	4,500	7,892
Chlorine Treatment Unit	571	562	1,133
Pumps and Motors	616	641	1,257
Collector Tanks	7,876	8,841	16,717
Transmission Mains	5,053	18,216	23,269
Total	**17,616**	**32,864**	**50,480**

d) Total Investment Cost

On top of the above costs the amount for preliminaries and engineering services should be added. The total cost for the two well-fields is as given in **Appendix 8.3.**

Items	Estimated Amounts (1,000 US$)		
	Ruiru	Kiunyu	Total
Investigations			3,080
Wells Drilling and Equipment	5,366	3,760	9,126
Treatment and Transmission Mains	17,616	32,864	50,480
Preliminaries and Engineering Services	4,884	7,924	12,808
Total	**27,866**	**44,548**	**75,494**

3 Northern Collector (Phase I) Tunnel and Related Works

This Section outlines the Preliminary Design Details of the Northern Collector (First Phase) and Related Structures such as weirs, tunnel entrances, tunnel outfalls and shaft to be implemented for the Phase I of the Project.

The Northern Collector Scheme Phase 1 has been selected to be implemented in the short-term in view to meet the Nairobi City Water Demand following the technical, economic and environmental screening done during the previous studies as summarized in The Water Sources Options Review Report (version 2).

The Scheme, under Phase I will divert raw water from Maragua, Gikigie and Irati Rivers to Thika Dam Reservoir through 11 kilometers long tunnel of 3.2m nominal diameter.

3.1 Geology and System Alignment

3.1.1 Geology

a) Available Geotechnical Investigation / Additional Investigations

The results of the Northern Collector Feasibility Study by Howard Humphreys and Partners, 1998 are documented in Chapter 5 of that Report. A total of 13 Boreholes were drilled, 8 Boreholes in Phase 1 (11.7km) and 5 Boreholes in Phase 2. For practical purposes, boreholes were drilled in the valley bottoms and that there are distances in excess of one kilometre between the investigation points.

Geological information from boreholes has been obtained at the following localities:

- Makomboki outfall Ch 0+069 to Ch 2+531, three boreholes, BH 13 at the outfall, BH 12, BH 11.
- Ch 2+531 to Ch 6+312, two boreholes. BH 10 at Kaanja Access Adit and BH 9 at Irati shaft.
- Ch 7+734 to Ch 11+736, three boreholes, BH 7, BH8 at Gikigie Intake, BH6 at Maragua Intake.

From the geological information obtained the Feasibility Report states:

- Predicted geology is approximate (section 5.6)
- Water levels are uncertain (section 5.4.2)
- Rock testing is limited (section 5.3).

In consideration of the above comments additional boreholes and laboratory testing is necessary in order to finalise the design of the underground works. A total of 6 boreholes are proposed to provide more geotechnical data. There will be two at the Maragua Intake and two at the Makomboki outfall. One borehole is positioned close to BH 9 within the valley to verify if the complex variable strata recorded in that hole persists and another borehole is located between Gikigie Intake and Maragua Intake. A seventh borehole has been provisionally positioned midway between BH 9 and BH 10. This may be drilled depending on accessibility to the site and on the results from the other holes.

The additional information will permit:

- Re-evaluation of the distribution of rock classes in percentages along the route
- More accurate estimation of the permanent support requirements within the tunnel.
- Clarify some rock class discrepancies between which have been identified within the Feasibility Report. These are discussed below under Ground Support.

b) Hydrogeology

Section 5.4.2 of the Feasibility Report records that water rest levels were found at shallow depths and may indicate that perched water tables are present. The permanent water table is thought to be much deeper. Variations in composition, density and porosity of the layers of volcanic strata would suggest the presence of perched water tables. Should the tunnel intersect the contact between rocks of different permeability then ground water is likely to be present. Additional investigation data will provide more data to verify this assessment.

c) Discontinuities

The Feasibility Report makes reference to the Sattima Fault as the major fault in the area with a maximum displacement in the region of 900 meters together with probable Holocene faults which have very small throws, rarely exceeding a few feet. It is probable that the alignment will intersect faults with small displacements, the frequency of which is not known. Further study is necessary to clarify the effect of the Sattima fault on the regional geology.

As a general rule the volcanic tuffs are massive rocks in comparison to the basalts which are likely to be jointed and blocky.

3.1.2 Alignment

a) Constraints

The alignment of proposed Northern Collector phase I tunnel was finalised, taking into account existing ground conditions (original ground levels) at proposed intakes locations, as well as slopes (required for hydraulic design).

The basic design proposed by Howard Humphreys in their 1998 report was checked and confirmed on the whole, with some adaptations and additions.

The alignment and longitudinal section of the proposed tunnel is given in **Figures 8.4** and **8.5** on pages 8-14 and 8-15 respectively.

b) Accesses

The need for accesses (both temporary accesses needed during construction and permanent accesses) was also considered. This led to finalise the location of the following accesses.

Table 8-6: Tunnel Accesses

Access	Chainage	Type of access
Maragua Intake	11775	Construction access (track)
Gikigie Intake	8725	Permanent access adit
Irati Intake and Shaft	6332	Permanent adit and shaft
Kaanja Access adit	3990	Construction adit
Makomboki Outfall	0	Construction access (track)

Figure 8-4: Alignment of the Proposed Tunnel

Figure 8-5: Longitudinal Section of the Proposed Tunnel

3.1.3 Tunnel Design

As explained in the previous paragraph, tunnel design considered topographical data as well as hydraulic constraints, so as to set the most suitable alignment and profile.

a) Seismicity

No reference is made to the levels of seismic activity that have been or are likely to be encountered along the route. Seismic activity is likely to be low as the alignment is a considerable distance from the Rift Valley fault system. However, further reference will be made to the relevant documents as well as TNWSP (Third Nairobi Water Supply Project) with respect to seismic potential.

b) Ground Support

Ground support is designed on the basis of rock classes as given in Figure 5.7 of the Feasibility Report. There will need to be a re-evaluation of the distribution of rock classes in percentages along the route in relation to discrepancies between the percentage of predicted rock support classes given in Chapter 5 and Table 7.1 of the report, as shown in Table 8-7.

Table 8-7: Ground Support

Support Class	Table 7.1	Section 5.6.1
1	11%	14%
2	15%	17%
3	54%	52%
4	20%	17%

Figure 5.7 in the Feasibility Report uses the results presented in Table 7.1. Considering the known variability in the geology of the terrain and the limited amount of data available it is likely that rock class percentages along the route could, in actuality, differ considerably. In order to determine the rock class percentages applicable to the ground conditions additional investigation data will be necessary to re-calculate the RMR and NGI 'Q' values at or around tunnel elevation. This data will be converted to rock classes and the amount of ground support can then be estimated. The typical tunnel supports and cross sections of the proposed tunnel are given in **Figures 8-6** and **8-7** on pages 8-17 and 8-18 respectively.

c) Drainage

The Feasibility Report records in Section 7.1.2 that ground water is not likely to be encountered in significant quantities. Given the uncertainty further measurement of water rest levels is required. This will entail:

- Water rest levels to be measured in the boreholes early in the morning prior to drilling
- In-situ tests to re-evaluate rock mass permeability.

The presence of falling water levels as a borehole proceeds would indicate perched water tables. Should ground water be present in considerable quantities the ratio of upslope to downslope excavation can be reassessed.

Figure 8-6: Tunnel Typical Support Details

Figure 8-7: Tunnel Cross Section

d) Portals

The design of the rock support to temporarily stabilise the tunnel portals at Maragua Intake and Thika Outfall is not covered in detail in the Feasibility Report, other than a comment that the portal face may be supported by shotcrete and grouted dowels. Boreholes BH6 and BH13 provide data for the intake and outfall respectively. Completely weathered rock is located above the tunnels in both locations but whereas at tunnel elevation the intake is generally within Grade III the outfall is almost entirely within Grade V to VI. The design of temporary support at the portals will need to take into account these differing rock conditions and a different approach to each portal may have to be considered. Additional investigations will provide this information.

Figure 8.8 on page 8-20 shows the general arrangement of the portal design with shotcrete, wire mesh and rock bolts or dowels where applicable. Depending on the slope height and slope inclination above the portals it may also be necessary to provide stability benches. This requires further study.

3.2 Hydraulic Design

3.2.1 Tunnel

As per Selected Development Scenario (Chapter 4.4), Northern Collector Tunnel was designed to convey flow made of various incoming partly diverted streams considered under Phase I (i.e. from Maragua River, Gikigie River, Irati River), as well as the prospective additional flows which will be brought later on by Northern Collector phase II.

The required design flows for the Northern Collector were unchanged from Howard Humphreys 1998 Report. They are summarised in Table 8-8 below.

Table 8-8: Tunnel Design Flow (1st Phase)

Intake	Flow Diverted, m^3/s	Total Tunnel Flow, m^3/s
Maragua	3.0	3.0
Gikigie	1.0	4.0
Irati	2.0	6.0

In Phase II additional flows will be diverted and the situation will become as summarised in Table 8.9.

Table 8-9: Tunnel Design Flow (2nd Phase)

INTAKE	FLOW DIVERTED m^3/s	TOTAL TUNNEL FLOW m^3/s
NORTH MATHIOYA	2.5	2.5
GITHUGI	1.0	3.5
HEMBE	1.0	4.5
S. MATHIOYA	1.5	6.0
MARAGUA	3.0	9.0
GIKIGIE	1.0	10.0
IRATI	2.0	12.0

Figure 8-8: Portal Cross Section Showing Support Details

The target tunnel hydraulic design parameters have been kept unchanged from Howard Humphreys report and are recalled below:

- The maximum velocity is limited to 3 m/s in order to reduce the erosion on the shotcrete lining of the tunnel and the lining, while being high enough to scour the tunnel clear of minor debris on the invert during periods of high flow.
- The normal flow depth does not exceed 67% of the tunnel height and the maximum flow depth under maximum flow conditions is limited to 75% of this. The maximum flow is defined as that with a statistical return period of 100 years. The intent is to prevent the inadvertent and intermittent filling of the tunnel. Not only does this cause irregularity in the flow, it also risks trapping air within the flow which can be released explosively, with the risk of damage to the tunnel.
- The maximum Froude number of the flow at a depth of 67% of the tunnel height is limited to 0.60. The purpose of this is to minimize the likelihood and amplitude of waves on the surface of the water. This will also help to avoid trapping air in large quantities within the flow.

Based on these design criteria, Northern Collector Phase I is oversized by far from an hydraulic point of view.

3.2.2 Intakes and Related Works

Intakes and related works (such as weirs, compensation flow release device, gabions) were hydraulically designed as per the criteria used in the yield analysis of the scheme.

The Hydraulic Design of intakes took into consideration the following Hydraulic Characteristics.

Table 8-10: Intakes Characteristics

River	Diversion Capacity (m^3/s)	Compensation Flow (m^3/s)
Maragua	3.0	0.645
Gikigie	1.0	0.100
Irati	2.0	0.481

As mentioned previously, Phase I Tunnel Capacity is 6.0 m^3/s but Tunnel should be designed to the ultimate capacity of 12.0m^3/s.

For Phase I, Maragua River Diversion Capacity to be considered is 3.0m^3/s but this capacity will change to 4.5m^3/s in future with the construction of the South Mathioya Transfer and the ultimate capacity with the construction of Northern Collector Phase II will be 9.0 m^3/s.

The design of weirs should therefore take into account these varying capacities and considerations so as to decide whether the diversion will be constructed to the ultimate capacity - in such a case control gates will be used to adjust the diversion capacity - or whether the weir has to be modified in future.

It should also be noted that Maragua River Diversion will need to be regulated / controlled in the future so as to close or reduce the diversion when Thika Dam is spilling and divert the flows to the proposed Maragua 4 Dam, if and when this dam is constructed.

Gikigie intake location was slightly changed from Howard Humphreys 1998 report, to a location downstream of the original site proposed, in order to optimise yield by taking advantage of a larger catchment area (by also catching stream merging with Gikigie stream just upstream bridge over existing road).

Gikigie Intake at proposed revised location will divert flows from the river and will send it to Northern Collector Tunnel through a short access tunnel of approximately 200m long with a slope of 4.5%.

As Irati River level at Northern Collector I crossing point is about 45 meters higher than the invert level of the Northern Collector I, a vertical shaft will have to be built to drive water from Irati River intake into Northern Collector I 45 meters below. Figures giving details for the Weirs and Outfalls are given in **Appendix 8.4**.

3.3 Other Design Aspects

3.3.1 Tunnel

a) Size (minimum section) / Accessibility

The nominal tunnel diameter is 3.2m in Grade IV rock changing to 3.5m in Grade I, II, and III. A smaller finished diameter in Grade IV is a result of the support which needs to be installed. Notwithstanding the design considerations, it is necessary to provide an opening of a minimum 3.2m diameter for the following reasons:

- A working height sufficient to accommodate labour and plant
- Requirement for ventilation, using either a venting in or out system with a minimum pipe diameter of 500mm
- A working width sufficient to accommodate access for vehicles for mucking out.
- A diameter sufficient to allow rock support to be implemented i.e. rock bolts or sprayed shotcrete. The latter requires an operator standing at least two metres from the rock face. Similarly the drilling of holes and the installation of rock bolts would require sufficient space to carry out the operation.

Access to the tunnels will be reached from portals as well as Gikigie and, possibly, Kaanja access adit. The Feasibility Report records that access to reach the Kaanja adit will be difficult. Further survey work may be required to locate the most suitable approach to the adit.

Permanent supports (steel ribs, shotcrete, dowels, rock bolts).

Permanent support will be based on the respective rock classes. The study will re-evaluate the support classes:

- Determine the extent of rock class 3 with support comprising 100mm shotcrete plus wire mesh. The diameter of the wire mesh given in Figure 5.7 should be increased from 3mm to 4mm for additional strength and stiffness.
- Reassess the amount of the route within rock class 4b which is steel ribs plus two layers of shotcrete. The percentage of 20% given in the Feasibility Report is to be reassessed.
- Investigate in detail the portal locations to accurately determine the rock class, which is likely to be rock class 4b.

- Examine the soil cover above the portals which could be loose and unstable
- Determine whether rock dowels or rock bolts are applicable at each portal.

Two additional boreholes at both the intake and outflow locations will provide supplementary data to verify the ground conditions.

Tensioned rock bolts, where necessary, will be required in Class 1 rock conditions. The Feasibility Report does not detail the bolt specification other than give the length and tensioning requirement. Additional details to the drawings are necessary, giving bolt diameter, yield strength, anchor head accessories (face plate, hemispherical washer and nut).

Shotcrete will be applied in layers of 50mm or 100mm and will be a requirement for the tunnel in rock classes II to IV. Shotcrete, when applied correctly, will give higher strengths than concrete.

The portals are likely to be in class III to VI rock and as such will require steel ribs and shotcrete within the portal excavation and shotcrete with pattern rock dowels surrounding the portal. The predicted length of rock class 4b from the Feasibility Report at Maragua Intake is 15m and the additional boreholes will provide data to verify this. There is no record of the predicted length of class 4 at the Makomboki outfall, other than 20% for a distance of 400m from the portal so this must be determined from the additional investigation.

No additional site investigation is proposed for the Kaanja and Gikigie access adits. The Feasibility Report however records that a substantial part of the Gikigie access adit will be in class 4 but no specific details are given for the Kaanja access adit.

b) Lining

Only the invert of the tunnel will be concrete lined though in Classes II to IV the shotcrete will also act as permanent lining. Additional site investigation data will permit the tunnel to be assessed in more detail with respect to the rock support classes and thus determine the extent of the lining.

c) Ventilation

The optimum method of providing ventilation will be examined. A conventional tunnel drilled and blasted using smooth blasting techniques will require good ventilation especially if the mucking out of tunnel spoil is carried out by diesel plant. Ventilation fans are normally positioned at the tunnel portals and usually comprise flexible hose 500mm to 600m diameter. Ventilation can be delivered straight to the working face or extracted. Dust produced from volcanic rocks after detonation is often fine and silica rich, and can be a health hazard.

d) Drainage

The amount of water derived from either the drilling or the surrounding rock is to be estimated and suitable drainage measures proposed. Tunnel driving is likely to be carried out both in the upslope and downslope directions and provision will need to be made for temporary drainage facilities particularly on the downward drive. These may take the form of sumps excavated into the sides of the tunnel from which water will be routinely pumped out or alternatively in the upstream drives drainage, channels can be cut.

Current geological data suggests that copious quantities of water are not likely to be encountered and this requires verification. Sections where there is ground water must be identified as there will be a need to design and implement drainage holes within shotcrete.

e) Power supply

There is need to provide for power extending from site entrance of each branch tunnel (main tunnel, adits) to the nearest transformer to power air compressors, hoists, water pumps and construction lighting in particular. In case no electricity line is available, any other arrangement such as diesel generators will be provided by the Contractor.

f) Tunnel Illumination

A 3-phase 4-wire electric line (or cable) will be provided by the Contractor for the purpose of temporary and later on permanent tunnel illumination.

g) Water Supply

A water pipeline connecting to the working faces of the tunnel will be designed and built by the Contractor, so as to provide water for drilling, dust prevention, sprayed concrete, etc.

3.3.2 Intakes and Other Structures (Weirs)

Details of main components of intake structures are given in egis/MIBP JV Preliminary Design Report Version 02 and Appendix 8.4.

Further details such as compensation flow devices will be confirmed once detailed survey is carried out.

The need to equip weirs with gates should be studied and finalised under the Final Designs.

3.3.3 Cofferdams for Construction of Intakes and Adits

Temporary cofferdams will be built before construction of intakes and adits, so as to divert flow during construction. Design of such cofferdams will consider a once-in-a-decade flood, ensuring that water will not enter the tunnel and threaten the safety of workers during rainy season.

3.3.4 Shaft (including ventilation details)

Rock classes within the Irati Shaft are given in the Feasibility Report and show that the upper 7m of the shaft will be in class 4 rock, thereafter the quality of the rock improves.

Drill and blast techniques will be necessary to excavate to the design profile. The method of excavation downwards requires examination. There are two options to consider:

- excavate downwards and remove the rock spoil to the surface. This can be time consuming, in removing spoil material and providing ventilation to ensure a clean working environment.
- Use raise boring equipment with mucking of the spoil through an enlarged bore.
- In the case of raise boring it would be necessary to prioritise the work schedule so that the shaft is excavated only after the tunnel drive has been completed beneath it. Access would entail an offset excavation from the tunnel to reach the base of the shaft but this presents a more expeditious way of removing spoil as well as venting the excavation.

Details of the Irati Shaft are given in **Appendix 8.5**.

3.3.5 Adits (including Construction Adits)

The selection of the number of adits to be used in order to gain access to the main tunnel will be carried out. Adit dimensions will be the same as the main tunnel so as to permit the use of the same steel support. Excavation of the Gikigie access tunnel is estimated to be 57% within Class 4b rock. This percentage will now be reassessed. Details of the proposed Adits are given in **Appendix 8.5**.

3.3.6 Mucking Out Storage Areas (Spoil Disposal) and Access Roads

The Mucking Out Storage Areas (Spoil Disposal) and Access Roads Details for Construction are given in **Appendix 8.6**.

3.4 Construction Programme

3.4.1 Additional Geotechnical Investigations

The programme for the additional investigations will take into account not only the amount of work to be undertaken together with anticipated daily drilling rates, but other considerations, namely:

- Accessibility to the location
- Consent of landowners to gain access to the site
- Mobilisation time and moving between holes
- In-situ tests within the boreholes, results and logging of the rock cores
- Laboratory testing and results
- Factual Report from the contractor.

There is provision for 6 boreholes with in-situ testing and accompanying laboratory tests. If necessary, and with time permitting, an additional borehole will be drilled approximately midway between BH 9 and BH10.

3.4.2 Construction Technologies

The methodology for driving the tunnel will be examined. The Feasibility Report records that the Basalt is very abrasive and any attempts to excavate the higher quality rocks using mechanical means must be treated with caution. From approximately Ch 7+730 to Ch 11+775 the tunnel drive will be predominantly within Basalt so it is most unlikely that a TBM or road header could be employed in this part of the tunnel. Further laboratory testing is necessary to determine if mechanical means can be used, at least in part.

Excavation method using standard drill and blast techniques will be assessed in terms of:

- Blasting technique, for example smooth blasting or pre-splitting.
- Expected daily production rates, availability of materials and expertise to carry out the work.

Disadvantages of drill and blast would include the control of blasting techniques to minimise both overbreak and blast damage to the surrounding rock. The latter would lead to an increase in the amount of rock support. Test results from the additional laboratory testing schedule will provide the necessary information to determine whether the use of a road header, in part, would be advantageous. Tests carried out to-date indicate that the

use of a road header would, as an absolute minimum, necessitate the use of high pressure water jet assisted cutting.

The excavation of the shaft would suit smooth blasting, and the most expeditious means of shaft excavation would be by raise boring. There is only a limited requirement for shaft excavation (46m) so a contractor must make an independent judgement with respect to the benefits of bringing to site relatively expensive drilling equipment to carry out this work.

3.4.3 Construction Schedule

Construction Schedule would depend on the number of working faces, which is the Contractor's decision as it depends on the number and type of equipment.

The decision about the number of working faces may also depend on the quantity of ground water encountered when digging the tunnel, as this may influence the working direction (in case of heavy flows, working in ascending way should be preferred).

Two main schedules were tentatively worked out:

- a construction schedule with 6 working faces
- a construction schedule with 3 working faces

Figure 8-9: Construction Schedule with 6 Working Faces

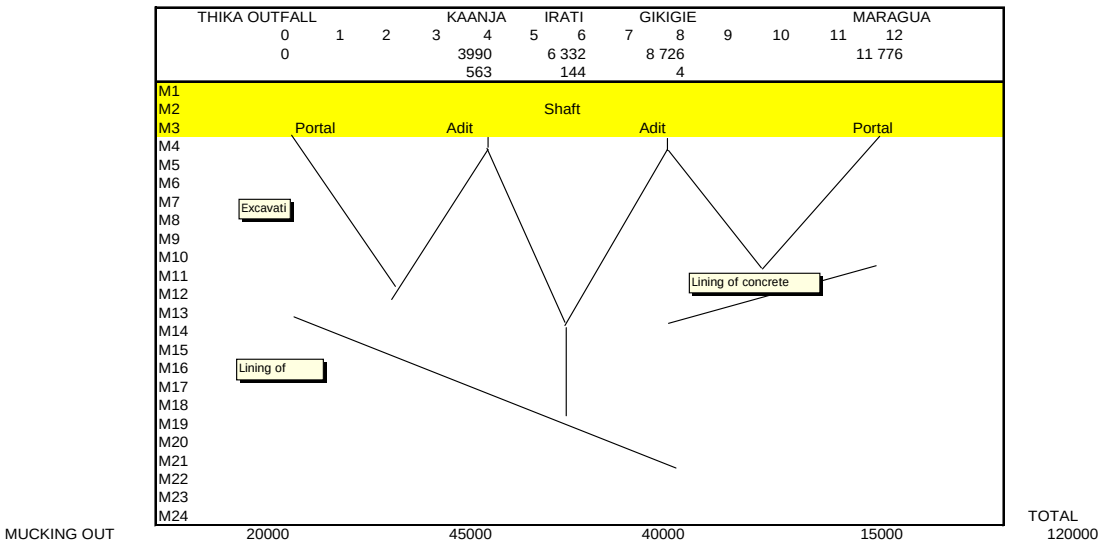
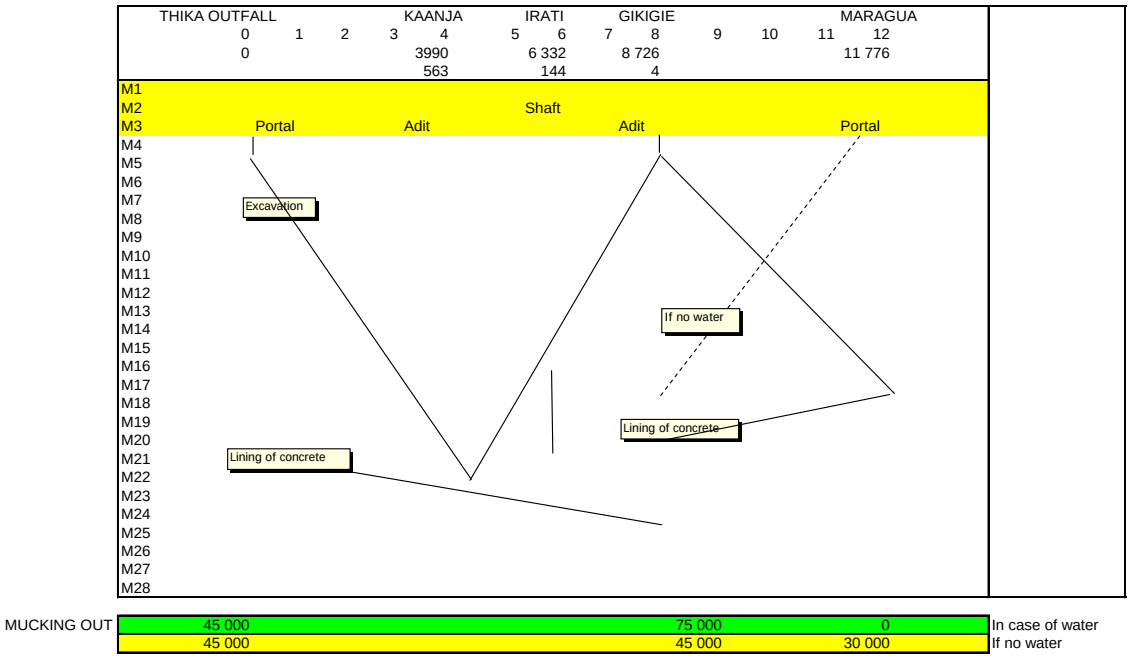


Figure 8-10: Construction Schedule with 3 Working Faces



3.5 Construction Cost

Unit rates for tunnels have been estimated for 3.2m diameter lined tunnels using the drill and blast construction method. Intakes and shafts costs are based on BOQ and local unit costs. An allowance of 15% contractor's preliminaries and general expenses and 9% engineering works and supervision are added to the unit rate in the estimates. Additional details are provided in Section 7: "Project Costs and Implementation Schedule".

Table 8-11: Unit Rates for Tunnels and Related Works

Item	Unit	Unit Cost (US$)
Driving and lining (drill & blast)	m	5,500
Intakes	each	1,111,111
Irati shaft (46m)	set	1,022,222
Thika outfall	set	556,000
Contractors preliminaries and general		15%
Engineering services (drilling works, distribution and storage)		9%

Based on the unit prices and estimated quantities the total cost for Northern Collector Phase I is estimated as follows.

Table 8-12: Tunnel Summary Costs (USD '000)

Item	Base Cost	Physical Contingencies	Price Contingencies	Total
Tunnelling	64 900	6 490	2 449	73 839
Weirs and Shafts	4 911	491	165	5 568
Total	**69 811**	**6 981**	**2 614**	**79 406**

4 Water Treatment Facilities

Nairobi City is presently supplied with water from four main sources as follows:

a) **Kikuyu Springs** – comprising of 3 Nr Springs located 18km west of the City, yielding a total of 4,800m^3/d (0.056m^3/s). The Springs were the first source of potable water for Nairobi, developed between 1900 and 1906.

b) **Ruiru Dam** on Ruiru River, located 25km North of the City. The Dam was constructed in 1950 and has a safe yield of 21,700m^3/d (0.25m^3/s)

c) **Sasumua Dam** on Sasumua River, located 60km North of the City. The Dam was constructed in between 1956 and 1968. It has a safe yield of 68,400m^3/d (0.79m^3/s)

d) **Thika Dam – Mwagu Intake System**:- This System comprises of the following sources:

- Mwagu Intake Weir on the Chania River, located 40km North of Nairobi
- Thika Dam, located 50km North of Nairobi. The Dam impounds water from Thika River, supplemented by flows diverted from the Kiama and Kimakia Rivers. The Dam was constructed between 1989 and 1994.

The design capacity of the Thika Dam-Mwagu System is 460,000m^3/d (5.3m^3/s). Due to various operational constraints, average production from the System is 415,000m^3/d (4.8m^3/s).

Water from the above sources is treated at 3 Nr Water Treatment Plants. These are:

i) Ngethu Treatment Works

At present, Ngethu Treatment Works treats the bulk of the water supply to Nairobi. It receives and treats raw water from the Thika Dam-Mwagu Intake System. The Treatment Works was developed in three phases between 1974 and 1996.

The Treatment Works employs a Full Conventional Treatment Process comprising Flocculation, Clarification, Filtration and Disinfection. Phase 1 of the Works, commissioned in 1974 with a design capacity of 64,000m^3/d, comprises of proprietary Units by Degremont (France) with 2 Nr Pulsator Clarifiers and 4 Nr "Aquazur" Type Rapid Gravity Sand Filters. Phases 2 and 3 of the Works, commissioned between 1984 and 1996 with a combined design capacity of 396,000m^3/d, comprise of a total of 8 Nr Circular Clarifiers and 28 Nr Rapid Gravity Sand Filters. Ngethu Treatment Works has a total installed capacity of **460,000m^3/d (5.3m^3/s)**.

ii) Sasumua Treatment Works

Sasumua Treatment Works receives and treats water from Sasumua Dam and is located about 1km downstream of the Dam. The Treatment Works was developed in three phases between 1956 and 1968.

The Treatment Works is a Full Conventional Treatment Process comprising Flocculation, Sedimentation, Filtration and Disinfection. Sasumua Treatment Works has a total design capacity of **63,700m^3/d (0.74m^3/s)**.

iii) Kabete Treatment Works

Kabete Treatment Works treats water from two sources: Kikuyu Springs and Ruiru Dam. It was the first Treatment Works to be developed for Nairobi, with the first Phase constructed in 1936-1938 to treat water from Kikuyu Springs. Extensions were subsequently constructed between 1946 and 1964 as the Ruiru Dam source was developed.

The Treatment Works is a Full Conventional Treatment Process comprising Flocculation, Sedimentation, Filtration and Disinfection. Kabete Treatment Works has a total design capacity of **20,000m^3/d (0.23m^3/s)**.

4.1 Proposed New Water Sources and Treatment Facilities

Under this Project, the water sources for Nairobi will be augmented through the development of the Northern Collector Tunnel Phase I which will transfer run-of-river flows from the following 3 Nr Rivers to the existing Thika Dam:

- Maragua River
- Gikigie River
- Irati River

As previously mentioned, the existing Thika Dam is the present source of water for the existing Ngethu Treatment Works (design capacity 460,000m^3/d). The Northern Collector Tunnel Phase I will transfer an additional 121,000m^3/d (1.4 m^3/s) of water into the Thika Reservoir. This new inflow will be treated at the proposed Ngorongo Treatment Works.

Details of the proposed Ngorongo Treatment Works are given in the following Sections.

4.2 Proposed Ngorongo Treatment Works

4.2.1 Location

The proposed location for the new Ngorongo Water Treatment Works is approximately 11km North West of Kiambu Town, 31km North of Nairobi City, at Survey of Kenya Co-ordinates N9876000, E251800.

The site is 2km off the Upper Limuru Road (D409), a tarmac road linking Kiambu Town with Limuru Town, on land that is presently part of a Coffee Estate owned by Gatatha Farmers Cooperative Society. Access to the site is via a gravel road, which will be upgraded to bitumen standard as part of the proposed Works. The Location of the Treatment Works is shown in **Figure 8-11** on page 8-30.

Figure 8-11 - Location Plan of Ngorongo Treatment Works

4.2.2 Raw Water Quality

An analysis of the quality of the raw waters from the various sources to be treated at the proposed Ngorongo Treatment Works has been carried out. The raw water sources are: the existing Thika Reservoir and the three source rivers for the Northern Collector Tunnel Phase I i.e. Maragua River, Gikigie River and Irati River.

For Thika Reservoir, results of Raw Water Quality Tests for the three years 2009 – 2011 have been obtained from the Nairobi City Water & Sewerage Co. Ltd. (NCWSC) Kabete Central Laboratory. These results have been used to analyze the raw water quality of this source. In addition, under this Project, Independent Testing of 2 Nr water samples from Thika Reservoir , one taken at the Dam surface and the other at the Dam Scour Level, was carried out in January 2012 at the Jomo Kenyatta University of Agriculture & Technology Laboratory.

There is no regular Sampling and Testing Data available for the 3 Northern Collector Tunnel Phase I source rivers. Analysis of raw water quality from these sources has been carried out based on a one-off Test done in January 2012 under this Project.

In conclusion, the raw water to be treated at Ngorongo Treatment Works from Thika Reservoir and the Northern Collector Tunnel Phase I source Rivers (Maragua, Gikigie and Irati Rivers) is **of good Physical, Chemical and Bacteriological Quality and suitable as a source of drinking water after appropriate treatment.**

It is recommended that a Regular Sampling and Testing Programme for Thika Reservoir and the 3 Nr Northern Collector Tunnel Phase I source rivers be undertaken during the Final Design Stage. This will generate more data on raw water quality of the sources, especially the 3 Nr Rivers for which such historical data is not available.

A brief analysis of the Raw Water Quality for each source is given in **Appendix 8.7**.

4.2.3 Recommended Treatment Process

Based on the Raw Water Quality in the existing Thika Reservoir and the likely quality with inflows from the Northern Collector (Phase I) Tunnel, it is recommended that a Full Conventional Treatment Process be designed at Ngorongo Water Treatment Works incorporating the following stages:

Aeration

(to increase dissolved Oxygen Levels, remove occasional excess Iron and Manganese and remove undesirable gasses such as Carbon Dioxide)

⬇

Raw Water Chemical Dosing

(Coagulation using Alum, Soda Ash & Polyelectrolyte;

Pre-chlorination to prevent algal growth in the concrete structures)

⬇

Flocculation & Clarification

⬇

Rapid Gravity Filtration

⬇

Disinfection

(by Chlorination)

⬇

pH Correction of Treated Water

(by dosing with Soda Ash)

Reasons for adoption of the above Treatment Process and the structures selected to achieve it are given in the following sections.

i) Aeration

Raw water will be conveyed from Thika Reservoir to Ngorongo Water Treatment Works over a distance of approximately **40km** via a DN 1300mm diameter pipeline. Due to the long distance of conveyance of raw water in a closed conduit, it is expected that the raw water reaching the Treatment Works will be low in Dissolved Oxygen levels. In addition, it may contain increased concentrations of other undesirable gases such as Carbon Dioxide (CO_2).

The Aeration process will increase the concentration of Dissolved Oxygen and remove any excess gasses present in the raw water such as Carbon Dioxide.

As previously noted, high levels of Iron (Fe) and Manganese (Mn) have occasionally been recorded in the analysis of the Chemical Quality of water in Thika Reservoir. The Aeration Process will remove the occasional excess concentration of Iron and Manganese through oxidation and precipitation of these ions.

ii) Raw Water Chemical Dosing

Raw water will be dosed with chemicals to aid in coagulation and removal of suspended solids. In addition, Pre-chlorination of the Raw Water will be carried out to prevent algal growth in the Treatment Works structures. Pre-Chlorination will also help to oxidise and precipitate any soluble Iron and Manganese in the incoming raw water.

For coagulation and floc formation, the following chemicals will be used:

a) Aluminium Sulphate (Alum)

Aluminium Sulphate [Al2(SO4)3.14H2O], commonly known as **Alum**, has been selected as the primary coagulant mainly due to its ready availability in Kenya, relative low cost compared to other available coagulants and ease of handling and storage. In addition, Alum is also the primary coagulant in use at other Treatment Works for water supply to Nairobi operated by NCWSC e.g. Ngethu Treatment Works, which means that the operator is familiar and experienced in its use.

Other coagulants available include Ferric Salts (Ferrous Sulphate and Ferric Chloride), Aluminium Chloride and Sodium Aluminate. These were ruled out as they are not readily available in Kenya and their costs are relatively high in comparison to Alum.

b) Soda Ash (Sodium Carbonate, Na_2CO_3)

When the alkalinity of the raw water is too low to allow optimum coagulation action of alum, **Soda Ash** (Sodium Carbonate, Na_2CO_3) will be used to raise the pH to the required optimal levels. Soda Ash is manufactured in Kenya and is readily available. The required dosage of Soda Ash will be determined by Jar Tests to be carried out in the Treatment Works Laboratory.

c) Polyelectrolyte

Polyelectrolyte will be used as and when required as a **coagulant aid**, especially during rainy seasons when the raw water turbidity is high, to reduce the amount of Alum required.

At present, NCWSC also uses Polyelectrolyte at the existing Ngethu Treatment Works to reduce the Alum dosage required especially during periods of high raw water turbidity thereby reducing the overall cost of chemicals. Although Polyelectrolyte has to be imported, the quantities required are relatively small. The Polyelectrolyte presently in use at Ngethu Treatment Works is Primco 732, usually sourced from South Africa. It is proposed that the same Polyelectrolyte be adopted for use at Ngorongo Water Treatment Works as the Operator is familiar and experienced in its procurement and use.

iii) <u>Flocculation and Clarification</u>

The following available Flocculation and Clarification structures have been considered for adoption at Ngorongo Water Treatment Works:

- **a)** Hydraulic Flocculators (Horizontal Flow and Vertical Flow Baffled Channel Basins)
- **b)** Horizontal Flow Sedimentation Tanks
- **c)** Vertical Flow Sludge Blanket Sedimentation Tanks.
- **d)** Proprietary Designs e.g. *Pulsator Clarifiers* from Degremont (France), PCI Upflow Sludge Blanket Clarifiers from Patterson Candy International (PCI), etc.
- **e)** Circular Centifloc Clarifiers with Mechanical Sludge Scrappers

The suitability of each of the above for adoption is briefly analyzed in the following sections.

a) Hydraulic Flocculators

Hydraulic Flocculation can be achieved by means of **Horizontal Flow ("around-the-end") Baffled Channel Basins** or **Vertical Flow ("over and under")** Baffled Channel Basins.

These have the advantage that they avoid the use of Electro-Mechanical Equipment and the related high operation and maintenance cost. They also require less skilled operation compared to Mechanical Flocculators.

Hydraulic Flocculators have the following main disadvantages:

- They cannot be adjusted to suit variations in raw water quality and have to be designed for a specific flow and small range of raw water conditions of turbidity.
- To facilitate easy cleaning and de-sludging between the Baffles which are normally spaced at 0.3 - 0.6m, the design flow depth in Hydraulic Flocculators is limited to 1.0m. Hydraulic Flocculators therefore require more land space than Mechanical Flocculators. For Ngorongo Treatment Works, the land space that would be required by Hydraulic Flocculators at the design capacity of 121,000m^3/d is **2,014m^2**, compared to **531m^2** required for flocculation in Circular Centifloc Clarifiers which incorporate Mechanical Flocculators.

For the above reasons, **Hydraulic Flocculators are not suitable for Ngorongo Water Treatment Works**. They are more suited for smaller Works and in places where personnel with the level of skills required to operate Mechanical Flocculators may not be available.

b) Horizontal Flow Rectangular Sedimentation Tanks

These Tanks have the advantage that they do not incorporate Mechanical Equipment for sludge removal. The Tank is de-sludged by manual operation of valves, relying on hydrostatic pressure of water in the tank to make the sludge flow. Their operation and maintenance costs and operational skill requirements are therefore much lower than for Clarifiers with Mechanical Sludge Removal Equipment. Another advantage of these Tanks is that interruption in flow of raw water does not affect the sedimentation process, unlike the case with Vertical Flow Sludge Blanket Sedimentation Tanks.

The main disadvantage of Horizontal Flow Rectangular Sedimentation Tanks is large land space requirements. For Ngorongo Treatment Works, the land space that would be required by 4 Nr Horizontal Flow Rectangular Sedimentation Tanks at the design capacity of 121,000m^3/d is **6,197m^2**, which is almost **2 times** the total land area **of 3,222m^2** required for clarification in the more compact Centrifloc Clarifiers. In addition, Horizontal Flow Sedimentation Tanks require separate Flocculation Units. A Flocculation / Sedimentation System incorporating Horizontal Flow Sedimentation Tanks preceded by Flocculation Units would require a lot of land space in a Treatment Works the size of Ngorongo.

For the above reason, **Horizontal Flow Sedimentation Tanks are not suitable for Ngorongo Water Treatment Works**.

c) Vertical Flow Sludge Blanket Sedimentation Tanks

Like Horizontal Flow Sedimentation Tanks, Vertical Flow Sludge Blanket Tanks do not incorporate Mechanical Equipment for sludge removal. The Tank is de-sludged by manual operation of valves, relying on hydrostatic pressure of water in the tank to make the sludge flow out. Their operation and maintenance costs are therefore much lower than for Clarifiers that incorporate Mechanical Sludge Removal Equipment such as Centrifloc Clarifiers.

In comparison with Horizontal Flow Sedimentation Tanks, Vertical Flow Sludge Blanket Tanks require less land space and do not require separate Flocculation Units as both flocculation and sedimentation take place within the same Tank (in a “Sludge Blanket”).

Vertical Flow Sludge Blanket Sedimentation Tanks have the following disadvantages that render them unsuitable except under very exceptional situations:

- Flow into the Tank cannot be stopped as this would lead to disintegration of the Sludge Blanket. These Tanks are therefore inappropriate except under conditions where continuous flow is assured.
- Their operational requirements are relatively high as they require constant monitoring of the Sludge Blanket and de-sludging by manual operation of valves.
- Land Space requirements: - For Ngorongo Treatment Works, the land space that would be required by Vertical Flow Sludge Blanket Sedimentation Tanks at the design capacity of 121,000m^3/d is **4,028m^2**, which is **25%** more than the total land area of **3,222m^2** required for Clarification in Centrifloc Clarifiers.

For the above reasons, **Vertical Flow Sludge Blanket Sedimentation Tanks are not suitable for Ngorongo Water Treatment Works**.

d) Proprietary Designs for Flocculation & Clarification Units

Proprietary designs for Flocculation & Clarification Units are available from various International Suppliers of Water Treatment products. Such proprietary products include:

i. **Pulsator Clarifiers** from Degremont (France) – these are the type of Clarifiers installed at the existing Ngethu Treatment Works, Phase I Works, capacity 61,000m^3/d, built between 1974 – 1978 (subsequent Phases II and III, built between 1984 – 1996, incorporated Centrifloc type of Clarifiers).

   The Pulsator Clarifiers at Ngethu are operating satisfactorily to date. Another large Water Treatment Works in the region, the Lower Ruvu Treatment Works in Dar-es-Salaam, Tanzania, incorporates Pulsator Clarifiers in both the existing Works and the presently on-going expansion Works (total design capacity 270,000m^3/d).

ii. **PCI Flat Bottom Upflow Sludge Blanket Clarifiers, With or Without Mechanical Sludge Scrappers**. These are patented by Patterson Candy International Pty Ltd. (PCI). These Clarifiers have been recently designed and built by PCI Ltd. in Nigeria (150,000m^3/d) and Turkmenistan (250,000m^3/d).

For large Works such as Ngorongo Treatment Works, Proprietary Designs offer cost competitive units with proven performance.

As the Ngorongo Water Treatment Works Project will be implemented through a Design and Build Contract, it is likely that some Bidders will offer their own Proprietary Designs for Clarification Units. Proprietary Designs, if offered by Bidders, will be evaluated in accordance with the detailed Specifications and Employer's Requirements for possible adoption at Ngorongo Treatment Works.

a) Centrifloc Clarifiers

Centrifloc Clarifiers are Circular Tanks in which both Flocculation and Clarification take place within the same Tank. A Centrifloc Clarifier consists of two zones – an inner Flocculation Zone and an Outer Clarification Zone. Raw water dosed with coagulant enters the Centrifloc Clarifier through the inner Flocculation Zone, which is equipped with Mechanical Flocculators that agitate the dosed water to stimulate floc formation. Flocculated Water then passes into the outer Clarification Zone where it is retained for a period of 2 - 3 hours to allow the flocs formed to settle. Clarified water is then drawn off over peripheral weirs into a Clarified Water Channel and conveyed to Filters.

Electric-Motor driven revolving Sludge Scrappers installed in the Centrifloc Clarifier continuously scrape settled sludge in both the Flocculation and Clarification Zones into Sludge Collection Hoppers in the floor of the Tank from which it is periodically drawn off by pneumatically operated valves and conveyed to Sludge Drying Beds.

The main advantages of Centrifloc Clarifiers are:

- Centrifloc Clarifiers are compact structures which offer significant savings in land requirements compared to the alternative Flocculation/Clarification structures considered.
- Centrifloc Clarifiers are presently in use at the existing Ngethu Treatment Works. The operator, NCWSC, is therefore familiar and experienced in the operation and maintenance of Centrifloc Clarifiers.

Centrifloc Clarifiers are appropriate for Ngorongo Water Treatment Works and have been adopted for Preliminary Design of the Works.

iv) Filtration

3 Nr Filtration Systems are available for consideration, namely **Slow Sand Filtration, Filtration using Pressure Filters and Rapid Gravity Sand Filtration**. Each Filtration System is briefly analyzed in the following Sections.

a) Slow Sand Filtration

Slow Sand Filtration is a form of biological filtration which relies on the formation of a biological (bacterial slime) layer known as ***schmutzdecke*** on the filter bed. The schmutzdecke enhances the screening efficiency of the filter bed by depositing on the sand grains and constricting the pore openings in the filter bed thus improving its straining ability.

An advantage of Slow Sand Filters over Rapid Gravity Sand Filters is that for raw waters with turbidity less than 50 NTU they do not require pre-treatment i.e. Chemical Dosing, Coagulation, Flocculation and Clarification.

The main disadvantages of Slow Sand Filtration include:

i. **Large Land Space Requirements**: Slow Sand Filters have much lower permissible Surface Loading Rates, 0.1 – 0.2$m^3/m^2/hr$, compared to Rapid Sand Filters (up to 8 $m^3/m^2/hr$) and Pressure Filters up to 30 $m^3/m^2/hr$). Though Slow Sand Filtration does not require pretreatment (Flocculation & Clarification) it would still require much more land space than the other Filtration Systems. For example, at Ngorongo Treatment Works (capacity 121,000m^3/d), Slow Sand Filters would require a total land area of 30,208m^2, compared to a total combined area of 4,800m^2 required for Rapid Sand Filters and the preceding Clarifiers.
ii. Slow Sand Filters have **higher manual operation requirements** than Rapid Sand Filters as they require constant cleaning, i.e. removing, washing and returning of the top sand layer in order to maintain the ***schmutzdecke*** micro-biological layer.

For the above reasons, **Slow Sand Filtration is not suitable for Ngorongo Water Treatment Works**.

b) Filtration Using Pressure Filters

Pressure Filters operate at higher filtration rates of up to $30m^3/m^2/hr$ compared to Slow Sand Filters ($0.1 – 0.2m^3/m^2/hr$) and Rapid Gravity Sand Filters ($8m^3/m^2/hr$). Pressure Filters therefore require much less land space than the other types of Filters.

However, Pressure Filters have the following main disadvantages:

- They are highly mechanized, which translates into much higher energy and maintenance costs compared to Rapid Gravity Sand Filters and Slow Sand Filters.
- They require higher levels of skilled operations staff.
- They are pre-dominantly made of steel/metal parts, which have very high maintenance requirements to prevent both internal and external corrosion

For the above reasons, **Filtration using Pressure Filters is not suitable for Ngorongo Water Treatment Works.** Pressure Filters are more suited to small capacity Works e.g. water supplies for Institutions such as schools and hospitals, rather than large Municipal Water Supplies.

c) Rapid Gravity Sand Filtration

This Filtration System is accomplished using **Rapid Gravity Sand Filters**. Compared to other Slow Sand Filters and Pressure Filters, Rapid Gravity Filters offer advantages of ease of operation, efficiency, and low maintenance requirements.

In addition, Rapid Gravity Filters are presently in use at the existing Ngethu Treatment Works meaning that the operator, NCWSC, is familiar and experienced in their operation and maintenance.

For these reasons, Rapid Gravity Filtration is the most appropriate Filtration System for Ngorongo Water Treatment Works and has been adopted for Preliminary Design of the Works.

v) <u>Disinfection</u>

The following prevalent alternative methods have been considered for disinfection of treated water:

- Ozonation
- Ultra-Violet Radiation
- On-Site Electrolytic Generation of Hypochlorite Solution
- Chlorination using Chlorine Gas or other Chlorine Compounds

Most of these disinfection methods are inappropriate for the Works under consideration mainly due to high costs and operational difficulties as analyzed in the following sections.

a) Ozonation

Ozone (O3) is the most potent disinfectant and oxidizing agent available for water treatment. It can be generated by passing filtered and dried air between plates with a high electric voltage.

Ozonation has the advantages that it works rapidly, produces no secondary tastes and odours and is particularly effective in removing viruses.

Ozonation has the following main disadvantages:

- Ozone (O_3) does not remain in water for more than about 30 minutes as it reverts to oxygen (O_2). Therefore it has no residual effect in water to guard against contamination in the Distribution Network.
- The capital and maintenance cost of the equipment required is relatively high compared to that of other disinfection methods e.g. chlorination
- It requires a high level of operation and maintenance skill, especially the air-filtering and drying apparatus.

For the above reasons, **Ozonation has not been adopted for the Works under consideration.**

b) Ultra-Violet (UV) Radiation

This method involves applying a given intensity of ultra-violet radiation for a specific period of time through a thin film of water. The water to be sterilized must be clear of soluble iron and other substances that absorb UV light and the equipment must be checked regularly to ensure the lamps are kept clean at all times to prevent the loss of intensity over time.

UV disinfection has the advantage that no by-products are formed in the water. However this results in the disadvantage that the effectiveness of the disinfection cannot be determined by measuring a residual level as is the case with chlorination. In addition, UV disinfection has no residual effect to guard against contamination in the Distribution Network. For these reasons, **UV Radiation has not been adopted for the Works under consideration**.

c) On-Site Electrolytic Generation of Hypochlorite Solution

In this method brine is passed through an electrolysis apparatus where it is subjected to an electric current. The brine is then broken down into sodium hypochlorite, with hydrogen gas as a by-product. The sodium hypochlorite is then conveyed to the chlorination point and dosed into the treated water while the hydrogen gas is safely vented into the atmosphere.

On-site Generation of Sodium Hypochlorite is ruled out for the Works under consideration due to its high capital costs, maintenance costs and high level of operational skill required.

d) Chlorination

Chlorination using **Chlorine in Gaseous form** has been selected as the **primary disinfection method** for treated water at Ngorongo Treatment Works.

Alternative Chlorine compounds available for disinfection of treated water include **Calcium Hypochlorite Granules (HTH) and Tropical Chloride of Lime (TCL)**. These compounds have to be mixed into solution form before they can be dosed into water.

Chlorine gas is recommended as the primary disinfectant instead of the alternative chlorine compounds because it is easy to handle, produces no residual sludges, and the dosing rate can be more accurately controlled. In addition, for a Treatment Works the size of Ngorongo, it would demand much less operation and storage requirements in comparison to preparing chlorine solutions for the large volumes of water to be treated. Chlorine Gas is also the primary disinfectant in use at other Treatment Works for water supply to Nairobi operated by NCWSC e.g. Ngethu Treatment Works, which means that the operator is familiar and experienced in its use.

To cater for periods when Chlorine Gas may be unavailable, a stand-by System of disinfection using Chlorine in Hypochlorite Solution form will be provided.

4.2.4 Treatment Works Components

The proposed Ngorongo Water Treatment Works, capacity 121,000m^3/d, will comprise of the following Key Units:

i. **Inlet Works** incorporating Raw Water Flow Measurement, 1 Nr Multiple Platform Aerator, 1 Nr Stilling Basin and Overflow Facilities
ii. **1 Nr Flash Mixer** for rapid mixing of raw water with chemicals–circular concrete structure, 11.5m diameter, equipped with an electric-motor driven Propeller Mixer
iii. **4 Nr Circular Centrifloc Clarifiers**, each of diameter 35m, for Flocculation and Clarification of raw water, equipped with electric-motor driven Flocculators and Sludge Scrappers
iv. **10 Nr Rapid Gravity Sand Filters**, each with a Filter Bed area of 11.8m x 7.2m (85m^2), including Filter Gallery and Filter Control Room
v. **Treated Water Storage Tank** – Reinforced Concrete Tank, internal dimensions 120m x 120m x 5m high, storage capacity **70,000m^3**, to provide storage capacity for approximately 12-hours production
vi. **Pump House & Air Blower Room** with Pumps and Air Blowers for backwashing of filters
vii. **4 Nr Sludge Drying Beds**, total surface area 2,400m^2
viii. **2 Nr Backwash Water Lagoons**, with total storage volume of 5,800m^3, and Backwash Water Recirculation Pumps
ix. **Chemical Storage Building** for Alum, Soda Ash, Polyelectrolyte and Hypochlorite – floor area 900m^2 – to provide 3 Months storage at the design throughput of 121,000m^3/d.
x. **Chemical Mixing and Dosing Building** - floor area 530m^2, with Mixing Tanks, Dosing Pumps and Associated Pipework for Alum, Soda Ash, Polyelectrolyte and Hypochlorite
xi. **Gas Chlorination Building**–floor area 256m^2, comprising of a Gas Chlorinators Room and a Chlorine Drum Store for 3 months storage at the design output of 121,000m^3/d
xii. **Administration Building**, total office floor area 700m^2, with Laboratory
xiii. **Workshop & Store** – floor area 225m^2
xiv. **Generator House &Switch Room** - floor area 52m^2 incorporating Stand-by Generator Room, Fuel Store and Electrical Switchboard/Distribution Panel Room
xv. **Staff Room** for Treatment Works Operators & other Subordinate Staff – incorporating Washrooms (W.Cs and Showers), Locker Room, Tea Room & Kitchen and Staff Room – total floor area 160m^2
xvi. **Gate House** - floor Area 19m^2

The Preliminary Design Engineering Drawings for the Treatment Works and associated components are given in Volume III of this Report.

The Bills of Quantities and Engineer's Cost Estimates for the Treatment Works and associated components are given in Volume II of this Report.

4.2.5 Other Facilities for Treatment Works Staff and the Neighbouring Community – Staff Housing & School

Amenities to be provided adjacent to the Treatment Works are Housing for Treatment Works Staff and a Primary School to serve the Treatment Works Staff as well as the neighbouring community, as described briefly below:

i. **Staff Housing for Treatment Works Staff**– As the Site is distant from Nairobi City, most of the key Treatment Works Staff will be housed on site. Following discussions with NCWSC on the staff required to be resident on site, it is proposed to provide the following Staff Housing:

- Senior Staff Houses - 4 Nr
- Medium Category Staff Houses - 12 Nr
- Junior Category Staff Houses - 36 Nr

Other amenities to be provided within the Staff Housing Area include:

- Guest House with 4 Nr self-contained rooms
- Club House/Recreation Centre
- Out-Patient Health Centre which will serve the Treatment Works Staff as well as the neighbouring community.

ii. **Primary School**– A single stream Primary School with a capacity of 240 pupils to serve the Treatment Works Staff and the neighbouring community.

4.2.6 Site Layout Plan of Treatment Works, Staff Housing & School

The Site Layout Plan of Ngorongo Treatment Works, Staff Housing and School is given in **Figure 8-12** on **Page 8-41**.

4.3 Design Criteria for Treatment Works Units

The Design Criteria and Key Data for the Treatment Works Units are given in **Appendix 8.8.**

4.3.1 Treatment Works Layout &Section

The Layout Plan and Section through the Treatment Works are given in **Figure 8-13** on page 8-42 and **Figure 8-14** on page 8-43 respectively. A Schematic Process Flow Diagram of the Treatment Works is given in **Figure 8-15** on page 8-44.

The Layout of the Treatment Works is planned in such a way that the Operators can move easily amongst the various components on paved footpaths.

The Administration Building is located and positioned in such a way to allow the Works Manager and Treatment Works Coordinator to have clear, unobstructed views of the other Structures in the Treatment Works.

The Chemical Storage Building, Chemical Mixing & Dosing Building, Gas Chlorination House and Workshop/Store are located to allow easy access for deliveries of chemicals and other supplies.

Provision has been made in planning the Treatment Works Layout for future expansion of the Works from capacity 121,000m^3/d to be constructed under the present Phase I (2012 – 2017) to capacity 285,000m^3/d (Phase II of the Works planned to commence after year 2018). The total land area to be occupied by the Treatment Works, including space for future expansion, is approximately 28.4 ha.

Figure 8.12- Layout Plan of Ngorongo Treatment Works, Staff Housing and School

Figure 8.13 -Layout Plan of Ngorongo Treatment Works

Figure 8.14-Section through Ngorongo Treatment Works

Figure 8.15 -Schematic Process Flow Diagram through Ngorongo Treatment Works

5 Raw Water and Treated Water Transmission Mains

This Chapter outlines the Preliminary Design Details of the Raw Water and Treated Water Transmission Mains for Phase I of the Project.

Raw Water will be transmitted by gravity via a Ferrous Main of approximate length 44 km from the existing Offtake at Thika Dam to the proposed Ngorongo Water Treatment Works Site near Kiambu Town. Full Conventional Treatment will then be provided at Ngorongo before the Treated Water is transmitted by gravity via a Ferrous Main of approximate length 17.6 km to existing Storage Reservoirs located at Kabete Water Treatment Works Site in Nairobi.

A Layout Plan showing the alignment of the proposed Transmission Mains with the location of the Proposed Ngorongo Water Treatment Works is given in **Figure 8-16** on page 8-46. Figure 8-16 also shows the existing transmission pipelines, currently supplying bulk water to Nairobi. Ground and Hydraulic Profiles of the Raw Water and Treated Water Transmission Pipelines are given in **Figures 8-17** and **8-18** on pages 8-47 and 8-48 respectively.

Generally the lengths of Raw Water Mains are kept short to minimise operational problems caused by settling of suspended solids or internal sliming. However, as raw water for this scheme is drawn directly from Thika Reservoir and is generally of good quality, therefore, the relatively long length (40km) Raw Water Transmission Main to Ngorongo Treatment Site is not considered to be a significant problem. In addition, the terrain through which the Main will traverse does not allow the Raw Water Main to be of a shorter distance than the proposed length.

The location of the Treatment Works and vice versa lengths of the Raw and Treated Water Mains has taken into account the proposed future modifications of the bulk water transmission systems from the existing Sasumua and Ruiru Dams in order to reduce pumping / operation costs.

Both the Raw Water Main, the Treated Water Main will traverse through farmland with undulating terrain till it approaches the peri-urban areas of Nairobi City. Around Nairobi City within the built up areas, the transmission main will be laid in road reserves.

In addition to the pipelines, appurtenances including air-valves, washouts, aerial crossings, etc., will be provided at appropriate locations for smooth and efficient operation. Flow measuring devices will also be provided for both the Raw and Treated Water Transmission Mains.

Figure 8-16: Layout Plan Showing the Existing and Proposed Transmission System

Figure 8-17: Hydraulic Profile of the Proposed Raw Water Transmission Pipeline

Figure 8-18: Hydraulic Profile of the Proposed Treated Water Transmission Pipeline

5.1 Design Philosophy

The hydraulics of the Raw and Treated Water Transmission System have been calculated incorporating the proposed alignment of the Transmission Mains and proposed location of the Treatment Works Site at Ngorongo. The principal design parameters considered for the transmission system are listed in Table 8-13, based on which the most economical and appropriate sizing of Transmission Mains has been determined.

Table 8-13: Design Parameters

Parameter	Unit	Value
Existing Thika Dam		
Scour Level	m asl	1985
Lowest Supply Level	m asl	2001
Raw Water Design Flow	m^3/d	120,960
Length of Raw Water Main	Km	44.0
Proposed Ngorongo Water Treatment works		
Raw Water Inlet Level	m asl	1926
Design Capacity	m^3/d	120,960
Treated Water Outlet Level	m asl	1909
Treated Water Design Flow	m^3/d	114,912
Length of Treated Water Main to Kabete	Km	17.6
Existing Kabete Reservoirs and Treatment Works Site		
Storage Reservoir Inlet Level	m asl	1818

5.2 Design Considerations

5.2.1 Materials of Pipes

a) Type of Pipes

The type of pipes commonly used in water supply networks in Kenya include: Grey Cast Iron (CI), Ductile Iron (DI), Galvanized Mild Steel (GMS), Coated Steel, unplasticised Polyvinyl Chlorine (uPVC), High Density Polyethylene (HDPE), Concrete and some existing Asbestos Cement (AC). The choice of pipe to be adopted for any given case will take into consideration the unit cost, durability, resistance to all external and internal forces it is subjected to, ease of transporting and laying, level of leakage and the overall maintenance requirements.

A.C. pipes are no longer commonly used due to widespread fears of the consequent effects of health of the asbestos fibres. In addition, AC and CI pipes are brittle and are therefore susceptible to damage.

It is common practice to use ferrous pipes (steel or ductile iron) in Kenya for large diameter transmission mains. The ferrous pipes are normally internally lined with cement mortar or epoxy.

The manufacturing specifications of the various types of pipes suitable for the Project Area are detailed in the standards given in the Table 8-14 on page 8-50.

Table 8-14: Pipe Manufacturing Standards

Type of Pipe	Standard
Ductile Iron (DI)	ISO 2531
Steel (S)	ISO 6761
Galvanized Mild Steel (GMS)	BS 534
uPVC	ISO 2505
HDPE	BS 3284

b) Pipe Protection

In water supply schemes, internal corrosion results in loss of pipe transmission capacity, pipeline failure, poor water quality and taste problems. Therefore, the resistance of the pipe material to corrosion is expected to be of a greater concern. External attacks, in particular for ferrous pipes, due to the aggressive nature of some soils has to be taken care of.

Ferrous pipes, which are prone to corrosion, wherever proposed shall be protected with an external coating and an internal lining. The types of protection commonly used are epoxy coating and cement mortar lining (to ISO 4179). Epoxy coatings are commonly used in Kenya. Cathodic protection (to CP 1021) will be used on some of the ferrous trunk mains on this Project where aggressive soils are encountered.

c) Selection of Pipe Type

The pipe type to be adopted will be decided during the bidding stage for the larger diameters (>800mm) of ferrous pipe (Steel and DI) alternatives in order to select the most economic one for each particular case.

A few situations in which different materials of pipes will be used are given in the Table 8-15:

Table 8-15: Selection of Pipe Types

Pipe Material	Properties	Situations to be Used
Ductile Iron	- Good resistance to corrosion - High strength and rigidity - Durable	- In soils and water of slightly aggressive nature - For larger mains with a high static or dynamic pressure
Steel and GMS	- Moderate resistance to corrosion - Shorter lifespan than DI pipes - Other properties as for DI pipes	- For larger diameter pipes steel is an alternative to DI - Can be used in aggressive soils if suitably protected
uPVC and HDPE	- Very good resistance to corrosion - Liable to degradation by UV light - More flexible than other types - Light, easy to handle, lay and joint	- For smaller diameter pipes - Suitable in more aggressive soils and waters - Ideal for service connections

d) Pipe Thickness

To safeguard the pipeline against failure, the type of pipe selected must be able to withstand both the external and internal forces it is subjected to. In this context, the wall thickness for each type of pipe varies with size according to the required pressure rating.

5.2.2 Pipe Friction Losses

Hazen-Williams Formula has been used in the hydraulic sizing of the pipelines. The formula is commonly used in the design of water transmission systems and is well documented and easier to use than the Colebrook-White equation. The equation is also accurate for typical pipe sizes and velocities found in general water supply practice. The equation is expressed in metric units as:

$$H\,(m) = \frac{6.78L}{d^{1.165}}(V/C)^{1.85}$$

Where:

H	=	Head Loss	(m)
L	=	Length of the pipeline	(m)
d	=	diameter	(m)
V	=	Velocity of flow	(m/sec)
C	=	Friction Coefficient, a non-dimensionless factor depended on pipe roughness.	

The formula is reasonably accurate provided that the flow is within the intermediate zone in the Moody diagram and Reynold's number does not vary considerably from the transitional zone (Ref. Twort, 2000). However, in the pipeline design, whenever pipe size and velocities vary considerably, the friction coefficient is adjusted accordingly and checks using the Colebrook-White formula done.

Based on experience on numerous projects in Kenya, the values of Roughness Coefficient 'C' that have been used are as shown in the Table 8-16:

Table 8-16: Roughness Coefficients 'C' for Various Pipe Types and Conditions*

Pipe Condition Pipe Type Pipe Age	Good <10 Years	Average 10 to 40 Years	Poor >40 Years	Very Corroded
uPVC, HDPE	150	140	140	-
CI, DI, Steel with cement mortar lining, AC and Concrete	120	110	100	90
Unlined Steel, GMS, CI	130	110	90	80

* N.B: *These values of '**C'** include for losses due to normal bends and fittings along the pipeline.*

5.2.3 Flow Velocity in Pipes

In order to minimize head losses and in some cases, to reduce the risks of water hammer phenomenon, the maximum flow velocities which has been considered is 2 m/s. In order to avoid settlement of sediment / debris in the pipes, the design will ensure that flow velocities are kept, as far as possible, above 0.5 m/s.

5.2.4 Operating Pressures

The river valleys along the pipeline route are generally deep ravines which will result in considerable variation in operating pressures along the pipeline. The maximum operating pressures will be within the nominal ranges shown in Table 8-17 below and have been determined from the proposed alignment and hydraulic profiles shown in Figures 8-17 & 8-18 (see detailed pipeline profiles in Volume III – Preliminary Design Engineering Drawings).

Table 8-17: Transmission Mains – Nominal Operating Pressures

Main	Diameter	Operating Pressure (bar)	
	mm	Maximum	Nominal Rating
Raw Water Main, Thika to Ngorongo Treatment Works	1300	23	25
Treated Water Main, Ngorongo Treatment Works to Kabete	1000	19	25

5.2.5 Cover and Slope to Pipes

Pipelines have been designed with as uniform a gradient as possible, so as to reduce the number of air valves and washout points. Minimum cover to the pipes will be 600mm with average cover of 1200mm. Pipelines in road reserves will be laid 1.5m from edge of road.

Pipelines passing beneath road surfaces and railway lines will be designed and laid in consultation with the relevant public authorities. At places where the over burden and traffic is high, the pipelines will be protected with pipe sleeves and or mass concrete surrounds.

5.2.6 Appurtenances

a) Washouts

Washouts have been located at accentuated low points along pipelines. A low point will be considered to accentuate if the succeeding high point is situated at a level which is 10m higher. Drainage from washout points will be located so as to avoid erosion of areas around the washout chamber. The Washout will be piped to a suitable stream or discharge point nearby. The Number of low points and the Washouts have been kept to a minimum.

The washout pipe will be sized as follows:

$d = 0.6\ D$ if the upstream and the downstream sides of the main are washed simultaneously

$d = 0.4\ d$ if only one side is washed at a time

Where:

d is the diameter at the washout in mm

D is the diameter of the main pipe in mm

b) Sectional Valves

Sectional Valves for operation and maintenance purposes have been placed at a distance apart of about 3km.

Wherever practical, Sectional Valves will be placed in a joint valve chamber with air valves or washouts and upstream of these valves.

c) Air Valves

All pressure pipes require venting to remove accumulated air pockets, to reduce water hammer effects and to discharge air during the initial filling of the pipes. Air valves are also located to facilitate the introduction of air when draining mains.

Large orifice ductile air valves will be installed along mains at all high points determined relative to the hydraulic gradients, generally at a maximum distance apart of 1km at long descents on pipelines.

All air valves will be equipped with isolating valves for easy removal and repair.

The chamber in which the air valve is sited will have a permanent drain in it leading to an open outfall which cannot be submerged. This factor is an important one which will decide the exact location of the air valve to prevent entry of polluted water into the system.

5.2.7 Aerial River Crossings

There are approximately 55 Rivers and Streams to be crossed between Thika Dam and Kabete, 17 Rivers / Streams will be crossed utilising pipe bridges while the rest will be on piers, support stools or under valley crossings. Special consideration will be made to allow for pedestrian crossings wherever the pipeline is along footpaths or roads so as to limit risky crossing by the local populace.

5.2.8 Chambers / Thrust Blocks / Indicator Posts

a) Chambers

The minimum plan dimensions of Chambers will be 2100 x 1800mm on the Raw Water Main and 1800mm x 1600mm on the Treated Water Main. This is also to allow easy access. All pipework within the chambers to be of ferrous type with a suitable protective coating. The cover shall be lockable and the chamber shall be drained through the floor or through a drain pipe. Flexible jointing of pipeline through the chamber wall to be provided in order to allow for any possible differential settlement between the chamber and the pipeline.

b) Anchor and Thrust Blocks

These will be provided for horizontal and vertical bends, at capped ends, valve locations, tees, changes of size and for pipes laid along steep slopes (> 1:6). These are designed for the highest pressures that may occur in the pipeline. They are generally not required when the axial thrust force, F, is lower than 0.05 x D kN where D is the outside diameter of the pipe in mm.

c) Indicator Posts

These will be provided at relevant locations, like gate valves, washouts, etc. and along pipelines at every 200 to 400m, except where they follow permanent roads and in rural areas where the spacing will be increased to about 500m. The posts will be 200mm x 200mm x 700mm high with the appropriate lettering and to an agreed colour scheme.

5.2.9 Wayleaves

Permanent Wayleaves are recommended to be acquired along the Raw Water and Treated Water Transmission Mains Routes.

The Raw Water Main traverses through rural agriculture farmland which is privately owned. The Treated Water Transmission Main traverses through rural agriculture farmland from Ngorongo Treatment Works to the peri-urban areas of Karuri, Loresho and Kabete. In the peri urban areas of Nairobi the Treated Water Transmission Main will be laid within the road reserves.

It is proposed that a 30m permanent Wayleave be acquired for the full length of the raw water and treated water transmission mains. In the built-up areas around Nairobi, it may not be possible to acquire a permanent Wayleave as the area is heavily populated and developed. It is proposed the pipeline will be laid in road reserves. In extreme situations, it may be economically and technically necessary to acquire some developed land.

5.3 Raw Water Transmission Main

The Raw Water Transmission Main will convey water from the Thika Dam to the proposed Water Treatment Works Site near Ngorongo. A 1400mm dia. outlet pipe has been provided at Thika Dam for connection of the proposed future pipeline.

Initially, the Raw Water Transmission Main traverses along the Thika River Valley within the riparian Wayleave for a length of approximately 5km. This is necessary in order to attain gravity flow to the proposed Treatment Works Site at Ngorongo.

Pumping over the Thika River Valley has been excluded as one of the options since it will be uneconomical (high energy costs). Alternatives of a gravity pipeline against a short tunnel across Thika Valley have been compared. In order to obtain the required hydraulic heads, the tunnel would have to include a pressurised pipeline. Both the options were priced on the basis of outline designs and the gravity pipeline option was found to be more economical.

The pipeline route from the dam will traverse across deep incised cultivated river valleys. No convenient corridor along roadside Wayleaves exist for the pipe to follow since the pipeline traverses across ridges. Most of the roads run along the valley ridges in the East - West direction. The selected route which traverses in the North to South direction has been selected to minimise costs, dislocation of people and property.

Large number of individual farmlands will be affected along the Raw Water Transmission Pipeline route with 70% comprising of tea farms 10% maize farms 10% coffee farms with the remaining 10% being other crops. In total, it is estimated that 125 hectares of land will have to be permanently acquired to form the pipeline Wayleave.

The initial part of the Raw Water Pipeline, length 5 km will traverse along the Thika Valley until the southern ridge level is low enough for the pipe to cross over the valley near Kigoro. From here the route crosses the Chania River downstream of Mwagu Intake and crosses Mwagu - Mataara tunnel close to Mataara Chamber before heading for Ruiru

Junction approximately along a straight line. Preliminary route location has been made to minimise disruption to the agricultural, commercial and residential areas and minimising engineering difficulties such as river crossings and very steep gradients in the valleys. A GPS Survey of the Pipeline Route has been carried out to enable the preparation of the Preliminary Design of the Pipeline. **The Raw Water Pipeline Plan and Longitudinal Profile at a scale of 1:4000 Horizontal and 1:400 Vertical, comprising of 37 A-3 Drawings has been prepared and is presented in Volume III – Preliminary Engineering Drawings. Also included are Drawings for Typical Fittings Details and Aerial Crossings**. The precise location of the pipeline will have to be determined during the Final Design Stage.

A 30 m permanent Wayleave is proposed to be acquired for the whole length of the proposed Raw water Transmission Main. The proposed Treatment Works Site is situated about 1.4 km west of the Sasumua Wayleave. A Wayleave will have to be acquired from the Sasumua Pipeline Wayleave to the Treatment Works. This Wayleave will also serve part of the Treated Water Transmission Main.

A 1300mm diameter pipeline will be required to transmit water from Thika Dam to Ngorongo Water Treatment Site. The minimum allowed residual head at the Treatment Site Inlet Works is 10m but the available head will be 26m at full capacity for the selected pipe diameter. A summary of the Raw Water Transmission Main is given in Table 8-18. Detailed Hydraulic Calculations for the pipeline are given in **Appendix 8.9**.

Table 8-18: Raw Water Transmission – Pipeline Details

Pipe		Flow	Velocity
Diameter	Length	(m^3/d)	(m/s)
(mm)	(km)		
1300	44.0	120,960	1.27

The pipeline design will incorporate air valves at high points and washouts at low points. It is estimated that 106 air valves and 83 washouts will be required. Traverse Anchor Blocks will be provided on the steep sections with slopes greater than 1:6 to secure the pipeline against slipping.

The Raw Water Transmission Main will cross 40 River Valleys and Streams out of which 16 crossings will be pipe bridges while the remaining crossings will be on piers, support stools or under valley crossings. Typical Pipe Bridge crossing for the Raw Water Pipeline is shown in Volume III, Drg. Nos. M389/NBI-MP/PDR/RWGM/RC/01 & M389/NBI-MP/PDR/RWGM/RC/02.

It is important that permanent swabbing facilities be provided along the Raw Water Pipeline length. It is recommended that the pipeline be divided into three sections with swabbing chambers at the start and end of these sections. The swabbing chambers will incorporate line valves and need to be sited in accessible positions where swabbing discharges can be disposed off conveniently and safely to a water course.

Flow measurement using ultra-sonic or electro-magnetic metres will be provided at the Thika Dam Offtake and the entry at Ngorongo Treatment Works as a minimum. Additional flow measurement metres can be provided at intermediate lengths say 10km. These flow metres will enable monitoring of water losses along the Raw Water Transmission Main.

Detailed Bills of Quantities and the Engineer's Cost Estimates for the Raw Water Transmission Pipeline are given in Volume II of this Report.

5.4 Treated Water Transmission Main

The Treated Water Transmission Main will be a 1000mm nominal diameter, length 17.6 km Ferrous Main. The exit level at the Treated Water Tank at the proposed Ngorongo Water Treatment Works will be at 1909 m asl.

The pipeline has been designed for gravity flow to transmit 114,912 m^3/d of treated water with the entry level at the existing Storage Reservoirs at Kabete Water Treatment Works site being 1818 m asl. The residual head, after allowing for frictional losses in the pipeline will be 21m above the entry level at Kabete Reservoirs. A summary of the Treated Water Main is given in Table 8-19.

Table 8-19: Treated Water Transmission - Pipeline Details

Pipe		Flow (m^3/d)	Velocity (m/s)
Diameter (mm)	Length (km)		
1000	17.6	114,912	1.94

The topography along this Treated Water Pipeline route is gentler compared to the Raw Water Transmission Pipeline. The pipeline will initially cross tea and coffee farmlands before it enters the commercial and residential urban areas of Karuri, Kitsuru and Loresho closer to Nairobi. The Treated Water Pipeline could have been laid in the existing Sasumua and Ruiru Pipeline Wayleave. The existing Wayleave is congested and has been encroached by private developers in some sections. It is proposed that the existing Wayleave will be extended by 12 m to enable laying of the proposed Treated Water Main. In the urban developed areas, there are defined routes along roads which can be used for laying the new pipeline. However, this will be expensive as it will involve longer lengths and bends will have to be provided. Also the reinstatement of road surfaces / footpaths will have to be carried out.

The Treated Water Transmission Pipeline will traverse through approximately 40% coffee farms, 20% maize farms, 10% tea farms, with the remaining 30% being small holding gardens and other crops. In total, it is estimated that 20 hectares of land will need to be permanently acquired for the pipeline Wayleave. Preliminary route location has been made to avoid dislocation of people, disruption of residential and commercial property and destruction of private property along the route. A GPS Survey of the Pipeline Route has been carried out to enable the preparation of the Preliminary Design of the Pipeline. **The Treated Water Pipeline Plan and Longitudinal Profile at a scale of 1:4000 Horizontal and 1:400 Vertical, comprising of 15 A-3 Drawings has been prepared and is presented in Volume III – Preliminary Engineering Drawings. Also included are Drawings for Typical Fittings Details and Aerial Crossings**. However, detailed investigation and survey during the Final Design Stage will be required to ascertain the precise location of the pipeline within the existing Wayleave or new Wayleave to be acquired.

The pipeline will approximately cross 15 river valleys and streams out of which 1 (one) will be crossed using pipe aerial bridge while the rest will be crossed using piers, support stools or under valley crossings. . Typical pipe bridge crossing for the Treated Water

Pipeline is shown in Volume III, Drawing Nos. M389/NBI-MP/PDR/TWGM/RC/01 & M389/NBI-MP/PDR/TWGM/RC/02.

It is estimated that 36 air valves and 25 washouts will be required at the high points and low points of the pipeline respectively.

Flow in the new main will be regulated using control valves at Ngorongo Treatment Works site and at Kabete Reservoirs. Similar to the raw water transmission pipeline, flow measurement using ultra sonic or electro-magnetic meters will also be provided at Ngorongo Treatment Works Outlet and Kabete Reservoir Inlet. An intermediate meter can also be installed to enable continuous monitoring of the water losses in the Treated Water Main. This will be prudent in monitoring the transmission losses due to illegal connections along this pipeline since it is expected to pass through urban areas.

Detailed Bills of Quantities and the Engineer's Cost Estimates for the Treated Water Transmission Pipeline are given in Volume II of this Report.

5.5 Proposed Modification to the Existing Transmission Systems

The main existing bulk transmission systems supplying water to Nairobi are:

- Sasumua Dam / Treatment Works (2496m asl) to Kabete Reservoir (Elevation 1818m asl)
- Ruiru Dam (1946m asl) to Kabete Reservoir (Elevation 1818m asl)
- Ngethu Treatment Works (1820m asl) to Gigiri Reservoir (Elevation 1711m asl) (also serves Kiambu Reservoir (Elevation 1666m asl)

The water demand in the High Level Zones of Nairobi which are served from the Kabete Reservoir is very high. As a result, treated water is pumped from Gigiri Reservoir to Kabete Reservoir. At present, 42,000m^3/day of water is pumped from Gigiri to Kabete Reservoir. Under the on-going works, this will increase to 84,000m^3/day.

From Kabete Reservoir, presently water is pumped to Uthiru Reservoir (Elevation 1890m asl) and Dagoretti Reservoir (Elevation 1940m asl) to serve Zones 2N, 2S, 3N & 3S which include areas of Karen, Langata, Uthiru, Dagoretti as shown in Distribution Zone Plan, **Appendix 8.10.**

The water demand in the High Level Zones of Nairobi is projected to grow substantially in future based on current and future trends of development. The present transfer system involving pumping of water from Gigiri Reservoir to Kabete Reservoir and on Uthiru and Dagoretti Reservoir involves high operation and maintenance costs.

Modification of the transmission system from Sasumua and Ruiru can result in substantial reductions of these operation and maintenance costs. The pumping of water from Gigiri Reservoir to Kabete Reservoir can virtually be eliminated under the proposed modification to the existing transmission systems.

In brief, the proposed modifications to the existing transmission systems are as follows:

i) <u>Realignment of Sasumua Pipeline</u>

- New Gravity Transmission Pipeline from Ruiru Junction to Dagoretti Reservoir (approximate size 900mm dia, length 37km)

- Use Existing Sasumua Pipeline (600mm dia.) from Ruiru Junction to Kabete Reservoir to transfer treated water from the New Ngorongo Treatment Works.

ii) Ruiru Transmission System

Existing Raw Water Transmission Mains from Ruiru Dam to Kabete Treatment Works are old. The flows have to be boosted using pumps to achieve the design capacity of the Treatment Works.

- Transmit water from Ruiru Dam to the proposed Ngorongo Treatment Works (capacity of the Treatment Works will be increased accordingly and the Treatment Works Elevation may have to be lowered by approximately 10m).
- Use Existing Sasumua Pipeline (600mm dia.) to transmit the additional treated water from Ngorongo to Kabete.

6 Environmental Evaluation

The Preliminary Environmental Impact Assessment Report Version 4 has been submitted under a separate cover. This Section outlines the Key Environmental issues.

This Section focuses on the potential impacts relating to Phase 1 and Phase 2 of the development of water sources for Nairobi: the development of Well Fields in Kiunyu and Ruiru areas, and the development of the Northern Collector Phase I to Thika Reservoir. The mobilisation of these additional water resources will also require additional water transmission and treatment facilities. The development of bulk water sources to supply Nairobi and 13 satellite towns will impact on the general water resources balance in the region as a whole.

Initial options for Phases 1 and 2 involve the development of two well fields at Kiunyu and Ruiru to supply groundwater (with an estimated total yield of 64,800 m^3/d) and development of the Northern Collector Phase 1 (with an estimated yield of 138,240 m^3/d). These developments will increase Nairobi water supply by 50% over current supply levels by 2017. Groundwater can be developed faster, but it is not yet a proven resource and requires further investigation that will be funded under WaSSIP additional financing. Phase 2 involves the development of the Northern Collector Tunnel and intake sites on the three rivers: Maragua, Gikigie and Irati, with abstraction and diversion of water to Thika Reservoir. These developments are expected to increase Nairobi water supply by 50% over current supply levels by 2017.

Environmental impacts resulting from the proposed diversion of water for the Nairobi water supply will include impacts from:

i. Construction of weirs, tunnels and associated structures,
ii. Construction of transmission pipelines and treatment works,
iii. Operation of these systems, including upstream impacts,
iv. Changes to the downstream hydrology of the river basins as a result of reduced flow in the rivers downstream of the intakes, and
v. Cumulative impacts.

Of these, the major environmental impacts are considered to be related to the reduced downstream flows. Cumulative impacts are also likely to arise from additional factors or developments not directly related to the upstream diversion of water via the Northern Collector tunnel to Thika Reservoir. Effects from different activities may also interact to cause additional effects not initially apparent when considering the individual developments or changes, and there may also be synergistic interaction between different factors.

The impacts mitigation due to the proposed Groundwater development of Kiunyu and Ruiru Wellfields is detailed in the Preliminary Design Report Version 02.

The following impacts and their mitigation have been detailed in the above Report:

1. Impacts on Base Flows in Rivers, and on Springs and Dug Wells

Groundwater resources are generally responsible for maintenance of a proportion of base flows in streams and rivers. In the case of the Nairobi Groundwater Body, it is not known to what extent natural groundwater discharge maintains springs and stream base flows, and thus what will be the environmental impact of increased groundwater abstraction.

In addition, as a result of increased abstraction of groundwater resources from specific strata there are likely to be impacts on local water supplies to households and communities that use springs or dug wells. Furthermore, low flows in rivers can induce groundwater discharge into streams if the hydraulic gradient between the river and the adjacent aquifer changes to favour this outcome. Extreme low flows in rivers as a result of upstream abstraction may therefore result in the long term in a reduced availability of groundwater.

Mitigation

- It will be necessary to install an increased network of river gauges and recording stations in order to cover the potentially impacted areas. Regular, daily monitoring and reporting of these river gauges will be necessary.
- At times when reduced base flows are considered to have occurred, or are likely, and where these fall below accepted Reserve Flow limits, it will be necessary to supply an increased flow from upstream resources in order to compensate for the reduced flow and to ensure adequate downstream environmental flows, as well as sufficient flow for communities reliant on these resources (compensation flows). It may also be necessary to reduce the levels of groundwater abstraction.
- All existing springs and dug water supply wells in the areas within the geological strata affected by the proposed groundwater well fields will need to be identified and mapped. The yields from these sources will need to be recorded and monitored. Alternatively, piped water supplies will need to be provided in those cases where these water sources are impacted by reduced groundwater levels resulting from abstraction.

2. Degradation of Aquifers

The present groundwater contribution to Nairobi water supply is limited and groundwater development is still considered to be possible.

According to the Review of Groundwater Resources (June 2011) it is considered that the groundwater abstraction can be increased by 2 or 3 times. However, since it is not known to what extent natural groundwater discharge currently maintains base flows,

the impact of increased groundwater abstraction on base flows is uncertain. Such impacts are possible and, as indicated above, flows will need to be carefully monitored in order that impacts related to reduced base flows can be addressed by suitable mitigation measures.

Aquifers are vulnerable to degradation during and following exploratory drilling in the following ways:

- Aquifers may be contaminated by entry through open boreholes by run-off water from the surface, such as in saline and industrial areas.
- Aquifers containing useable-quality water may potentially be connected by drill holes to aquifers with inferior-quality water or to leakage zones. Cross flow may be induced by natural pressure differences or pressure differentials induced by pumping.
- Uncontrolled flow of pressure aquifer water through drill holes between aquifers of different quality water or through uncontrolled flow to wastage at the surface.

Contaminated groundwater aquifers and wetland water regimes have the potential to affect the habitat and diversity of the aquatic flora and fauna. Groundwater aquifer contamination may potentially result, as some streams and rivers may be fed by groundwater.

Reuse of treated wastewater through artificial recharge of aquifers is seen as efficient alternative method for effluent disposal. This is especially pertinent, given localized declining groundwater levels beneath Nairobi (Review of Groundwater Resources, June 2011). However, as the groundwater resource is increasingly widely exploited, such injected water will be abstracted relatively soon after injection and the natural purifying behaviour of the aquifer should not be taken into account. Primary, secondary and advanced treatment will be necessary to make its quality acceptable for direct injection into the groundwater system.

Mitigation

- Careful attention should be given to ensure that the well is fully cased as it passes through the water table; and
- Ensure that all required safety measures are in place and that staff are aware of procedures that reduce potential contamination of groundwater.
- In order to limit the impact on the groundwater levels, the groundwater development should be located close to the rivers. According to the Review of Groundwater Resources (June 2011) a potential of some 75,000 m^3/day should be available in these sectors. The best sectors for such groundwater development will be identified once exploratory groundwater prospecting is conducted.
- In the other sectors, where groundwater abstraction for public water supply already exists, this abstraction can be increased without major problems. The exact location for such additional boreholes should be set up after further hydro-geological prospection in order to limit the local drawdown, and potential negative impacts on the groundwater resource.
- The Water Act has general guidelines on protection of water sources against pollution. However, it does not set specific protection zones around public

water supply wells. The definition of such zones is now viewed as a necessity, as well as an immediate protection of the area surrounding each well to prevent any accidental chemical or bacteriological pollution of groundwater resources.

3. Loss of Vegetation and Impacts on Agricultural Land

Potential vegetation loss will result from building and establishment of necessary infrastructure, from drilling activities themselves and from construction of new access tracks, or modification to existing tracks.

Site establishment would result in an increase in dust due to vegetation clearing and vehicles and trucks driving to and from the site along farm dirt roads. Limited dust would be generated by the actual drilling activities. However, it is considered that dust generation would be minor and would be of a very short duration and the significance of this impact is considered to be low.

The total footprint of vegetation to be affected would be approximately 50 m x 50 m per drilling site, as well as the area of the access road. As far as possible, existing access roads must be used in order to limit the construction of new access tracks.

Mitigation

- Ensure that only the necessary vegetation cover is removed to reduce the amount of exposed bare ground.
- Demarcate the site camp and access road prior to any vegetation clearing.
- Ensure that only vegetation within this designated area (and the access road) is impacted on.
- Remove only the necessary vegetation during site establishment.
- Any topsoil removed should be stockpiled and replaced during rehabilitation.
- Rehabilitate all disturbed areas on completion of the drilling activities.

4. Impacts from Drilling Activities

Earthen Pits or Drilling Sumps, also known as Reserve Pits, excavated adjacent to drilling rigs are commonly used and set aside for the disposal of drilling muds and other material used in the drilling process. Drilling Sumps can contaminate soil, groundwater, and surface water with metals and hydrocarbons if not managed and closed properly.

Mitigation

- Drilling mud should not be disposed of in any area where it can potentially enter and contaminate the drainage system.
- Where topsoil has to be removed it should be stored nearby in low mounds together with any plant litter. Topsoil should be returned as soon as possible (preferably within 6 months) to maintain seed viability and microbial activity. If drilling sumps are required, then soil and sub-soil should be stockpiled separately and replaced in the reverse order to its excavation.

5. Noise Impacts

The proposed drilling operations would result in a constant noise generation during drilling and would include noise from vehicles and trucks driving to and from the site. During site establishment, large trucks and vehicles would drive to and from the site, while during drilling operations, staff would move about to and from work. The potential noise impacts would be at the local level, of high intensity and short term.

Mitigation

- Liaise with the surrounding landowners and should they feel the noise is significant, drilling activities should not occur at night.

6. Accidental Spillage

During storage and transfer of oil and diesel for drilling operations, there is a potential for an accidental spill onto open ground. Diesel and oil would be required during drilling. Diesel and oil drums would be transported to and stored on site. During the transfer of these drums, there is potential for an accidental spill onto the natural ground. The potential impact of an oil / diesel spill on the surrounding environment would be at the local level, is considered to be of high intensity and short term.

Mitigation

- Ensure that all diesel and oil drums are stored in a fully bunded area.
- Ensure that the transfer of diesel and oil from drums occurs in the fully demarcated and bunded area, otherwise drip trays must be used.
- Ensure that all staff are aware of procedures to be followed for dealing with spills and leaks.
- Ensure that spills are immediately removed along with all contaminated material and disposed of at an approved site for disposal of hazardous material.
- Ensure that all contaminated material is stored in a bunded area before being disposed of.
- Ensure that suitable spill kits are available on site, to be applied to all contaminated areas that will absorb or breakdown the spills. The quantity of such materials shall be able to handle the total volume of the hydrocarbons stored on site.

6.1 Cumulative Impacts – Abstraction From Northern Collector River

The Gikigie River joins the Maragua River approximately 4.8 km below the proposed Gikigie Intake Weir. Further downstream, the Irati subsequently merges with the Maragua River after flowing for 29 km. Below these junctions, impacts from reduced flows released at the Intake Weirs will be related to the combined releases from each weir. Records from the river gauge at Maragua (RGS:4B01) represent flows below the junction of all three rivers and enable an assessment of the changes in flow at this point to be estimated. RGS:4BE01 lies approximately 22 km along the course of the Maragua river below the junction with the Irati. Flows at this point include flows from a larger catchment that includes additional tributaries originating from below the Aberdare Forest boundary. However, the Aberdare Forest catchments provide important dry season flow.

Cumulative impacts at Maragua 4BE01 are expected to include the following considerations:

1. Reduced flows as a result of diversion of a majority of the flows originating from the Aberdares at Irati, Gikigie and Maragua intakes to the Northern Collector, resulting in:
2. Reduction in the flow reaching Masinga Reservoir and therefore a reduced flow available for hydroelectric power generation;
3. Some short periods or single days with potentially zero flow or near-zero flow. These periods will normally be preceded and/or followed by further periods with extreme low flow;
4. Less flow available for use in existing and future agricultural activities in downstream areas (e.g. irrigation), in order to provide food required by the increasing population of Nairobi.

Cumulative impacts relate to the aggregate of past, present and future actions, and may also arise from additional factors or developments not directly related to the upstream diversion of water via the Northern Collector tunnel to Thika Reservoir. Effects from different activities may also interact to cause additional effects not initially apparent when considering the individual developments or changes, and there may also be synergistic interaction between different factors.

Potential factors that may ultimately interact with impacts from changed downstream flows on the Irati and Maragua Rivers include the requirements for increased food resources for an increased population in Nairobi, some of which may require increased use of irrigation. Siltation of Masinga reservoir is also a factor that is likely to interact with the changes in flow. Reduction of reservoir capacity by 30% by 2050 due to siltation is considered likely[1].

Potential factors also include the longer term impacts of climate change as well as the potential changes that are likely to be brought on by “Peak Oil” and the inevitable increase in international oil prices. The increase in international oil price, coupled with the reduced availability of oil, will impact on consumers and is likely to result in less daily movement between Nairobi and adjacent areas, and a resulting shift in demand for water from Nairobi to the adjacent areas. Increased oil prices may also put increased pressure for development of hydropower, including mini-hydro. Trends in Brent Oil crude prices are indicated by **Figure 8.19** on page 8-64. These trends indicate an approximate doubling of crude oil prices by 2017. The potential interactions with impacts related to both climate change and international oil prices are less likely to be directly relevant within the time period up to 2017. However, its relevance and impact will increase significantly thereafter, with one impact being a dramatic change in population distribution and movement in the Nairobi area and adjacent districts. There are also some indications that flow regime patterns may already be changing (see **Figure 8-23** on page 8-67).

[1] Droogers, P. (2009). Climate Change and Hydropower, Impact and Adaptation Costs: Case Study Kenya. Report Future Water: 85.

Hoff, H., Noel, S. and Droogers, P. (2007). Water use and demand in the Tana Basin: Analysis using the Water Evaluation and Planning tool (WEAP). Green Water Credits Report 4, ISRC - World Soil Information, Wageningen.

In addition, excessive abstraction of water resources before 2017 will preclude subsequent alternative use of these resources for agriculture (in response to the predicted rise in temperature and the resulting increased evapotranspiration).

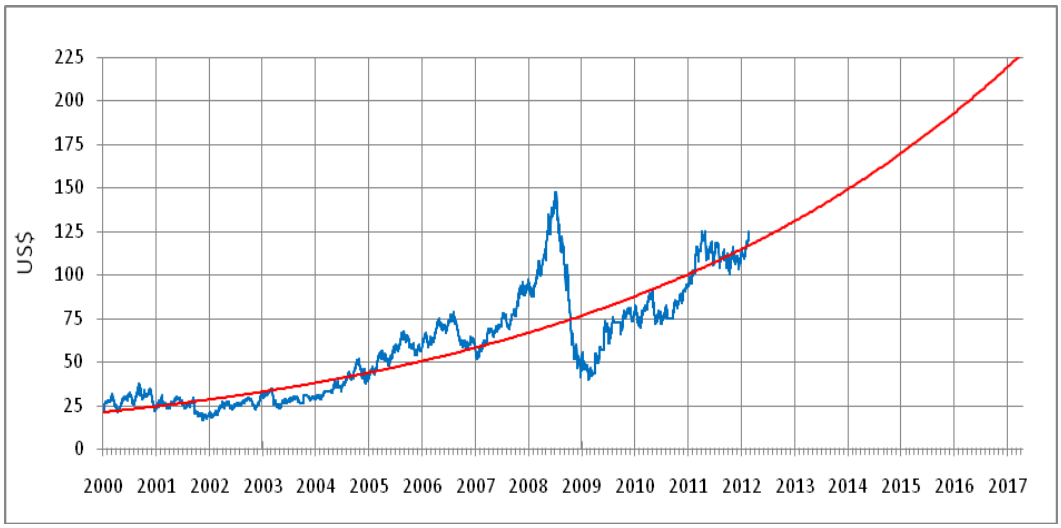


Figure 8-19: Trends in International Crude Oil Prices: Daily Brent Crude Since Year 2000 (US$ per barrel), with Best-Fit Trend Line (power curve, R^2=0.801) Extended to Forecast Till Year 2017.

Note: This same trend carried forward to the year 2035 indicates an increase in crude oil prices to over 15 times current prices.

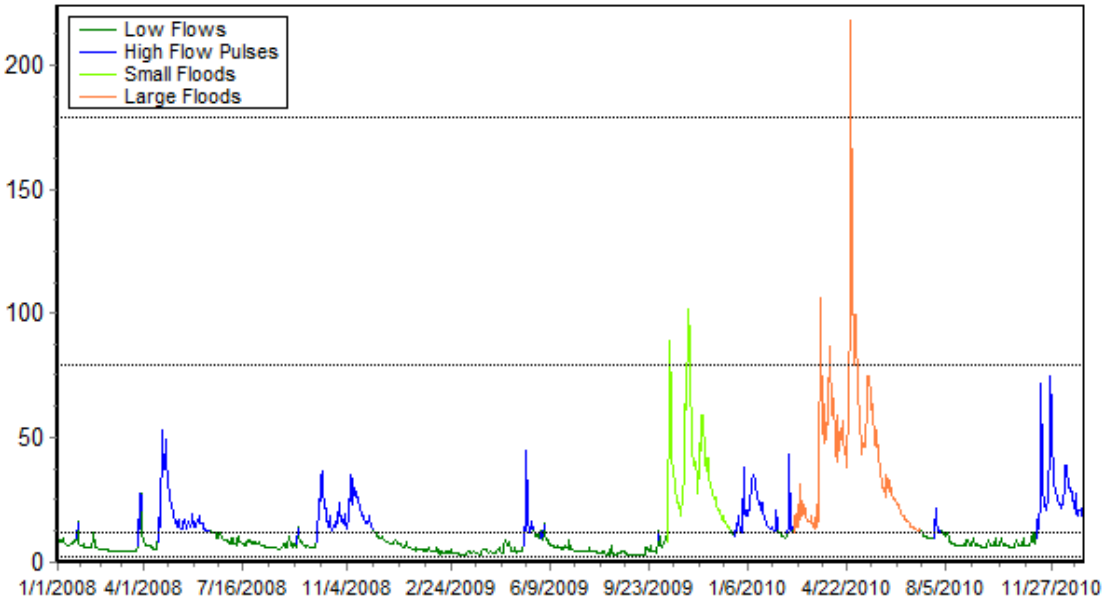


Figure 8-20: Flows at Maragua RGS:4BE1, 2008-2010 (m^3/sec), illustrating characteristic seasonal patterns of flow with occasional periods of small floods and large floods (extreme low flows were not recorded during this period).

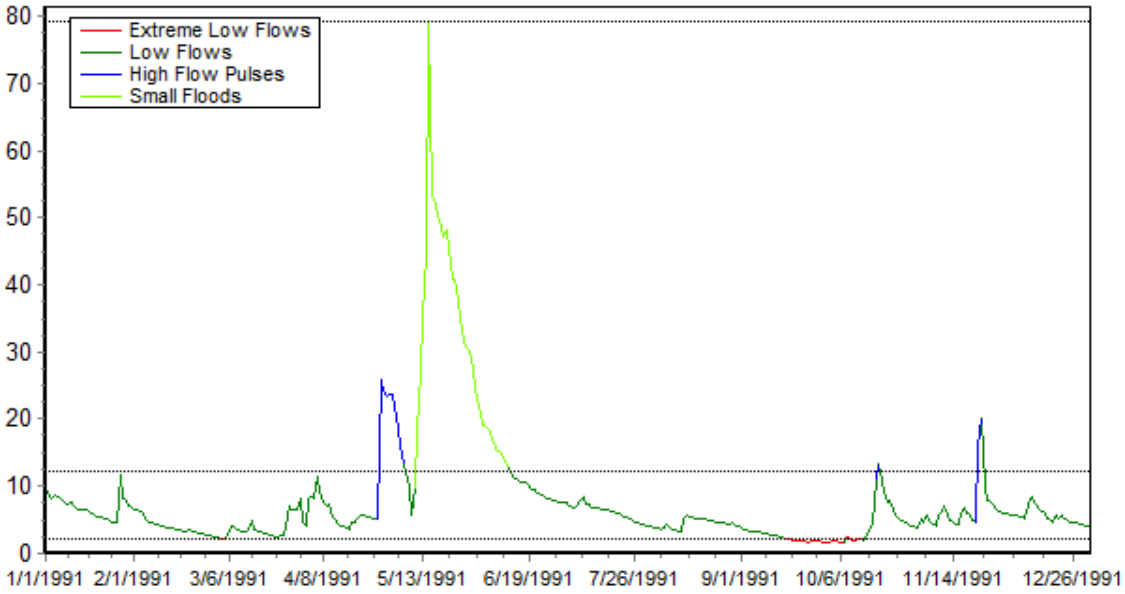


Figure 8-21: Natural Flows at Maragua RGS:4BE1 during 1991 (m^3/sec), illustrating a period with extreme low flow.

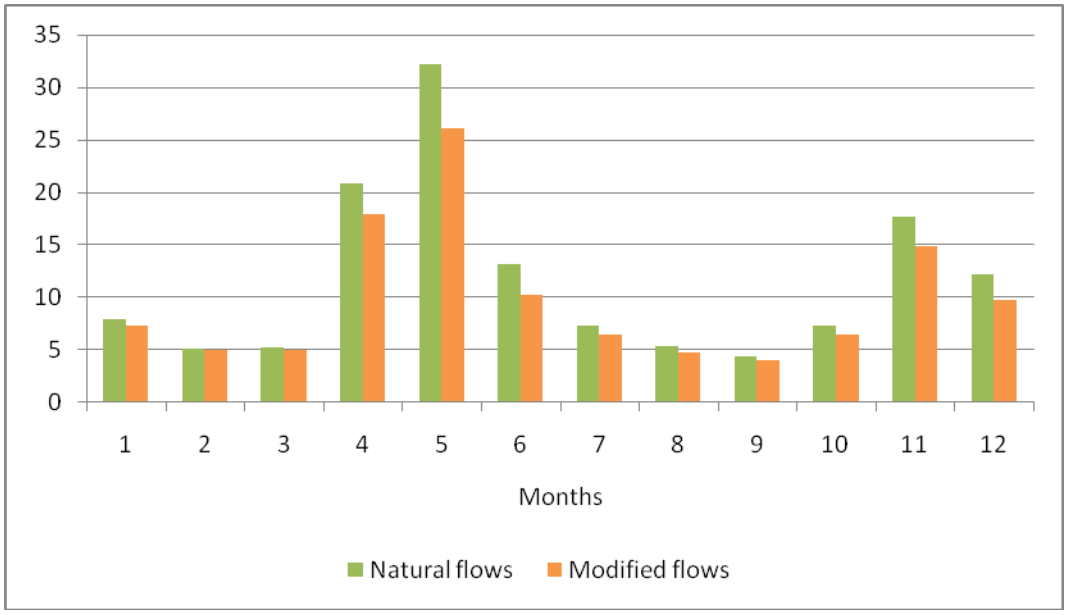


Figure 8-22: Flows at Maragua RGS:4BE1 (1973-2010). Differences between the average monthly Natural flows and Modified flows with Reserve Flows based on Q_{95} released at Northern Collector intakes (Irati, Gikigie and Maragua).

Changes in Flow in Maragua River at RGS:4BE01

Natural flows at Maragua RGS:4BE01 are illustrated by the flow patterns shown in Figures 8-20 and 8-21 above. The differences between the average monthly natural and modified flows with release of reserve Flows based on Q_{95} are shown by **Figure 8-22** above.

The possibility of upstream abstraction resulting in short periods, or single days with zero flow downstream can be illustrated by recorded natural flows during 1991 and estimates of modified flows. For example, in 1991, a period of 27 days with extreme low flows under

natural flows (see **Figure 8-21**) results in, following upstream abstraction and release of Q_{95} based Reserve Flows, a period of 8 days with zero flow and a further 13 days with flows of less than 0.8 m^3/sec. Modelling changes in flow using the 1973-2010 time series results in 0.2% of daily flows equal to zero (in 15 separate occasions), and 0.75% of daily flows of less than 1.0 m^3/sec. The extreme low flow threshold for natural flows at 4BE1 is 2.2 m^3/sec. These zero flow periods can be mitigated by the release of greater flow volumes from the Northern Collector intake sites at those times when these zero flows or very low downstream flows are considered likely.

Mean annual flow reaching Masinga Reservoir from Maragua River can be expected to be reduced by the diversion of upstream flows into the Northern Collector tunnel. Available published information on average monthly flows into Masinga Reservoir are indicated in Table 8-20, (1995-1997). Taking the daily 1995-1997 flow data from Maragua 4BE1, modified to include upstream abstraction for the Northern Collector with release of Reserve Flows based on Q_{95}, results in an overall annual average reduction of inflow of 2.32% for inflow to Masinga Reservoir, or a reduction in volume of 2.72 m^3/s relative to average inflow of 125.51 m^3/s (1995-1997). Flows in the Tana downstream of Masinga Reservoir are also expected to reduce.

Table 8-20: Average flows into Masinga Reservoir (m^3/sec), and potential changes following diversion of water to the Northern Collector Phase 1

	Masinga 1995	Masinga 1996	Masinga 1997	Masinga Average 1995-97	Maragua 4BE1 natural	Maragua 4BE1 modified	Masinga with modified 4BE1	% change
January		103.3	21.83	62.57	4.42	3.17	61.32	2.00%
February	10.05	86.71	13.59	36.78	5.06	4.22	35.94	2.28%
March	49.32	57.35	16.08	40.92	5.08	4.06	39.9	2.49%
April	679	36.47	169	294.82	14.53	11.29	291.58	1.10%
May	289.8	70.27	363.9	241.32	28.46	22.93	235.79	2.29%
June	253.7	119.7	287	220.13	12.68	8.82	216.27	1.75%
July	170.8	122.8	187.5	160.37	7.87	5.52	158.02	1.47%
August	99.25	82.22	83.38	88.28	6.04	4.21	86.45	2.07%
September	61.01	41.61	26.59	43.07	4.86	3.60	41.81	2.93%
October	39.06	15.39	175.9	76.78	14.35	11.63	74.81	3.54%
November	26.77	25.24	255.7	102.57	37.74	33.02	97.85	4.60%
December	86.91	27.64	300.9	138.48	16.48	12.45	134.45	2.91%
Average	152.74	69.19	145.50	125.51	13.13	10.41	122.79	2.32%

Source: van Loon, A. and Droogers, P. (2006). Water Evaluation and Planning System, Kitui - Kenya. WatManSup project. WatManSup Research Report No 2.

These Masinga inflows compare with the estimated mean discharge of 91.28 m^3/s for the period from 1957 to 1990 at Masinga quoted by the "Mutonga/Grand Falls Hydropower Project Feasibility Study Report" (March 1998), where discharge includes additional factors such as evaporation and other losses from the Reservoir.

In areas adjacent to the Northern Collector intakes, agricultural activities are predominantly tea plantation. The small areas under food crops are for subsistence farming and are not for sale to Nairobi. At lower elevations below the tea zone, the predominant agriculture is commercial coffee. The agricultural potential in Muranga District generally decreases from northwest to southeast, mainly because of decreasing rainfall and soil fertility. In areas with

less rainfall, and with a reduced proportion of commercial tea and coffee, an increasing demand for food crops required by the increasing population of Nairobi is likely to lead to an increased demand for irrigation. For example, in July 2010, it was reported that farmers in Muranga District would benefit from KShs 50 million to help them invest in irrigation schemes (Daily Nation, July 10 2010) and that 17 schemes would use sprinkler, hose, and drip methods of irrigation. With an increase in the local population in areas downstream of the Northern Collector intakes, coupled with an increase in demand for food from a greater population in Nairobi, it is considered likely that there will be increased pressure for use of available resources for irrigation in suitable sites within relatively easy transport distance from Nairobi.

With an increase in the local population in the Muranga area, and an increase in demand for food from greater populations in Nairobi and satellite towns, it is considered likely that there will be increased pressure for use of available resources for irrigation and improved soil water management. However, the estimated decrease in flow at Maragua RGS:4BE1 does indicate that the overall impact of abstraction for the Northern Collector is relatively small.

The National Water Resources Management Strategy acknowledges the issue of agricultural requirements for water:

> Since the agricultural sector accounts for a large proportion of water use in Kenya, introduction of water demand management in this sector is imperative. More efficient irrigation approaches and technologies also need to be adopted. These include:
>
> (i) Assessing the irrigation potential of soils in terms of water loss. This includes determining soil texture, moisture retention properties and the slope and then choosing the more water efficient soils.
>
> (ii) Identifying the suitable water saving technology and the efficient production level.

This will, however, require funding to promote appropriate technologies and enable their wider adoption and use. It is suggested that part of the mitigation of impacts caused by the upstream abstraction of water in the Irati, Gikigie and Maragua Rivers should include funding to assist with the adoption of appropriate technologies.

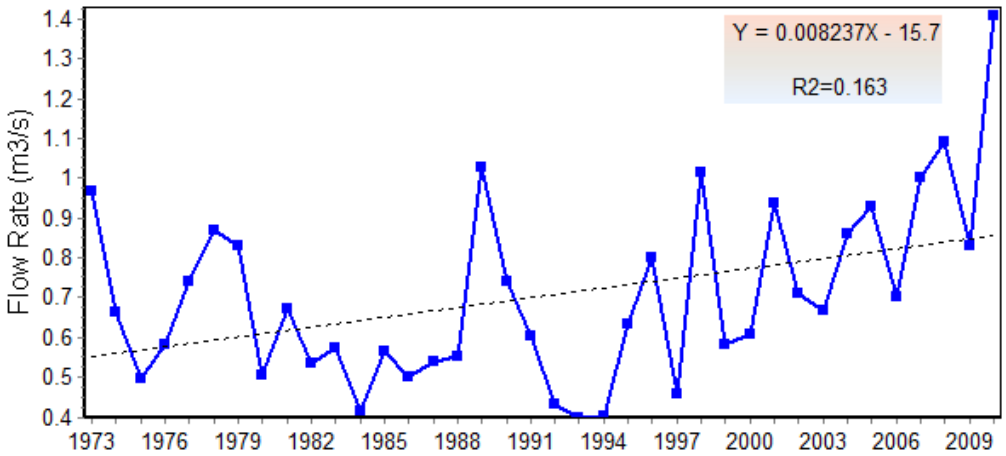


Figure 8-23: Maragua intake natural flow, 1973-2010, 7-Day Minimum, indicating a potential trend towards higher flows.

6.2 Upstream Catchment Areas

6.2.1 Catchment Protection

Deforestation in the Aberdare Range and reduced vegetation cover in the other parts of the river catchments would inevitably result in increased runoff during higher rainfall periods and in increased turbidity and suspended solids in the river flows. This would result in siltation at the weirs and intakes, as well as in downstream reservoirs, and requirements for more expensive water treatment.

An important and major part of the catchments of the proposed Northern Collector weirs and abstraction sites are included within the protected areas of the Aberdares, including the Aberdare National Park and neighbouring Aberdare Forest Reserve. Significant parts of all of the catchments associated with the proposed Northern Collector schemes are therefore considered to be under a “high” protection status. Major parts of each catchment lie within the Aberdare Forest Reserve land (see **Figure 8-24** on page 8-69), with a smaller portion of the upper catchments within the National Park.

It is recommended that the Forest Reserve land is managed to provide maximum catchment protection, and that any potential deforestation in these areas is minimized.

Much of the land within the catchments outside the protected areas consists of relatively steep sided valleys, with roads and households largely limited to the higher land between valleys, or in some flatter areas in valley bottoms. Land use and land cover includes smallholder tea as the dominant crop (see **Figure 8-25** on page 8-70), together with small areas of smallholder cultivation of annual food crops, and woodlots, as well as significant amounts of natural riparian vegetation along river banks. Cultivation on such steep sided valleys requires terracing in order to reduce the risks of soil erosion. Terracing is encouraged under smallholder tea (see Section 6.2.2) and it is recommended that efforts to promote sustainable land management for tea and all other crops should be actively supported by the project. The utilisation of the riparian zone of all rivers, both perennial and seasonal, is governed by restrictions, under which no tillage or cultivation is permitted and the draining of wetlands and swamps is subject to permits issued by the Authority (WRMA).

Costs of active support for catchment protection will be minor. Improved sustainable land management will also provide benefits to the local communities.

Below the diversion structures on the Northern Collector schemes it is also recommended that regular land management and control measures will be required for catchment protection, in particular in order to reduce the risks of soil erosion. Where possible this should be combined with local on-farm water harvesting measures and agricultural practices such as Conservation Tillage. In particular Conservation Tillage limits soil loss and decreases erosion, enhances soil structure and nutrient status, reduces runoff, conserving soil moisture and therefore limits requirements for external water sources. This will require a comprehensive sustainable land management plan adopted and managed by all of the relevant ministries involved – including water, agriculture and environment.

The impacts related to catchment protection are considered to be “manageable issues” with no negative impacts. However, the longer term benefits resulting from improved and sustainable land management are expected to be significant and should in the long-term override the costs.

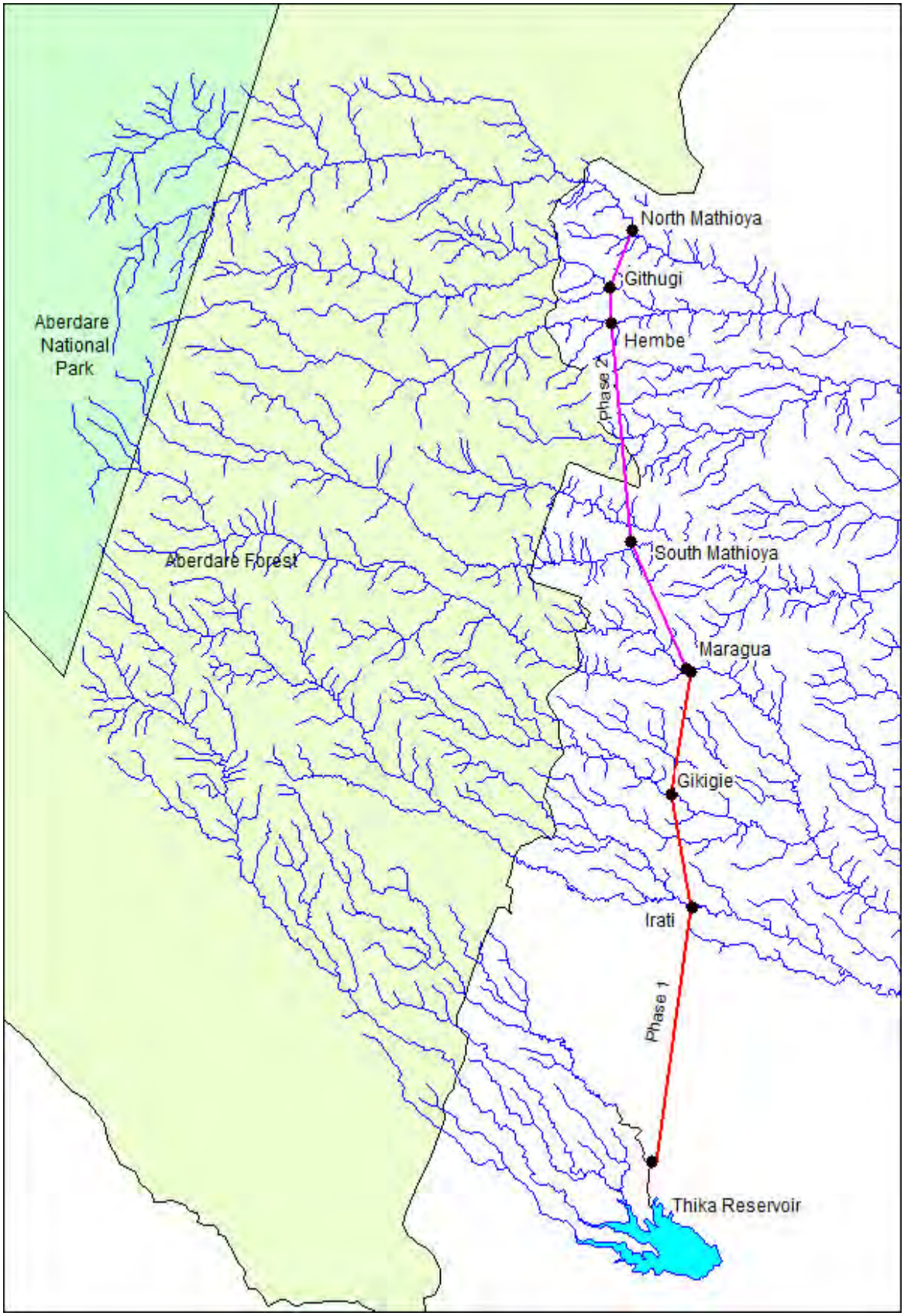


Figure 8-24: Northern Collector tunnel (including Phase 1 and Phase 2) and Thika Reservoir: Showing Protected Forest areas, National Park land, and rivers connected to the Project

Figure 8-25: Land Use Adjacent to Site of Proposed Maragua Intake Weir, Illustrating Cultivation of Tea as the Dominant Land Use

6.2.2 Water Quality

According to the Millennium Ecosystem Assessment (2005) all the world's ecosystems are deteriorating, but the freshwater ecosystems are the worst off as a result of water extraction, flow regulation, and pollution. Water quality describes the physicochemical characteristics of the water body. These vary naturally with the weather or seasons and with the spatiotemporal variation of the water flow, i.e., the flow regime.

Water quality and river flows are fundamentally linked. These links can be direct or indirect and will vary over time. Direct influences include instances where concentrations or transport of pollutants in streams is influenced by flows. Indirect influences are of particular importance and refer to the ways in which the flow regime influences stream habitat and ecological health. This in turn influences ecological processes occurring in those streams. These ecological processes (for example the natural processing of organic matter and nutrient inputs to streams) in part determine the prevailing water quality.

Runoff from agriculture and development, including pollution from septic systems and sewers, and other human-related activities increase the flow of both inorganic nutrients and organic substances into ecosystems. For example, excess levels of Phosphorus are often linked to point-source pollution from sewage. If the low-flow situation is prolonged or water quantity reaches extremely low levels, ecological communities are impaired. Low-flow situations are also particularly sensitive to water quality stressors. Concentrations of substances that are continuously added, but in low doses (e.g. sewage), will increase and may reach levels that are toxic to organisms.

It is a particular challenge to satisfy the needs of both humans and nature, without sacrificing one or the other, especially when low flow situations are likely to result in reduced water quality. New policies and institutional commitment are needed to make improvements, including in the ways water flow in rivers is modified by direct abstraction. Any water extraction from a stream during extreme low flows and low flows can exacerbate these problems. The primary requirements for provision of good quality water supplies will be to:

- Minimize negative impacts of upstream land use on water quality, including runoff and erosion;
- Prevention of excess nutrients entering the drainage systems;
- Prevention of agricultural pesticides and herbicides entering the rivers;
- Minimize pollution from inputs such as sewage;
- Minimize change in woody cover and land use within the catchments, as well as;
- Provision of Reserve Flows that include environmental flows of sufficient volume to maintain critical ecological functions.

Flow schemes designed to avoid extended periods of low water will be especially important.

Primary impacts will be related to land use within the catchments, and specifically to changes in woody cover and agricultural land use. The major parts of each catchment lie within the protected areas of the Aberdares and are therefore unlikely to change. Important land use within the settled parts of the catchments includes smallholder tea plantation, smallholder agriculture, and woodlots. Smallholder tea is the dominant land use.

Much of the land within the catchments has relatively steep slopes and maintenance of appropriate land use and land cover on these slopes will be an important consideration. The growing of tea represents an important land cover, especially on the steeper slops. Whilst changes associated with the construction and operation of diversion structures may result in some changes in land use in the immediate area of each diversion structure, these are considered to be relatively minor and, importantly, should be manageable and should not have an impact on water quality.

The various river sources examined and reported in the Howard Humphries report (1998) were of similar quality and the water suitable for use as water supplies given appropriate treatment. Possible changes in the management of small scale agricultural land in parts of the catchment in the intervening years may result in increased runoff from cultivated areas. However, it is considered that after storage and appropriate treatment the water will be suitable as a source for potable supply.

It will be necessary to carry out regular water quality assessments as part of future management strategies. This will contribute towards appropriate and sustainable land management procedures within the catchments, for example limiting the application of agricultural chemicals and a focus on improved water and land management.

As part of long term land management approaches designed to promote water quality, it is recommended that measures to promote Conservation Agriculture should be adopted. Conservation Agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are

reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. Soils under CA have high water infiltration capacities reducing surface runoff and thus soil erosion significantly. This improves the quality of surface water reducing pollution from soil erosion, and enhances groundwater resources.

6.2.3 Importance of Tea Cultivation

Tea is an important crop in all areas of the catchments below and adjacent to the protected areas. Tea is a high value crop that thrives on acid upland soils that are poorly suited to other crops. In terms of its environmental impact, tea has advantages over other crops grown in these zones. The deep roots and ground cover provided by tea trees result in relatively good soil and water conservation. Although terracing is initially costly to construct, it is more affordable for high value cash crops such as tea than for lower value food crops. In Kenya terracing is now reported to be mandatory for anyone wishing to obtain a license to produce tea[2]. However, even in areas without fully developed terracing, the smallholder tea plantations will continue to provide high degree of catchment protection and should be actively encouraged in all areas.

A potential cause of deforestation in tea producing areas is the use of wood for drying the tea leaves. For example, tea factories of the KTDA have contributed to deforestation in some places in order to fuel this process. However, this is not an inevitable impact, and alternative fuels can be used in the drying process and timber can be sustainably harvested from dedicated managed woodlots.

As with other intensive forms of agriculture there are the usual environmental risks associated with excessive fertiliser and pesticide use. The main external input requirement for tea is nitrogenous fertiliser, which for optimum productivity needs to be applied at higher doses than for many other crops because it is the nitrogen bearing leaves that are removed when harvesting tea. Pests and diseases, however, represent less of a threat to tea than to other commercial crops and although tea productivity can benefit from the use of herbicides, it is not economically viable on smallholder plots.

Lipton and the Kenya Tea Development Agency (KTDA), supported by a grant from the UK's Department for International Development have piloted new methods for encouraging Kenyan smallholder tea growers to adopt more sustainable and more profitable farming practices. This model was seen as a success and KTDA is now committed to rolling out the Farmer Field School approach across its entire organisation[3]. This important initiative has resulted in the development of higher levels of social capital, and the programme has

[2] Stockbridge, M. (2006). Background paper for the Competitive Commercial Agriculture in Sub–Saharan Africa (CCAA) Study. All-Africa Review of Experiences with Commercial Agriculture: Environmental Impacts.
Ovuka, M. 2000. More People, More Erosion? Land use. soil erosion and soil productivity in Muranga District, Kenya. Land Degredation and Development 11: 111-124.

[3] Hiller, S., D.D. Onduru and A. de Jager (2009). Sustainable tea production: An assessment of Farmer Field Schools in Kenya. LEI Wageningen UR, The Hague
Mitei, Z. (2011). Growing sustainable tea on Kenyan smallholder farms. International Journal of Agricultural Sustainability 9(1)

resulted in increased annual yields and a renewed focus on improved water and land management.

It is recommended that an important component of land management within the catchments will be a requirement for close cooperation with KTDA and the provision of active support to the Farmer Field School initiative in all relevant catchments. For example, buildings constructed at each of the Intake Weir sites could be made available for use by local communities involved with the Farmer Field School initiative, and other similar approaches to sustainable agriculture.

6.3 General Recommendations

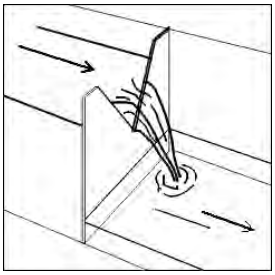
A policy for abstraction of variable amounts depending on the natural flow is recommended. Recommendations for operating rules at each of the proposed abstraction sites along the Northern Collector will need to be defined during detailed design stages. It is clear that the preferred option should be a set of operating rules based on variable abstraction rates, and that these will provide the best mechanism for providing downstream Reserve Flows.

However, at the current stage, the computation of yields and the overall water balance modelling has been prepared assuming a Q_{95} flow at each abstraction site, with additional flow at Irati to compensate for increased compensation flow requirements.

Recommendations for required designs and operating procedures to be defined at the detailed design stage include the following:

- Development and refinement of the recommended guidelines for variable abstraction and variable downstream flow release to enable computation of yields and water balances, whilst at the same time maintaining both downstream Environmental Flows and downstream Compensation Flows. These guidelines will need to be determined independently for each abstraction site depending on the specific requirements for Compensation Flows.
- Guidelines and strategies for release of Reserve Flows should be regularly reviewed and updated as necessary, with guidance from appropriate authorities, including the Catchment Area Advisory Committees (CAACs).
- Design of calibrated triangular, or V-notch weirs at each abstraction site with mechanisms for abstraction of variable flows. This will provide variable yields and at the same time enable variable downstream Reserve Flows, preserving the integrity of downstream environments, and provide vital resources to downstream communities reliant on these water resources. Installation of V-notch weirs is also important because Triangular or V-notch weirs measure low discharges more accurately than horizontal weirs. V-notch weirs should always be used when frequent low flows are included in the overall range to be measured.

V-Notch Weir



- Designs for fish ladders need to be reviewed and fully incorporated in the designs of all proposed weirs. Sufficient flow must be allowed for and passed downstream through fish ladders, particularly at those times of year when fish and other aquatic species are likely to require to move upstream or downstream, e.g. for purposes of breeding. This is likely to be at times of natural high flow pulses and small floods.

Operating rules should therefore allow for the passage of sufficient flows to enable these important movements to take place.

- As part of the downstream Compensation Flow requirements, it will also be important to consider and incorporate the likely increases in the future requirements for irrigation supplies to provide agricultural produce to an increasing population in Nairobi and adjacent areas, whilst maintaining important agricultural production resulting in foreign earnings.
- In cases where downstream water requirements are likely to be constraining factors, e.g. for agricultural requirements, the incorporation of small impoundments or other water storage facilities should be considered at selected downstream sites. Any such sites, either proposed or existing, should be incorporated within the operating procedures.
- Operational procedures will need to be established so that, under periods with naturally low flows (e.g. extreme low flows), sufficient flows are allocated to:
  a. Cater for downstream demands from communities, households, agriculture (crops and livestock), and commercial or industrial requirements,
  b. Provide environmental flows of sufficient quantity to prevent critical decline of downstream aquatic environments,
  c. Ensure the maintenance of water quality (including the requirements related to sewage treatment and disposal), and
  d. Provide flow for Nairobi water supplies whilst taking account of reservoir storage. Rationing of water to consumers may need to be considered under such circumstances.
- A "*hands off*" flow (HoF) will also need to be defined below which no extraction or diversion of water can take place. As part of the variable abstraction guidelines, the recommended absolute "hands off" flow specifically for environmental purposes would be flows equal to the Q_{98} flow, plus the required Compensation Flows. Depending on specific downstream demands and associated Compensation Flow requirements (household water needs, livestock requirements, subsistence irrigation, commercial irrigation, and other commercial or industrial requirements), mechanisms will need to be defined to enable the adjustment of this hands-off flow level so as to ensure adequate flows to sustain these downstream environments and communities. For example, if Compensation Flow is required at the Q_{95} flow level, then the hands off flow would be set at $Q_{95} + Q_{98}$.
- In situations where downstream flows, e.g. at Maragua RGS: 4BE1, are during dry periods likely to be less than the minimum Q_{98} level, or where there is potential for zero flows, increased releases must be made from all of the upstream intake weirs in order to compensate for these very low flows or zero flows.
- An important recommendation is that all flows must be monitored on a regular daily basis above and below each of the weirs and intake structures. Together with other flow data, the data will then be available to form the basis for day-to-day operational management decisions.
- Regular monitoring and updating of downstream water abstraction and use will need to be carried out. This includes, for example, the use of water by households and communities, or for use as irrigation supplies. This should include both licensed and unlicensed abstractions. This information will need to be fed into

regular operating procedures in order to optimise the use of available water resources and continue to provide environmental flows capable of maintaining downstream environments and critical environmental services.

- It is recommended that the Water Management Authority should, in collaboration with the Catchment Area Advisory Committee (CAAC), formulate a catchment management strategy for the management, use, development, conservation, protection and control of water resources within each catchment area. This should include mechanisms for enabling communities to participate in managing the water resources within these catchments. The Authority should also appoint a catchment area advisory committee if this is not yet present for the relevant catchment area.

The abstraction of water at the proposed sites for the Northern Collector Tunnel, Phase 1 will inevitably result in the creation of a relative water scarcity situation downstream of these sites. The following Policy Message and Recommendation from the "Kenya, State of the Environment and Outlook 2010" report[4] are particularly relevant when considering the requirements for operating rules for downstream Reserve Flows below the abstraction sites.

Policy message: *Given the linkages between water and human and environmental health as well as the major sectors of the economy, access to clean and safe water in adequate quantities is a prerequisite for the attainment of Vision 2030. It is therefore vital that measures are urgently instituted to address the water scarcity challenge that the country is currently grappling with especially in light of the fact that this crisis is projected to rapidly worsen as population increases and climate change and their derivative effects take their toll.*

Recommendation: *Ground the concept of integrated water resources management (IWRM) which takes cognizance of the multi-faceted nature of water problems and calls for comprehensive management of water resources based on an ecosystem approach and an appreciation of the needs of the diverse users and the broad range of potential impacts of water use.*

The importance of integration of the environment into decision making is also illustrated in the following diagram outlining the importance of environmental services and ecological functions.

[4] NEMA (2011). KENYA State of the Environment and Outlook 2010. Supporting the Delivery of Vision 2030. Summary For Decision Makers. National Environment Management Authority, Kenya.

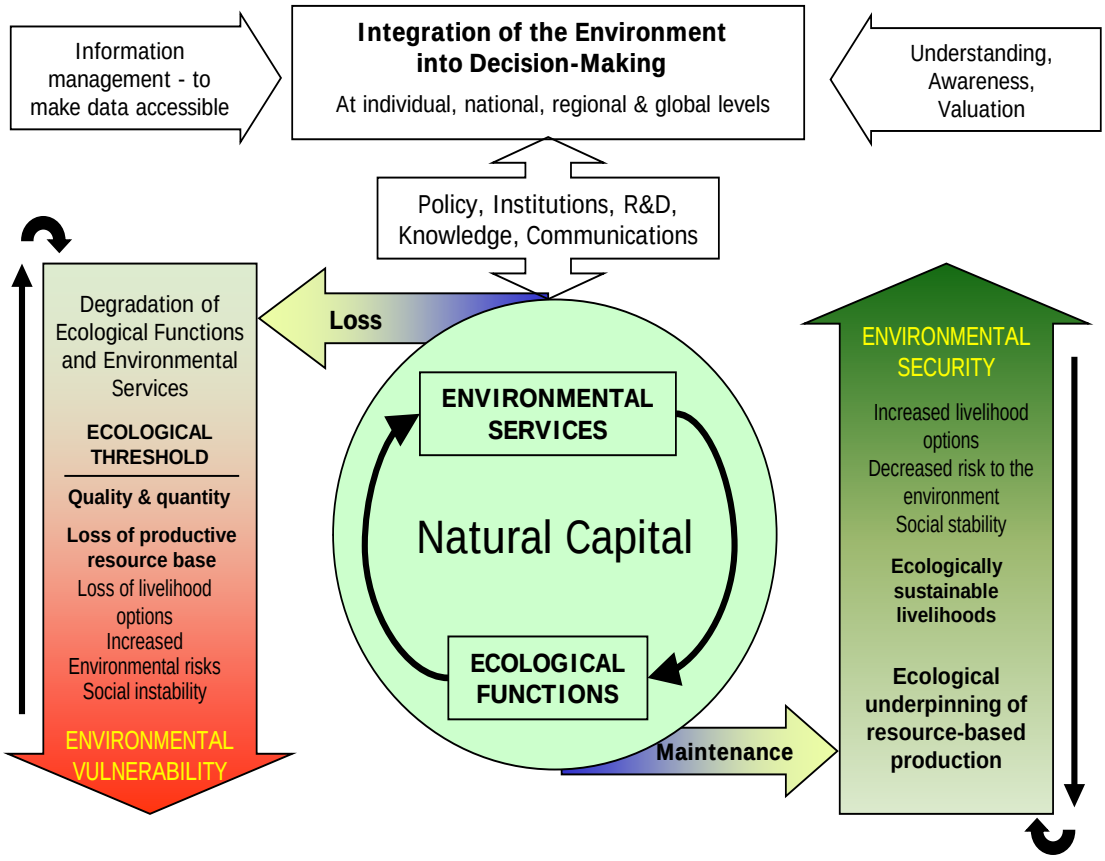


Figure 8-26: Integration of the Environment into Decision Making

6.4 Impacts and Mitigation Measures

Environmental and socioeconomic impacts resulting from the proposed diversion of water for the Nairobi water supply during Phase 1 (Groundwater development) and Phase 2 (Northern Collector Phase 1) will include impacts resulting from:

a. Construction and development of groundwater well fields in Kiunyu and in Ruiru areas,

b. Construction of weirs, and other structures associated with intake facilities on Irati, Gikijie and Maragua Rivers, along the Northern Collector Phase I tunnel to Thika Reservoir,

c. Construction of the Northern Collector Phase I tunnel,

d. Construction of transmission pipelines and treatment works,

e. Resettlement and compensation,

f. Operation of these systems, and

g. Changes to the downstream hydrology of the river basins and downstream availability of water as a result of reduced flow in the rivers following abstraction at the intake sites.

Potential environmental impacts will result from the creation of the diversion sites and structures themselves, and from operational management of diversion sites and the impacts on downstream riverine ecosystems, including maintenance of instream and

riparian habitats. Downstream impacts on riverine ecosystems are considered to be the primary environmental impacts associated with the development of these water supply abstraction sites. The most important mitigation measures are the release of good quality Reserve Flows capable of maintaining important environmental services, and at the same time capable of satisfying downstream water requirements. Additional impacts are related to a) construction and b) operation of the diversion sites themselves and associated transmission pipelines.

Of these, the major long term potential environmental and socioeconomic impacts are considered to be related to the changes in hydrology resulting in a significant reduction in downstream flows. Impacts resulting from construction, for example of intake structures and pipelines, are considered as short term impacts that will be manageable with the adoption of recommended mitigation measures.

6.4.1 Protected Areas and Endangered Species

The Irati, Gikigie and Maragua Rivers combine and subsequently flow into Masinga Dam in the Tana River Catchment. Downstream of the proposed intake sites, and upstream of Masinga Reservoir, there are currently no protected areas associated with the rivers from which abstraction is planned. The nearest protected area, Mwea National Reserve, is fed by rivers from Mt. Kenya. No direct impacts on protected areas are expected.

Hinde's Babbler, *Turdoides hindei*, is a threatened Kenyan endemic bird species, classified as vulnerable, occurring around some of the upper Tana tributaries. The decline of this species has been attributed largely to the clearance of scrub, on which it depends for breeding, feeding and cover. Recorded locations include the Mukuruweini valleys Important Bird Area (IBA). This lies within catchments of the Thiha and Sagana Rivers shortly to the North of the North Mathioya River.

Surveys reported by Shaw et. al (2003)[5] do not record *Turdoides hindei* as present along the rivers downstream of the planned intake sites. Indications are of a continuing decline of this species, but if conservation efforts are successful, the species may spread to areas along the North Mathioya River and ultimately to other rivers flowing from the Aberdares, in which case it may be necessary to review environmental flow releases.

The Aberdares themselves are also considered as an Important Bird Area. However, this IBA is upstream and provides almost all of the catchment area. Preservation of the Aberdare Forest is considered to be of critical importance for maintenance of water supplies for Nairobi. There are currently no IBAs recorded within the area affected by reduced downstream flows.

An amphibian, *Phrynobatrachus irangi*, a species of frog threatened by habitat loss, was recorded at Kimande, near the Aberdare forest boundary[6]. The IUCN Red List records this population as possibly extinct because of severe modification of the native habitat by subsistence farming. The species has not been recorded in areas affected by reduced

[5] Shaw,, P. Musina, J. & Gichuki, P. (2003). Estimating change in the geographical range and population size of Hinde's Babbler Turdoides hindei. Bird Conservation International. 13: 1–12.

[6] Drewes, R. C., & Perret J. L. (2000). A new species of giant, montane *Phrynobatrachus* (Anura: Ranidae) from the central mountains of Kenya. Proceedings of the California Academy of Sciences, 52, 55-64.

downstream flows, and none of the proposed Intake Weirs on Irati, Gikigie and Maragua Rivers are expected to have an impact on this species.

The Maragua, Gikigie and Irati Rivers each provide riparian vegetation along their length. Over this stretch of river no specific important ecosystems are identified with the exception of the riparian vegetation that provides an important natural corridor. Reduced flows will have an overall negative impact on the riparian vegetation cover, with expected long-term effects as indicated below:

A healthy riparian vegetation cover provides a number of important functions:	A degraded or reduced riparian cover:
• Supports a diversity of aquatic habitats, as well as habitats adjacent to the rivers. • Stabilises the stream banks. • Filters sediments and nutrients, which reduces pollution of the river. • Is a high productivity zone that provides food for aquatic species. • Allows selective timber harvesting, forage production and apiculture. • Shades the river, which reduces fluctuations in water temperature. • Helps to maintain the water table.	• Has fewer aquatic habitats because there is less live and dead vegetation. • Reduces the stability of the stream banks because there are fewer roots and less vegetation to hold the soil together. • Allows sediments and pollutants to enter the river more easily. • Deposits less organic matter in the stream, which means there is less food for aquatic species. • Allows more light to reach the river, increasing water temperature, promoting algal growth and reducing water quality. • Can alter the depth of the water table.

The long-term changes to riparian vegetation, combined with expected increases in clearance for agricultural activities, are expected to have a negative impact on the species diversity and populations of many birds, small mammal and other wildlife species using these resources. As a result, population numbers of some bird species are expected to decline downstream of the intake structures. Impacts are expected to reduce in intensity further downstream as other tributaries merge with the main rivers and the effective catchment area increases, providing some seasonal hydrological changes.

6.4.2 Impacts from Construction

Potential negative impacts that can be expected from construction of the proposed weirs at Irati, Gikigie and Maragua, together with the construction of the Northern Collector Tunnel (Phase 1) and access shafts, and the construction of the tunnel outfall include:

- Loss of land and requirements for land acquisition.
- Soil erosion resulting from site preparation and construction activities, including from the construction of weirs, tunnels and pipelines.
- Change in local topography during site preparation/grading.
- Pollution from machinery and construction activities.
- Construction of access roads, temporary settlement and workmen’s camps, and permanent offices and settlement required to maintain and run each of the weirs.

- Disposal of rock and other material excavated from the Northern Collector Tunnel and access shafts.
- Pollution from machinery and construction activities, including accidental spillage.
- Possible impacts on hydrogeology as a result of tunnelling.

Impacts from construction activities were also considered by the Howard Humphries (1998) report and those impacts remain relevant.

Due diligence and monitoring during construction activities can be expected to mitigate the majority of potential negative impacts due to construction and operational activities. Loss of land would need to be covered by compensation. This compensation will need to factor in the potential long-term loss of household income resulting from the loss of any land currently used for tea plantation.

Improvements made to existing access roads may provide benefits. Potential positive impacts include improved access enabling farm produce to gain better access to markets. Positive impacts also include local employment opportunities and the creation of a local market, although small, for materials and consumables that can be sourced locally. The overall impacts from construction are considered to be manageable assuming that appropriate mitigation measures are adopted.

Detailed designs for the proposed weirs, intake structures and associated tunnels and pipelines are not available at this stage, but preliminary assessments and scoping of likely impacts from construction are indicated by **Figure 8-27** on **page 8-80**. Similar levels of impact will be experienced by the development of each of the weirs and associated intake structures and connecting tunnels.

Construction of tunnels and associated outlets is an essential project component. Possible impacts resulting from the construction of tunnels include the creation of underground fractures with impacts on hydrogeology leading to alteration of underground drainage. In addition, the steep terrain increases the likelihood of local earth movements and landslides. Any construction activities, including tunnelling may increase the chance of landslides.

In addition, a technical committee should be established to assess potential impacts before and during construction activities, as well as to evaluate damage caused and assess required compensation. The technical committee should include environmental assessment experts and should be an integral component of the construction process.

a) Maragua Intake

Preliminary designs of intake weirs were presented in the Howard Humphries (1998) report. These designs included geographic co-ordinates enabling the proposed locations to be identified. The general arrangement of the Maragua Intake Weir was examined and compared with the current situation at that site. The proposed weir is 18.5m wide and the crest is at 2077.75m, 4.75m above the river bed level and will be constructed a short distance above the existing road bridge. Construction of the weir will require significant permanent clearance of riparian vegetation at this site. In addition, there will be permanent loss of smallholder tea, with resulting long-term impacts on household incomes for the current users of this land. There is no readily available area for a spoil dump.

It is considered essential that the design of the proposed weir should be modified to incorporate a calibrated triangular, or V-notch weir together with mechanisms for abstraction of different flows will provide for variable yields and at the same time will enable

variable downstream Reserve Flows that preserve the integrity of downstream environments.

Figure 8-27: Proposed site for the Maragua Intake Weir

b) Gikigie Intake

The layout of the Gikigie intake weir is similar to that at Maragua. The site is shortly above an existing road bridge, which has recently been constructed (June 2011). The proposed weir is 10m wide and the crest is at 2079.9m, 3m above the river bed level (Howard Humphries, 1998). It is expected that construction of the weir, adit, portal entrance and associated structures will result in the permanent clearance of significant areas of riparian vegetation as well as clearance of some parts of adjacent smallholder tea plantation.

As with Maragua, no area for a spoil dump has been identified.

It is also considered essential that the design of the proposed weir should be modified to incorporate a calibrated triangular, or V-notch weir in order to enable variable downstream Reserve Flows.

Figure 8-28: Proposed site for the Gikigie Intake Weir

Just below the proposed site for Gikigie intake weir the river is joined by a tributary (**Figure 8-29** on **page 8-82**). The flow from this tributary will contribute towards environmental flows downstream of the intake and abstraction. Whilst this tributary covers a smaller catchment than that controlled by the proposed weir, the flows in this tributary are currently unavailable.

Relocation of the proposed Gikigie weir to below the junction of these two streams (by approximately 150 metres) would slightly increase the flow available for Nairobi water supply. However, this option would have negative impacts on downstream environmental flows and compensation flows. Flows from this smaller tributary will contribute towards improved downstream environmental flows. Specifically these flows will be enhanced by an increased variability of downstream flows, including occasional high flow pulses.

The preliminary designs for the Gikigie Intake weir given in the Howard Humphries (1998) report indicate fish ponds adjacent to the site of the proposed weir. These ponds will need to be rehabilitated and or reconstructed following the completion of construction and tunnel excavation activities at Gikigie. At the same time there is also the opportunity to expand the

ponds and/or increase their number, and this can be seen as part of the compensation available for the local community.

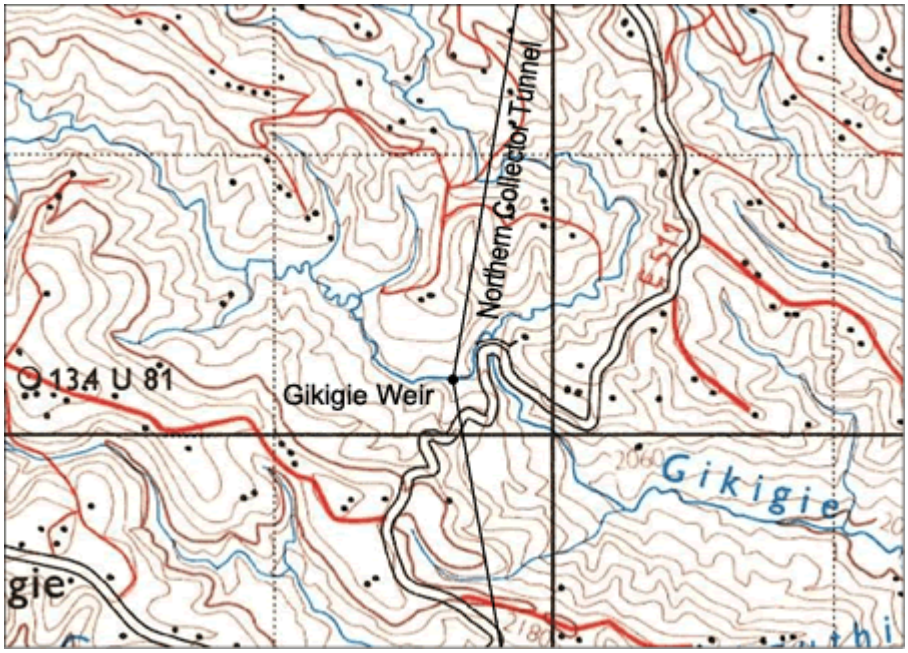


Figure 8-29: Location of the Proposed Gikigie Weir

c) Irati Intake

Problems were identified with the location of the proposed Irati weir, intake and shaft. The position indicated by the geographic co-ordinates presented on the preliminary designs in the Howard Humphries (1998) report, when overlaid on the 1:50,000 scale map, show that the two tributaries join at the same spot where the plan indicates the main weir is (**Figure 8-30** on **page 8-83** site A). Combined flow from these two tributaries has been used in the modelling of available water sources on the Irati for diversion to the Nairobi water supply. There is no indication of any tributary in the preliminary design drawing. The Howard Humphries report states that "The river weir is 14.5m wide and the crest is at 2008.9m, 900mm above the river bed level." Locating the weir on the 50,000 map using the co-ordinates given on the preliminary design, the elevation at the identified site of the weir is between the 2,100 and 2,120 metre contours. Furthermore, whilst the main text in the Howard Humphries report states 2,008.9 metres, the preliminary design drawing indicates 2,108.9 metres (2008.9 is now assumed to be a typing error).

The preliminary design drawing, however, clearly indicates a small island at the site of the weir. About 500 metres downstream of the road crossing there is a small island of the same shape. The elevation at the site of this small island is 2,107 metres (using Aster digital elevation data). This site is below the junction of the two tributaries (**Figure 8-30** on page 8-83 site B) and may have been the intended site for the Irati Weir. However, this is about 500 metres downstream of road crossing and a more likely site for the Irati weir is now considered to be closer to the road crossing (**Figure 8-30** on page 8-83 site D).

Assuming the modified location for Irati Weir, there will be no requirement to relocate, or modify the road crossing the Irati River in order to accommodate the weir and associated structures.

Construction of the weir will require permanent clearance of riparian vegetation at the site. However, it is likely that there will be no requirement for clearance of permanent crops

such as tea, as long as the required facilities adjacent to the Irati intake weir can be located appropriately so as to avoid areas covered by tea plantation. Crops grown at or immediately adjacent to the site of the weir are annual crops such as maize, brassicas and other crops used for household consumption, whilst the land is also used for grazing livestock. Compensation for the loss of the productive agricultural land will be required for the households using these areas.

As with the Maragua and Gikigie intakes, no area for a spoil dump for material excavated during construction of the Northern Collector tunnel has been identified. It is also considered essential that the design of the proposed weir should be modified to incorporate a calibrated triangular, or V-notch weir.

An important consideration is that the smaller of the two tributaries that form the Irati at this point also serves as one of the sources of the Kigumo Rural Water Supply Scheme (Figure 8-30 site C). Consideration should be given to the rehabilitation and rebuilding of the Kigumo water supply intake so that this important rural water supply is incorporated with the overall plans for Irati Weir and Intake.

Figure 8-30: Location of proposed Irati Weir and Intake Shaft: A. Site identified by co-ordinates given in Howard Humphries (1998) report, B. Site of island in river (red circle); C. Intake for Kigumo Rural Water Supply Scheme (white circle); and D. Proposed site for the Irati Weir.

d) Outlet Works

The purpose of the tunnel outfall works above Thika Reservoir is to release the water from the Northern Collector tunnel safely without erosion of the river banks. The river bed level is 5 metres below the intended outfall. The outfall structure will be founded on rock so as to minimise potential erosion. It will be necessary to construct an access track from the main road to the outlet site.

The site of the proposed outlet works is largely covered by trees, with some relatively open grassland adjacent to this area. This is surrounded on all sides by tea plantation (**Figure 8-31** below). Clearance of the natural riparian vegetation will be required. Clearance of areas cultivated with tea will be necessary for parts of the tunnel outlet structures, and also for construction of the access road and any associated buildings required for administration and running of the site, with impacts on household incomes.

Increased flows along this short stretch of the river between the outlet works and Thika reservoir are likely to result in increased erosion of river banks, especially in areas where riparian vegetation cover is cleared as part of the construction process. Measures to control river bank erosion should be installed at these sites.

Figure 8-31: Proposed Site for Outlet Works above Thika Reservoir, Showing Riparian Vegetation and Surrounding Tea Plantation

Consideration should be given to the installation of a mini-hydro power facility at the outlet works. This can provide power to local communities, and will also go some way towards offsetting the potential reduction in hydropower production at Masinga caused by the decreased flow into Masinga Reservoir as a result of the abstraction for the Northern Collector.

e) Excavated Material from the Northern Collector Tunnel

Construction activities will result in significant volumes of spoil derived from the rock excavated from the tunnels. No areas for spoil dumps have been identified. However, all the indications are that there are no suitable sites in the vicinity of the Northern Collector tunnel and intake sites. Disposal of the material excavated from the tunnel in dumps in this area will have inevitable negative environmental and social impacts. Resultant spoil dumps will remain bare for some years, will cause problems of erosion, and are likely to become colonized by invasive species.

It is recommended that no permanent spoil dumps are used. It is strongly suggested that instead of considering the excavated material as spoil, requiring disposal, it should be used as raw material for a range of activities such as road repair and construction, and for use as building material, including the making of bricks for buildings.

The most critical area for disposal of excavated material is likely to be near to the Gikigie intake structure, with up to 135,000 m^3 of spoil (assuming a 1.8 bulking factor). For Gikigie this may require as many as 11,200 lorry loads to remove the spoil (assuming 10 m^3/truck or about 20 tonnes per truck load). Over a 12 month construction period, this would be up to about 40 trucks per day or as many as 80 per day if trucks with a 10 tonne capacity are used. The Kaanja access adit, if constructed, would also require a large storage area (81,000 m^3 assuming 1.8 bulking factor) if stored on-site. At the Maragua intake, the storage volume required would be 54,000 m^3 (with 1.8 bulking factor). At the Makomboki outfall, a significant quantity of material will also be extracted. The presence of tea plantations at the Makomboki outfall will require careful design of an access track for removal of all of this material for disposal elsewhere. Similarly, the steep slopes of the terrain and the tea plantations adjacent to all of the other sites also indicate that there should be no on-site or local storage of excavated material.

It is recommended that on-site storage of excavated material should be minimized and that only temporary storage sites should be constructed near each of the access sites. It is also recommended that the spoil is transported away from the sites at a rate similar to the rate of extraction. The emphasis should be for the material to be transported for either temporary or permanent storage at suitable sites elsewhere.

On-site storage of excavated material will require the construction of fully bunded structures to contain all of the spoil so as to prevent erosion and siltation in the rivers, constructed at least 40 m buffer zone between the bunded storage area and the edge of the river. Excessive sedimentation of the rivers can cause flooding, require expensive clearing or channel maintenance, or reduce the capacity of downstream water storage units. It may also damage valuable riparian vegetation and degrade downstream agricultural areas situated alongside or close to the rivers or in floodplains.

If temporary and/or permanent storage areas are required for disposal of the excavated material, the use of abandoned quarries should be considered. Plans will need to be drawn up for disposal, as part of quarry rehabilitation measures, of that portion of the spoil which cannot be reused. As indicated above, transport of the spoil to selected abandoned quarry sites will require a significant number of lorry loads on a daily basis. It is therefore likely that the rural roads that provide access to these sites will require to be upgraded and/or regularly maintained in order to provide access for these transport vehicles as well as for all of the normal traffic on these access roads. In particular, the regular access by transport related to tea harvesting is considered to be of critical importance.

As indicated above, the preferred outcome for the management of all spoil generated by excavation of the Northern Collector tunnel is the reuse of all spoil material that is generated, for example for engineering purposes, for use as building material, or for road repair, construction and maintenance.

6.4.3 Pipelines and Water Treatment Plant

a) Transmission and Distribution Pipelines

The proposed Raw Water Gravity Main from Thika Dam to the Ngorongo Treatment Works site will be a 1300 mm dia. Ferrous Pipe, capacity 1.6 m^3/s (140,000 m^3/d), length 40 km. If both Northern Collector Phase 1 and 2 yields are to be transmitted, proposed pipeline will be 1800 mm dia., or alternatively the Phase 1 main will be augmented by another 1400 mm dia. pipeline.

The Raw Water Pipeline will be connected to the existing high level off-take at Thika Dam at an elevation of 1985 m. From Thika Dam the pipeline will traverse along Thika River for approximately 3 km to enable gravity transmission, at which point it changes direction towards Ngorongo Treatment Works site. The pipeline then traverses through tea and coffee farms across steep river valleys, crossing the Kiama, Kimakia Rivers and Chania River near the existing Mataara Chamber. The pipeline crosses the Mwagu-Mataara Tunnel. It then crosses Karimenu, Ndaragu, Thiririka, Komothai, Gatamayu and Ruiru Rivers. After crossing the Ruiru River, the pipeline follows the wayleave for the Existing pipelines from Sasumua and Ruiru Dams. At Ngorongo the Raw Water Pipeline changes direction to the proposed Ngorongo Treatment Works located at an elevation of 1924 m.

It is estimated that there are approximately 55 drainage lines crossed by the proposed pipeline route between Thika Dam and the Ngorongo Treatment Plant. Between the treatment plant and Kabete Reservoir there are a total of 12 drainage lines. Apart from the main rivers discussed above, most of these drainage lines are small and may only have running water for short periods during the year. Steel aerial bridges on reinforced concrete columns are not expected to be used when crossing these minor drainage lines.

The Proposed Treated Water Main, dia 1400 mm, length 20 km, transfers water from Ngorongo Treatment Works to the existing Kabete Reservoir in Nairobi for onward distribution within Nairobi. The proposed Treated Water Main traverses highly developed areas especially near Nairobi before the reaching Kabete Reservoir (Loresho and Karuri areas).

The Proposed Treated Water Main shall be laid adjacent to the Water Mains from Sasumua and Ruiru in most places. However it has been noted that permanent buildings have been constructed on the existing Pipeline Wayleave. Unless these buildings are demolished and additional wayleave for the new Pipeline acquired, the route may have to be shifted along existing road wayleaves and other undeveloped areas.

The Proposed Main will be provided with Air Valves and Washouts at appropriate locations. The appurtenances will be installed in Reinforced Concrete Manholes with lockable covers to prevent vandalism. The water from the washouts will be directed through the natural drainage into nearby water courses to prevent damage due to erosion. Sectional Valves to isolate pipeline sections for maintenance purposes will be provided at approximately every 3 km.

Where the Pipeline crosses rivers, steel aerial bridges on reinforced concrete columns will be provided. Wherever possible, the bridges will also be used as pedestrian crossings for the local population.

b) Potential Impacts from Transmission and Distribution Pipelines

The installation of transmission and distribution pipelines will result in potential disturbance to natural habitats, as well as to agricultural land and to communities. Habitat restoration and maintenance will be required after pipeline construction is completed. Most of the pipelines will be in agricultural or settled areas that are already significantly environmentally altered and land will need to be acquired for the wayleave. Positive impacts from pipeline construction include the creation of job opportunities, as well as the potential for improved habitats for local wildlife species and natural vegetation along the wayleave if this strip of land is managed appropriately.

Construction of pipelines can be expected to include the following negative impacts:

- Impacts on local flora and fauna as a result of clearing vegetation along the pipeline. This impact can be expected to be short-term if all mitigation measures are carried out. Impacts will be long-term if habitat restoration is not carried out.
- Land acquisition for pipeline wayleave, loss of productive agricultural land and/or building land, together with associated needs for resettlement and compensation requirements.
- A significant part of the area traversed by the pipeline is predominantly agricultural. Impacts on agricultural areas, and on agricultural production will include the following:
    - Impacts resulting from the clearing of land along the pipeline route. This will result in loss of agricultural production. The severity of these impacts will depend on the specific crops. Permanent long-term crops such as tea and coffee will suffer long-term loss of production and require replanting and suitable habitat restoration. Compensation will need to take into account the number of years required for the crop to reach maturity and start production after replanting. Annual crops, for example such as maize, can be expected to be in production during the following year if suitable habitat restoration measures are carried out.
    - In some cases this is also likely to result in difficulties in access to affected fields or parts of fields during the preparation of the pipeline route and during the actual laying of the pipeline.
    - Impacts will also include the removal of borders or hedges to fields. Depending on the nature of the agricultural activity, temporary barriers may be required, for example fields with livestock. Some of the field borders are also likely to include trees that are of value to the community.
- Increased erosion as a result of excavation for the pipeline, including potential water quality impacts, especially where the pipeline route crosses streams or other drainage lines.
- Soil erosion and potential pollution of rivers or streams crossed by the pipeline.
- Changes to the natural drainage where the pipeline crosses small streams and other drainage lines, in those cases where the pipeline is buried underground and may therefore block or impede the drainage. In these cases there may be localised impoundment or creation of wet/muddy condition upstream of the pipeline crossing point. At crossing points on the main rivers, steel aerial bridges on reinforced concrete columns will be provided and changes to the drainage is considered unlikely in these cases.
- Impacts on roads where transmission pipelines cross roads.
- Noise generation and vibration resulting from use of heavy machinery during construction.
- Temporary construction camps, including generation waste that will require disposal.
- Disposal of solid waste material from excavation and earthworks.

Mitigation Measures include:

- A technical committee, including environmental assessment personnel, should be established to assess the damage caused and assess required compensation.
- Incorporation of measures in the design and routing of pipelines that require less vegetation clearance.
- Compensatory plantation of trees and other vegetation should be carried out at the rate of a minimum of five trees planted for every tree cut. All trees should be indigenous species.
- Prepare and implement an erosion control plan.
- The exact pipeline route will need to be delineated well in advance of any construction activities together with preparation of a detailed list of affected households and other buildings, numbers of people impacted, and property owners, as well land use and specific habitats traversed by the pipeline route.
- A Resettlement Action Plan should be prepared. Involuntary displacement should be avoided.
- Loss of crops, as well as trees and other natural resources should be compensated. Compensation for loss of crops should take account of the time taken to restore production of the replacement or restored crop. For example, tea and coffee will take longer to restore production than annual crops such as maize or vegetables.
- Compensation for affected land and property assets lost should be provided. Full cost of compensation, relocation or resettlement should be provided. Compensation will need to be provided in lieu of loss of earnings.
- Provision of new or modified infrastructure to compensate for loss or impacts to existing facilities (including roads, schools, health facilities, market areas etc.).
- Traditional rights should be protected.
- Measures should be taken to ensure that, where possible, employment opportunities are given to people from local communities.

Table 8-21: Impacts Related to Pipeline Construction and Operation

Issues	Nature of Impacts	Mitigation Measures
Land clearance	Impacts on local flora and fauna as a result of clearing vegetation along the pipeline. Short-term if all mitigation measures are carried out. Impacts will be long-term if habitat restoration is not carried out. It is recommended that where trees are cut down, at least five new trees are replanted as part of the habitat restoration measures.	• Baseline surveys • Habitat restoration • Monitoring
Loss of land	Land acquisition for pipeline wayleave, loss of productive agricultural land and/or building land, together with associated needs for resettlement and compensation requirements.	• Resettlement Action Plan • Compensation for loss of land and for loss of household income

Issues	Nature of Impacts	Mitigation Measures
Loss of Agricultural Production	Clearing of land along the pipeline route will result in loss of agricultural production. Compensation will need to take into account the number of years required for the crop to reach maturity and start production after replanting. For example, Coffee may reach full maturity at the age of seven or eight years but produce some crop after four or five years. With Tea it may be three years before a new plant is ready for harvesting.	• Habitat restoration • Compensation to enable restoration or replanting • Compensation for loss of earnings
Soil erosion	Increased erosion as a result of excavation for the pipeline, as well as potential water quality impacts, especially where the pipeline route crosses streams or other drainage lines.	• Erosion control plan • Due diligence during construction
Modified Drainage	Changes to the natural drainage where the pipeline crosses small streams and other drainage lines, and where steel aerial bridges on reinforced concrete columns are not provided.	• Laying of the pipeline will need to be planned to ensure that local drainage is not modified
Workmen's camps and Settlements	Noise generation and vibration resulting from use of heavy machinery during construction.	• Careful planning and location of campsites • Provision of adequate sewage and waste disposal facilities • Provision of adequate services • Provide local employment
	Temporary construction camps, including generation waste that will require disposal.	
	Disposal of solid waste material from excavation and earthworks.	
Access roads	Impacts on roads where transmission pipelines cross roads.	• Include in detailed design
Access for maintenance	Long-term access to the pipelines will be required for routine checking and maintenance. Assuming that most of the pipeline length is buried with limited surface structures, the overall impacts will be relatively low.	• Careful location of pipelines
Leakage	Leaks are likely to occur along tunnels, along transmission and distribution pipelines, and at treatment works. Leakage may result in health risks, e.g. Malaria, Cholera and other water related diseases.	• Regular monitoring and maintenance • Early leak detection reduces possible public health risks
Local water supplies	Consideration should be given to ensure that all communities traversed by the pipelines, including rural areas, are provided with piped water supplies, as a priority.	• Provide adequate local, rural and urban water supplies along pipeline routes

c) Ngorongo Water Treatment Plant

The proposed Ngorongo Treatment Works is located 11 km North West of Kiambu Town. The site is presently part of a coffee estate owned by Gatatha Farmers Cooperative Society. Access to the site is via a 2 km all-weather gravel road. Under the Project, it is proposed to upgrade this to bitumen standard. The Ngorongo Treatment Works Site, including the Staff Housing and School, will occupy a total area of approximately 38.9 ha.

Proposed Treatment Process

The Ngorongo Treatment Works is a Full Conventional Water Treatment Works with a design capacity of 145,000 m^3/d in the first Phase to be implemented between 2012-2017.

In the second phase planned for implementation beginning 2018, the capacity of the Treatment Works will be augmented to a total of 290,000 m^3/d. The proposed treatment process is as follows:

i. Aeration of Raw Water by means of a Multiple Platform Aerator
ii. Dosing of Raw Water with the following chemicals to assist in coagulation, floc formation and trapping of suspended impurities.
    a. Aluminium Sulphate (Alum) to be used as the main coagulant.
    b. Soda Ash (Sodium Carbonate) to be used to adjust the raw water pH when there is insufficient alkalinity in the raw water for optimum coagulation using alum.
    c. Polyelectrolyte to be used as a coagulant aid when necessary, especially in periods of high turbidity of the raw water.
iii. Flocculation and Settlement in Clarifiers: circular type clarifiers incorporating mechanical flocculators and mechanical sludge removal equipment
iv. Filtration in Rapid Gravity Sand Filters
v. Disinfection: Chlorine Gas will be used as the primary disinfectant. A stand-by system of disinfection using chlorine in Hypochlorite solution will be provided to cater for periods when Chlorine Gas may be unavailable. Chlorine is also an oxidizer, so it helps to remove iron, hydrogen sulfide, and other minerals.
vi. Dosing with Soda Ash (Sodium Carbonate) to adjust the pH of the treated water, if necessary.

Treatment Works

The Ngorongo Treatment Works will comprise of the following components:

i. Raw Water Inlet works incorporating a Multiple Platform Aerator and a Flash Mixer with an electric motor-driven propeller mixer for rapid mixing of chemicals.
ii. Clarifiers: 4 circular Clarifiers each of internal diameter 35 m, incorporating a central Flocculation Chamber with a Mechanical Flocculator and equipped with mechanical sludge removal equipment.
iii. Rapid Gravity Sand Filters: 10 Filters, each with a filter bed area of 11.8 m x 7.2 m (85 m^2), including Filter Gallery and Filter Control Room.
iv. Clear Water Tank: capacity 70,000 m^3, to provide storage capacity for approximately 12-hours production.
v. Chemical Storage Building for Alum, Soda Ash, Polyelectrolyte and Calcium Hypochlorite to provide 3 Months storage at the design throughput of 145,000 m^3/d. Floor area 900 m^2.
vi. Chemical Mixing & Dosing Building, floor area 530 m^2, with mixing tanks, dosing pumps and associated pipe work for Alum, Soda Ash, Polyelectrolyte and Calcium Hypochlorite.
vii. Gas Chlorination House, floor area 225 m^2, incorporating Chlorine Drum Store to provide 3 Months storage of Chlorine Gas at the design throughput of 145,000 m^3/d and Gas Chlorinators.
viii. Sludge Drying Beds: Four, with a total area of 2400 m^2.
ix. Backwash Water Lagoons: Two with total storage volume of 5,800 m^3, and Backwash Water Recirculation Pumps.
x. Workshop & Store: floor area 235 m^2.

xi. Administration Building & Laboratory: office floor area 700 m^2.

xii. Generator House and Main Switchboard (Distribution Panel) Room - floor area 52 m^2.

xiii. Staff Room for Treatment Works Operators & other Staff, incorporating Washrooms (W.Cs and Showers), Locker Room, Tea Room & Kitchen and Staff Room. Total floor area 235 m^2.

xiv. Site and Ancillary Works including Access Roads, Fencing, Foul Water Sewers and Septic Tank, etc.

Figure 8-32: Proposed Ngorongo Treatment Works Site

Staff Housing

Housing for staff will be provided adjacent to the treatment works. A total of 59 Houses of varying sizes will be provided for the various cadres of staff. Potable water supply will be provided to the houses from the treatment works. In addition, a guest house with 4 self-contained rooms will be provided. A Foul Sewer System and Septic Tank will be provided for collection of sewage from the staff houses. Other social amenities to be provided in the staff housing area include: A Club House for treatment works staff, and an Out-Patient Health Centre to serve the treatment works staff and their families as well as the community living near the treatment works, as well as a shop / essential provisions store for residential and other staff.

Primary School

A single-stream Primary School will be provided adjacent to the Treatment Works/Staff Housing area to serve the Treatment Works staff as well as the community living adjacent to the Works. The school will have 8 class rooms, each of floor area 60 m^2. At a population of 30 pupils per classroom, the capacity of the school will be 240 pupils. A Foul Sewer System and Septic Tank will be provided for collection of foul sewage from the school. Other facilities to be provided at the school include: an Administration Block (floor area 110

m^2), Library (floor area 83 m^2), Ablution Facilities, and a Hall (floor area 366 m^2). The Hall will also be available for use as a Social Hall for the Treatment Works Staff and neighbouring community. Sports Fields including football, netball and volleyball fields will be provided.

Wastes Generated by the Treatment Works

The various wastes generated by the Treatment Works will be dealt with as follows:

1. Sludge from the Clarifiers, which will be mainly silt/sediments with minor traces of chemicals dosed into raw water to assist in coagulation (Alum and Soda Ash) will be discharged into four Sludge Drying Beds (total area 2400 m^2) located within the Treatment Works site. The sludge will be left to dry before being removed and buried in Disposal Pits on the Treatment Works Site. The Treatment Works area has adequate space for disposal of sludge by burying. Alternatively, the sludge/silt can be sold to farmers in the area for use as soil conditioner/filling material. Testing for trace metals is to be undertaken regularly before sale of sludge.
2. Residual sludges from Alum and Soda Ash Mixing Tanks will be discharged to Soak Pits located within the treatment works site. The Soak Pits will be de-sludged periodically as required. The sludge removed will be dried and buried on site.
3. Disinfection of treated water is to be carried out using Chlorine Gas, which produces no residual sludge. However, a stand-by System of disinfection using Chlorine in Hypochlorite Solution form will be provided to cater for periods when Chlorine Gas may not be available. As with sludge from Alum and Soda Ash Mixing Tanks, sludge from Hypochlorite Mixing Tanks will be discharged to Soak Pits. After drying, the sludge will be buried in Disposal Pits located within the Treatment Works Site.
4. Washwater from the Filters will be collected in two Backwash Water Lagoons, with a total storage volume of 5,800 m^3. The wash water will be retained in the Lagoons for 24 hours to allow heavy solids to settle before being pumped back to the Inlet Works for re-circulation through the treatment system. Periodically, the Lagoons will be manually de-sludged and the sludge transported to the Sludge Drying Beds for drying and disposal.
5. The volume of chemical wastes expected from the Treatment Works Laboratory is minimal and will be disposed of safely in the Soak Pits provided for disposal of residual sludges from Alum / Soda Ash Mixing Tanks.
6. Any overflows occurring in the Treatment Works will be safely conveyed to the nearby Kiu River through an Overflow/Drainage Pipeline to avoid damage to neighbouring property.
7. A Foul Sewer System and Septic Tank will be provided for collection of foul sewerage from the Treatment Works buildings including Administration Building and Staff Room.

Figure 8-33: Ngorongo Treatment Works Site, Illustrating Coffee Plantation as the Current Land Use.

d) Expected Impacts from Construction of the Water Treatment Works

The expected impacts from construction of the Ngorongo Treatment Works include:

Issues	Nature of Impacts	Mitigation Measures
Land clearance	The removal of a substantial area, estimated at 38.9 ha, of Coffee Plantation which is currently part of a coffee estate owned by Gatatha Farmers Cooperative Society.	• Compensation for the loss of the area under coffee.
Livelihoods	Impacts on the livelihoods of the members of the Gatatha Farmers Cooperative Society as a result of the reduced area of Coffee.	• Provision of alternative livelihood options, including employment at the Treatment Works.
Flora and Fauna	Impacts on local flora and fauna as a result of clearing vegetation are expected to be minimal.	• Baseline survey • Tree planting as compensation for clearance of trees.
Workmen's camps and Settlements	Noise generation and vibration resulting from use of heavy machinery during construction. Temporary construction camps, including generation waste that will require disposal. Disposal of solid waste material from excavation and earthworks.	• Careful planning and location of campsites. • Provision of adequate sewage and waste disposal facilities. • Provision of adequate services. • Provide local employment.
Pollution	Construction activities will create air, dust and noise pollution. Contamination from wastes and oil/fuel spills may occur. Contamination from dust, and from oil/fuel spills, may spread to adjacent agricultural land, potentially reducing its value.	• Pollution control measures • Due diligence during construction

e) Expected Impacts from Operation of the Water Treatment Works

The potential negative impacts from operation of the Ngorongo Treatment Works include those related to the treatment of wastes from the water treatment process. The proposed treatment and disposal of wastes, as outlined above, are expected to result in little or no pollution in the surrounding area as the wastes will be disposed of on-site. Positive impacts can be expected from the disposal of some wastes that are suitable for use by farmers in the area for use as soil conditioner/filling material.

The proposed disposal of material on-site in Soak Pits provided for disposal of residual sludges from the treatment process is seen as positive from an environmental perspective. However, it will be necessary to ensure that the soak pits are maintained and that no material from these areas is allowed to contaminate adjacent areas – for example as a result of overflow. It will also be necessary to ensure that these residual sludges do not contain potentially harmful chemicals that may ultimately contaminate groundwater sources. Regular laboratory testing of residual sludges will therefore be required. Agricultural chemicals resulting from agricultural activities in catchment areas may also require additional or special treatment of water before distribution. Assuming that this precautionary laboratory testing is carried out, the waste sludge produced by the water treatment works can be considered to be not toxic, and as long as it is contained in the soak pits, it will not cause any environmental concern.

Storage of chemicals on-site can result in problems of pollution if these storage facilities are inadequate. It will therefore be important to ensure the safe storage and disposal of all chemicals used on the treatment site.

Positive impacts can be expected from the provision of social amenities in the area, including the proposed primary school. This will be available for children of staff of the treatment works as well as the local community. However, it may be necessary to increase the number of places available within the school depending on the actual demand for these facilities in the area.

6.4.4 Impacts from Operation of Intakes

Impacts from operation of weirs are listed in Table 8-23. Primary environmental impacts resulting from operation of the intake weirs and Northern Collector Tunnel are related to the significant change in downstream hydrology. These result from changes to water flow patterns, changes in quantity (in particular the loss of flood events), and also from a deterioration in downstream water quality. Changes in water quality are themselves a direct response to the changes in flow regime. In addition, the normal or base flows will, after installation of the intake weirs, change to the flows similar to those currently classified as “extreme low flows”.

The provision of adequate downstream environmental flows, as a component of Reserve Flows, is considered to be essential for all rivers, as described above under “Downstream Reserve Flows”. Similarly, provision of adequate compensation flows is viewed as being critically important.

An important consideration is the cumulative impact arising from the combined operation of all three weirs with release of downstream Reserve Flows. Cumulative impacts include the following factors (see section 4 on Cumulative Impacts):

- Short periods or single days with zero flow, preceded and/or followed by further periods with extreme low flow.

- Reduction in the flow reaching Masinga Reservoir (by an estimated 2.32% on an average annual basis, based on monthly flow data from 1995-1997).
- Less flow available for use in existing and future agricultural activities, especially for use during dry seasons, in order to provide food required by the increasing population of Nairobi.

The reduced flow reaching Masinga Reservoir can be expected to have an impact, although relatively minor, on the potential hydropower production capacity. However, the use of the water flowing in the Northern Collector Tunnel could possibly be used to power a mini-hydro plant.

Catchment protection is viewed as an important task during operation of the intake weirs. Careful planning and management of land use in the catchments will limit the inflow of sediments and excessive nutrients. In particular the following measures are considered to be important:

- Complete protection and careful management of the Aberdare Forest Reserves to ensure continued catchment protection. Any felling of trees within the forest reserves should be kept to a minimum and if carried out must be confined to small areas surrounded by intact forest.
- Provision of active support to the KTDA Farmer Field Schools initiative mentioned above will be a positive approach and one that is likely to result in improved water and land management within catchments, as well as improved social capital and sustainable farming practices.

Weirs will trap some sediment. Reduced downstream flows will also result in a reduced sediment transport. Sediment transport is an important function of river flows, and this serves to maintain aquatic habitats and downstream environments. Changes to sediment transport will have inevitable impacts on downstream systems. Sediment will also not be available for riparian vegetation, and for downstream agricultural systems, some of which may partly depend on some of the alluvium deposited by flood events. The design of the proposed weirs should allow for sediment release.

Mitigation is possible through the release of good quality Reserve Flows from all structures, including environmental flows and compensation flows. However, it is important that flows and downstream demands are comprehensively monitored and that when abstraction is not required, no water is diverted unnecessarily for Nairobi water supplies and it is allowed to flow downstream in the source rivers. Similarly, when monitoring indicates that downstream requirements may be in deficit, abstraction volumes will need to be adjusted accordingly.

The use of gravity fed pipelines for distribution of water from Thika Reservoir is important. This will reduce the overall requirements for pumping, and will have long-term environmental benefits as a result of reduced use of energy, as well as reduced operating costs. Similarly, priority should be given to the maximum use of gravity fed pipelines elsewhere in the distribution network.

6.4.5 Impacts and Mitigation Measures

Mitigation measures are aimed at eliminating, offsetting, or reducing adverse environmental impacts and may have a number of different actions or objectives, including:

- Avoidance: Avoiding activities that could result in adverse impacts; avoiding certain resources or areas considered to be environmentally or socially sensitive.

- Prevention: Measures aimed at preventing the occurrence of negative environmental impacts and/or preventing activities that are likely to have harmful environmental and social impacts.
- Preservation: Preventing any future actions that might adversely affect an environmental resource. This may for example be achieved by extending legal protection to selected resources.
- Minimisation: Limiting or reducing the degree, extent, magnitude or duration of adverse impacts. This can for example be achieved by scaling down, relocating, or redesigning individual elements.
- Restoration: Restoring affected resources to an earlier (and possibly more stable and productive) state, typically a 'pristine' condition.
- Compensation: Creation, enhancement, or protection of resources at an alternative suitable and acceptable location, or compensating for lost resources. The sustainability of compensation measures should be considered, e.g. the loss of future household income due to the loss of productive agricultural land may not be sustainable from a one-off compensation payment but could be offset by activities designed to provide long-term and improved sources of household income.

Table 8-22: Impacts Due to Construction of Weirs, Intake Structures and Tunnels

Issues	Nature of Impacts	Mitigation Measures
Loss of land	Land will be acquired to enable construction of and provision of adequate buffer zones round weirs, treatment works, pipeline wayleave, workmen's camps and working areas. Loss of smallholder tea plantation in particular will lead to long-term changes in household incomes.	• Compensation for loss of land • Compensation for loss of household income
Change in land use	Change in land use from one dominated by natural riparian vegetation with adjacent tea plantations, to a cleared area with weir, intake structures and associated infrastructure. Clearance of riparian vegetation will disrupt natural wildlife corridors.	• Minimize clearance of natural vegetation • Creation of wildlife corridors
Access roads	Access roads will be required to enable construction, as well as for subsequent system operation. Maragua and Gikigie can largely use existing access, but new access tracks will be required for Irati.	• Compensation for loss of land
Soil erosion and Siltation	Combined with the steep terrain, exposed earthworks required for site preparation and construction are likely to result in increased soil erosion. Siltation created during construction will pass downstream, with potential negative impacts on the environment and on water quality.	• Erosion control measures • Due diligence during construction
Pollution	Construction activities will create air, dust and noise pollution. Contamination from wastes and oil/fuel spills may occur. Contamination from dust, and from oil/fuel spills, may spread to adjacent agricultural land, e.g. tea, thereby significantly reducing its value.	• Pollution control measures • Due diligence during construction

Issues	Nature of Impacts	Mitigation Measures
Solid Waste Disposal	Construction activities will result in significant volumes of spoil at some locations, especially from tunnels. Disposal of spoil may have a negative impact unless carefully planned, or used for other activities such as road construction, or building materials. Instead of being classified as spoil it should be seen as a potentially useful raw material.	• Careful planning of spoil disposal • Use spoil for road repair & construction and as raw material for other construction
Workmen's Camps and Settlements	Camps required for construction workers may overburden local services. Problems may occur in relation to disposal of waste and sewage, and surface waters may be contaminated, with associated dangers to public health. Induced settlement is likely to occur as a result of construction. This may be beneficial to local communities, but will also stress local resources, including water supplies and household fuel. There may also be health risks and increased requirements for health services. The construction phase may also provide local employment opportunities, but these must be scheduled to avoid peak tea picking activities.	• Careful planning and location of campsites • Provision of adequate sewage and waste disposal facilities • Provision of adequate services • Provide local employment
Hydrogeology	Tunnelling may result in changes to underground drainage as a result of underground fractures.	• Detailed investigation during construction
All Issues	A technical committee should be established to assess potential impacts before and during construction activities, as well as to evaluate damage caused and assess required compensation. The technical committee should include environmental assessment experts.	

Table 8-23: Impacts due to Operation of Weirs

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Change in downstream flow in Irati, Gikigie and Maragua Rivers. Including Cumulative Impacts from the combined changes in downstream flow of all three rivers.	Change from a natural flow to a flow similar to a permanent low flow, extreme low flow or drought condition as a result of: a) diversion of water at weirs, and b) retention of this water in Thika Reservoir Loss of downstream water resources, and reduced ecosystem services in the impacted rivers. Reduced water quality as a result of downstream flows being similar to extreme low flows. Loss of vegetation and wildlife dependant on these water resources. Reduced potential for settlement and agricultural development downstream. Changes in the water table as a result of reduced flows in the rivers. Extreme Low flows can induce increased groundwater discharge into streams, resulting in reduced availability of groundwater.	• Long-term. Permanent. • High impact without adequate EFR • Low impact if good quality Reserve Flows are adopted and managed • Release Reserve Flow adequate to sustain all required downstream water resources • Establishment of a comprehensive monitoring programme and technical committee • Install mini-hydro power facility at tunnel outlet

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Reduced flows available for use by households	Reserve flows include Compensation flows and there will be a need for a complete inventory of required compensation flows, together with a need for ensuring that all households are included in rural water supply schemes.	• Inventory of all needs • Release of adequate compensation flows • Rural water supply schemes for all households
Periods with very low or zero flow	Some periods with zero flow and very low flow are predicted to occur further downstream. Reserve Flows released from upstream sources will need to be monitored and adjusted accordingly.	• Release Reserve Flow adequate to sustain all required downstream water resources
Change or loss of habitat downstream as a result of changed hydrological regime. Including cumulative downstream impacts.	Loss of riparian vegetation. • Reduced stability of stream banks due to fewer roots and less vegetation binding the soil. • Potential increase of pollutants entering the rivers.	• Long-term impact • High impact without EFR. Low impact if a good EFR is put in place
Effects of reducing the flow of nutrients downstream	Reduced nutrient availability in downstream areas may result in a reduction in productivity of downstream systems, including cultivation in alluvial areas downstream.	• Long-term. Permanent • Mitigation possible through EFR and sediment transport enabled by flood events
Trapping of sediments	Nutrients captured in Thika Reservoir, especially those that tend to bind with fine sediments, will no longer be available to downstream systems and may result in eutrophication in the reservoir.	• Incorporate sediment release capabilities in weirs. • Incorporate sediment release capability in Thika Reservoir.
Sedimentation at interface between inflowing stream and the reservoir	Unless sediments are filtered out before entering the Northern Collector tunnel, increased sediment deposits will form at reservoir entrance.	• Long term. Low impact. • No mitigation other than removal of accumulated sediments.
Change in aquatic environments and reduced potential for fish migration, and movement of other aquatic species	The potential for passage of fish upstream will need to be assessed at the detailed design stage of each structure, to ensure survival of fish species, including endemics and potentially threatened species.	• Designs for fish ladders need to be reviewed and fully incorporated in all proposed Intake weirs.
Power lines	The presence of power lines creates a potential hazard to larger bird species.	• Mitigation thorough appropriate design of power lines and transmission towers.

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Access roads	Improvements to existing access roads and development of new access tracks open up new areas to development and if carefully planned with inputs from local communities can provide local benefits. Material excavated from the tunnel can be used for road maintenance or rehabilitation.	• Low impact if mitigation measures are adopted. • Mitigation through careful routing of access roads.
Settlement resulting from project operation	In addition to operational staff, induced settlement is likely to occur in the surrounding area, creating potential stress on local resources and facilities, including fuelwood.	• Planning of settlements and provision of fuel resources.
Impact from presence of pipelines	Long-term access to the pipelines will be required for routine checking and maintenance. Assuming that most of the pipeline length is buried with limited surface structures, the overall impacts will be relatively low.	• Careful management and location of pipelines.
Leakage from pipelines and contamination of supply lines	Leaks are highly likely to occur along transmission and distribution pipelines, and possibly at treatment works. Contamination of supply pipes may also occur at these sites. Leakage may result in health risks, e.g. Malaria, Cholera and other water-related diseases.	• Regular monitoring and maintenance is essential. • Early detection of leaks reduces the possibility of public health risks.
Public health risks	Reduced water quality as a result of reduced flows will result in increased health risks for downstream communities or households dependant on untreated river water. An increase in faecal bacterial concentrations and waterborne pathogens as a result significantly reduced flows combined with inflow of contaminants from upstream is likely and needs to be monitored on a regular basis.	• A programme for regular monitoring of pathogens, and assessment of risks from waterborne diseases.
Inflow of effluents and pollutants from upstream sources	Inflow of dissolved effluents and pollutants will have an impact on water quality with potential impacts on human health. Inflow of solid wastes and pollutants are likely to have a negative impact on the natural environment.	• Regular water quality monitoring. • Active management and clearance of solid wastes may be necessary. • Sewage and effluent collection and treatment facilities for all settlement within catchment areas.
Effects from changes in groundwater levels	Changes in local groundwater regime are possible as a result of reduced downstream flows.	• Long-term. • Uncertain impact.
Impacts due to proposed treatment works	Use of hazardous chemicals, including chlorine. Agricultural chemicals resulting from agricultural activities in catchment areas may also require additional or special treatment of water before distribution.	• Proper procedures for use and disposal of chemicals. • Adequate Reserve Flows for dilution of wastes, and sludge from treatment. • Catchment management.

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Risks from Seismic Activity	The proposed Northern Collector Tunnel is in an area with recorded seismic activity. Data are recorded at the seismic station at Kilima Mbogo. Seismic activity could have an impact on tunnels, as well as the existing Thika Reservoir. Annual inspections of the Northern Collector tunnel should be conducted, and there should be a contingency plan to be followed in the case of earthquakes.	• Risks will need to be fully assessed as part of detailed design. • The tunnel should be issued with an annual compliance certificate that it is seismically sound.

6.4.6 Aquatic and Riparian Environments

a) Impacts on Aquatic and Riparian Species

Endemic and Introduced Fish Species

Weirs, dams and other structures along a river or stream will have inevitable impacts on fish species living in the rivers. In particular, obstacles to upstream movement or migration need to be avoided and, where present, fish ladders or other means of passage need to be provided. The passage of fish upstream through the diversion structures is considered in the Howard Humphries (1998) report, which states that "Inlet and outlet portal and shaft design will need to take into consideration free movement of fish species". The Howard Humphries report included considerations for the passage of migratory fish species on all weirs for the Northern Collector tunnel. For example, the intake for the Irati River indicated that the river diversion weir and compensation flow conduit will provide passage to fish at all states of river flow. On the Gikigie River the proposed design for the compensation flow conduit provided a potential passage for migratory fish under normal flow conditions. A short cascade would enable fish to enter the flume built into the conduit and from there swim through a short length of 250 mm diameter pipe. When the river is in flood, the 600 mm diameter overspill weir discharge pipe would also be passable.

However, the Howard Humphries (1998) report only appears to consider trout when considering environmental impacts on fish species. The trout, although present in some of the rivers flowing from the Aberdares, is an introduced species (and can be reintroduced as and when considered necessary). Of much greater concern are the indigenous species of fish, including small *Barbus* that may be present in the upper reaches of these rivers and streams. For example, *Barbus thikensis* is present in the Chania River, the original type locality is the Thika River, and is recorded in fast flowing water typical of the upper reaches of the rivers under consideration as sources for the Nairobi water supply. A wide range of other fish species have also been recorded, including *Alestes*, *Barbus*, *Clarias*, *Labeo*, *Sarotherodon* (Tilapia), and others, some of which are endemic to the catchments. Two *Labeo* species found in the Tana, namely *Labeo cylindricus* and *L. gregorii* both migrate into upstream tributaries at the time of the first floods. Reduction in flows and the resulting hydrological alteration will have inevitable long-term negative impacts on such species.

It is considered important that designs for fish ladders are reviewed, are updated, and are fully incorporated in the final designs for all proposed weirs, and that these are combined with the release of downstream Reserve Flows. Designs must be suitable for the passage of local endemic fish species. The potential for passage of fish upstream through the

planned diversion structures will need to be assessed in detail at the detailed design stage of each diversion structure in order to ensure survival of the local fish species, including endemics and potentially threatened species.

It is recommended that the designs for fish ladders are based on a combination of “pool passes” and “nature-like bypass channels”.

The principle behind “pool passes” is the division of the height to be passed into several small drops by forming a series of pools. The passage of water from one pool to another is either by surface overflow, through one or more submerged orifices situated in the dividing wall separating the pools, or through one or more notches or slots. The “nature-like bypass channel”, being similar to a natural stream, is a waterway designed for fish passage around the obstruction. The function of a “nature-like bypass channel” is restorative in that it replaces a portion of the flowing water habitat which has been lost due to impoundment by the intake weir. Both of these channels are characterised by a low gradient along their full length.

It is recommended that the downstream entrance to the artificial channel, either “pool passes” or “nature-like bypass channels”, be located as close to the obstruction as possible. Given the low gradient required along their length, for reasons of limited space it is sometimes difficult to position the entrance immediately below the obstruction, which means it may need to be placed further downstream. This may restrict the efficiency of these passes so it is strongly recommended that the entrances should be placed as close to the bottom of the weir as possible.

Invertebrates

Invertebrates play a major part in river functioning, whilst their forms, ecological and habitat requirements are diverse. They are responsible for retaining and breaking down organic material, recycling minerals and nutrients, and contributing to energy processing in the river at different trophic levels. Most benthic invertebrates are detritivores, although some are herbivores and some are carnivores. Other possibly lesser effects include the transport of organic material into and out of the river and structural activities such as case building and gluing or enmeshing particles of silt and sand. Burrowing invertebrates, such as worms, are also important in aerating sediments and releasing nutrients.

Changes to flow regimes can have significant impacts on invertebrate communities, and may result in long-term changes to ecological processes. Adequate provision of environmental flows, including periods of low flow, freshets and high flows, will be important in helping to maintain invertebrate communities.

Vegetation is a dominant part of most riverine ecosystems, where it fulfils a number of critical functions. This is the case along all of the riverine environments downstream of the proposed intakes and reservoirs. Aquatic and riparian vegetation stabilise river channels, river banks and floodplains; contribute towards the attenuation of floods (recharging local groundwater resources); influence water temperature and quality; and provide habitat, refuge and migration corridors for terrestrial and aquatic fauna. The structure, composition and overall condition of the vegetation determine the degree to which it is involved in ecosystem functioning. The vegetation also provides many resources used by man, including food, and has an aesthetic component that is also valued by man. Aquatic and riparian vegetation is adapted to the full range of flows experienced by the relevant stretch of river. Modification of the flows, for example changing from natural flows to a flow regime that is equivalent to a permanent low flow, “flatlining”, drought flow or extreme low flow, can

be expected to have long term negative consequences, especially for riparian vegetation and communities that are adapted to a range of different flow regimes.

The potential impacts on the different components of aquatic and riparian ecological communities emphasize the importance of maintaining adequate downstream Reserve Flows, including the full range of periods of extreme low flows, low flows, high flow pulses, and periods with high flows.

b) Impacts on Diseases

Permanent low, or extreme low flows, are known to have an impact by increasing the populations of a number of disease vectors. This includes the invertebrate hosts of Malaria, Schistosomiasis (Bilharzia) and Fascioliasis (liver fluke disease) as well as faecal bacterial contamination and associated waterborne pathogens. An increase in diarrheal diseases is a likely outcome the reduced water quality resulting from the extreme low flows in rivers downstream of the abstraction.

Diarrhoea is the third most common cause of mortality and morbidity in the country[7], and Kenya is committed to addressing diarrheal disease through a comprehensive approach. The maintenance of adequate downstream Reserve Flows and a flow regime that reduces the impacts of increased faecal bacterial concentrations and waterborne pathogens should be considered as an integral component of this approach.

For malaria mosquitoes, flow rate is important. An increase in the frequency of Low Flows will tend to increase vector populations in downstream environments. Mosquito larvae have no way of combating stronger currents and therefore are swept out of riverside pools and shallow areas by short periods of higher flows and short high flow pulses.

Retreating flood waters may however create new pools and breeding opportunities for mosquitoes, and the short duration of the larval stage means that short pulses of higher flows generally need to be repeated within 10 days. Regular flushing, for example at weekly intervals from intake weirs, will result in significant reductions in populations of the mosquito vectors in downstream areas and in reduced potential for malaria transmission.

In Kenya, both human urinary Schistosomiasis caused by *Schistosoma haematobium*, and ruminant Schistosomiasis caused primarily by *S. bovis* are common. These two species are closely related and are often sympatric, because both species depend on particular species of freshwater snails as intermediate hosts. Both species are transmitted in Kenya by members of the *Bulinus africanus* group and a number of other *Bulinus* species. The bodies of water that potentially harbour *Bulinus* and their associated Schistosomes are often man-made impoundments, slow flowing rivers, or small seasonal streams that are used intensively by both humans and livestock, thus bringing together all the required hosts of these Schistosomes. Villages without piped water are marked by higher initial prevalence of *S. haematobium* infection[8]. The snail hosts of Bilharzia, are likely to increase in number under situations dominated by low flows or extreme low flows.

[7] Policy Guidelines on Control and Management of Diarrhoeal Diseases in Children below Five Years in Kenya. Ministry of Public Health and Sanitation, Division of Child and Adolescent Health, March 2010.

[8] Muchiri E.M., Ouma J.H. & King C.H.(1996). Dynamics and control of *Schistosoma haematobium* transmission in Kenya: an overview of the Msambweni Project. Am J Trop Med Hyg. 55(5 Suppl): 127-34.

Fascioliasis, a zoonotic disease of domestic herbivorous animals such as sheep, cattle and goats, which are the definitive hosts, is caused by infection with the liver fluke, *Fasciola hepatica* and *F. gigantica*. Massive infestation is common in sheep and bovines, and it can also occur in humans. Eggs are discharged with faeces and embryos develop in water and hatch into larvae which invade and develop in intermediate snail hosts. Cercariae are released from the snail and encyst aquatic vegetaton or other surfaces. Infection is acquired by livestock, or humans, eating the contaminated vegetation. Although animals may be able to support large worm burdens without developing serious disease, *Fasciola* spp. can cause severe, even fatal disease in humans. Flushing of streams with high flow pulses is an effective method of control.

Snails are susceptible to higher flow pulses and are likely to be washed away. Additionally stronger currents are thought to reduce breeding success as snails expend more energy attempting to resist dislodgement. Flushing of streams with high flow pulses is considered an effective method of control.

There are also a large range of water-related microbial infectious diseases, including pathogens transmitted by range of different routes. Similarly, a change in faecal bacterial concentrations and associated waterborne pathogens as a result of runoff and inflow of contaminants is possible and needs to be monitored. While water quality affects transmission rates of many water-related diseases, changes in water flow or water quality, which can influence the population dynamics of vector species that transmit infectious diseases and intermediate hosts for microbial pathogens, also influence the prevalence and transmission dynamics of infectious diseases.

The reduced flows resulting from upstream abstraction will inevitably reduce the potential for flushing of contaminants downstream. This will increase the concentrations of and potential dangers from bacterial concentrations in rivers, with associated risks when untreated river water is used, for example by rural households. Similarly, the potential negative impacts on vector control and disease transmission resulting from significantly reduced downstream flows further reinforces the requirements for a Reserve Flow that includes regular high flow pulses and other periods of higher flows.

Mitigation

It is recommended that regular higher flow periods are released from each of the intake weirs when suitable upstream flows are available, and that this practice is adopted as a standard management practice. These higher flow releases may for example be released during periods of high flow pulses, small floods and large floods. Consideration should also be given to the release of higher flow periods using parts of the normal base flows.

c) Interbasin Transfers

Environmental impacts related to interbasin transfers include fish and wildlife habitat changes and water quality changes. Impacts on the Athi basin are not expected to be significant as the rivers on which the proposed Northern Collector tunnel Phase 1 intakes are situated (Irati, Gikigie, Maragua) are connected to tributaries of the Tana. All negative impacts resulting from reduced downstream flows will therefore occur in the Tana basin. Changes in aquatic habitats will primarily result from hydrological changes discussed above under environmental flows.

Transfers of water will take place from these rivers, via transfer to Thika Reservoir, and ultimately to locations within the Athi basin. It is therefore expected that increased consumption will result in increased waste water flowing into the Athi River. The impacts of

this increased flow into the Athi will largely depend on the quality of the waste water treatment process.

Transfer of flow from upper Tana tributaries to the Athi River basin could potentially result in some fish species present in the upper Tana basin being transferred to the Athi. However, because of the passage through filters and pipelines, and the subsequent treatment of the water, this is considered to be unlikely.

Socioeconomic impacts related to interbasin transfers include the ability of the source basins to supply water to established and future users of the water resources, and economic and operational impacts on hydropower generation. Interbasin transfers will result in reduced downstream flows in rivers flowing into the upper Tana and ultimately into Masinga reservoir. In addition to impacts on hydropower potential, the reduced inflows to Masinga reservoir may have some impact on the potential for development and management of Reserve Flows on the Tana, including environmental flows, targeted at downstream communities and environments on the Tana River.

As a result in the changes in availability of water resources in areas downstream of the interbasin transfers, there may also be changes to the ability of a region to attract or sustain economic development.

6.5 Environmental Monitoring Plan

In order to fully achieve mitigation of potential impacts, it is necessary to monitor actual impacts and the mitigation measures that are incorporated, and to adapt management strategies based on the results of monitoring. The Environmental Monitoring Plan (EMP) will need to be developed in detail alongside the detailed designs for individual components of the programme.

The objectives of the Environmental Monitoring Plan include:

- Ensuring compliance with relevant regulatory authority requirements and guidelines. These may be national and/or international.
- Ensuring that the allocation of project resources and budget are sufficient so that the scale of EMP-related activities, e.g. mitigation, is consistent with the potential significance of impacts.
- Verifying environmental performance through recording of information on impacts as they occur.
- Responding to changes in project implementation that may not have been considered in the EIA.
- Responding to unforeseen events, and changes in circumstances.
- Providing feedback for continual improvement in environmental performance.

The Environmental Monitoring Plan will need to include recommendations that the following be monitored:

- Regular monitoring of flows upstream and downstream of all diversion structures and storage reservoirs. This will also include the monitoring and reporting of the volume of Reserve Flows, including both Environmental Flow and Compensation Flow components.
- Monitoring of sediment loads at intake weirs and downstream of intakes.
- Periodic surveys of aquatic fauna upstream and downstream of the intake weirs, as well as in Thika reservoir. These surveys should be designed to deliver an up-to-date and comprehensive assessment of the aquatic and riparian communities, to create a baseline, to monitor changes, and to allow for subsequent monitoring of

impacts on these communities. Surveys should include both native and introduced species.

- Changes to riparian vegetation downstream of the intake weirs.
- Changes in demand for water downstream of the intakes. This should include household water supplies with changes in household numbers and population densities, as well as changes in demand related to increased demand for agricultural production (including small scale irrigation, commercial irrigation and livestock requirements).
- Changes in the quality and availability of water supplies from rivers and associated streams and impacts on public health, including those communities dependant on downstream flows. This should include regular testing for chemical pollution from agricultural inputs upstream of intake points, as well as monitoring of potential faecal-bacterial pollution and other communicable disease health risks.
- Land use and land cover, including forest cover in the Aberdares catchment area, as well as agricultural activities in the catchment areas of the rivers associated with the Northern Collector phase 1, and the catchment of Thika Reservoir.

In order to achieve the above objectives, the Environmental Monitoring Plan should also include:

- Definition of the environmental management objectives to be followed in order to enhance benefits and minimise adverse impacts, including during construction and operational phases.
- Description of the actions needed to achieve these objectives, including by whom, and with what resources, as well as necessary monitoring or verification.
- Consideration should also be given to address possible changes in the project implementation, emergencies or unexpected events.

Construction Phase

Separate EMPs should be prepared for Construction and Operational phases. Construction Environmental Management Plans will be required to deliver a practical and achievable plan of management and to ensure that potential environmental impacts during the construction phases are minimised. Plans will need to be developed prior to construction, but can only be proposed once sites are finalised and full design and construction details are available. The following issues will need to be included:

- Physical setting, flora and fauna, ensuring minimal environmental impact and proposing mitigation measures, including the setting aside of alternative terrestrial and aquatic habitats for preservation to compensate for loss of habitats;
- Prevention of interruption to existing infrastructure installations and services, including the building of alternative access routes as required;
- Resettlement and land compensation, including compensation for potential loss of livelihoods;
- Ensure that noise and vibrations are kept to acceptable standards, including the impacts from blasting associated with construction activities for tunnels;
- Water quality management, dust and air quality, soil and groundwater contamination control
- Waste management, land contamination, erosion and sediment control, and
- Environmental Performance Monitoring.

Operational Phase

Operational Environmental Management Plans will also be required. These should focus on sound environmental management practices undertaken to minimise adverse impacts

on the environment during normal operation of the intake sites, reservoirs and water transmission tunnels and pipelines. The following issues will need to be included:

- Overall management strategy, including environmental performance monitoring and regular reporting. It is recommended that a scientific advisory committee be established to aid with long-term environmental monitoring.
- Maintenance of environmental integrity, including the provision of adequate downstream Reserve Flows:
    a) Provision, maintenance and monitoring of Environmental Flows,
    b) Preservation of those habitats that depend on these flows,
    c) Provision, maintenance and monitoring of Compensation Flows for downstream communities affected by reduced flows,
    d) Provision, maintenance and monitoring of flows required for purposes of downstream agricultural production, including irrigation, livestock, and the needs of factories (e.g. tea and coffee), and
    e) Preservation of water quality standards, including the minimization of potential impacts on public health resulting from reduced downstream flows.
- Minimization of leakages in transmission pipelines and in the distribution pipeline network.
- Disposal of wastes resulting from the water treatment process so as to ensure that there is no contamination of surface water and groundwater, or areas adjacent to the treatment works.
- Energy management, including measures to ensure minimizing greenhouse gas emissions.

Environmental Monitoring Plans may also be required for areas of specific ecological or social value, for example to ensure preservation of potentially important habitats or social amenities that may form part of the planned route for the proposed pipeline from Thika Reservoir to the treatment works, or other pipeline routes.

6.5.1 Draft Environment Management Plan

There are three main elements or phases to the environment management plan. During the pre-construction phase important baseline information will need to be collected and this will form the basis for environmental monitoring during the subsequent construction and operational phases. The environment management plan in the construction phase will require to focus on detailed monitoring of potential impacts and on mitigation and/or compensation for impacts.

Pre-Construction Phase

An important task in the pre-construction phase will be to set up a series of important monitoring systems that will be capable of providing the important critical required during the construction phase and also during the subsequent operational phase. Chief amongst these are the establishment of additional river gauges required to provide important information on the downstream flows so as to ensure adequate Reserve Flows, together with an up-to-date and complete listing of all abstractions of water from the Irati, Gikigie and Maragua rivers – including both licensed and unlicensed abstractions. Regular daily monitoring of all flows will be required and a system for rapid reporting of these flows, perhaps by mobile phone systems, so that adequate downstream Reserve Flows can be maintained – including both environmental and compensation flows.

In addition, there will need to be surveys of aquatic and riparian fauna upstream and downstream of the intake weirs, as well as aquatic fauna in Thika Reservoir. These surveys will provide up-to-date assessment of the aquatic and riparian communities, and will create a comprehensive baseline from which to monitor changes and potential impacts on these communities. Surveys should include both native and introduced species. Surveys of aquatic fauna should include surveys of fish species present in the Maragua, Gikijie and Irati Rivers, and in Thika Reservoir and Thika River. Surveys of riparian fauna should include seasonal surveys of bird species to determine the numbers of species and population numbers. These data on bird assemblages (including migratory species) will subsequently be used as indicators of riparian condition as components of environmental monitoring during construction and operational phases.

The management of disposal of material excavated from the Northern Collector tunnel will need to commence during the pre-construction phase. It is recommended that no permanent "spoil dumps" are used. Instead of considering the excavated material as "spoil" requiring disposal, it should be used as raw material for a range of activities such as road repair and construction, and for use as building material, including the making of bricks for buildings. It is therefore recommended that on-site storage of excavated material should be minimized and that only temporary storage sites should be constructed within reach of each of the access sites. It is also recommended that the excavated material is transported away from the sites at a rate similar to the rate of extraction. The emphasis should be for the material to be transported for either temporary or permanent storage at suitable sites elsewhere.

Table 8-24: Pre-Construction Phase Information Requirements

Information Requirements		**Actions, Surveys or Data Recording**
Monitoring of water resources	Adaptive water management needs reliable and comprehensive data on which to base decision making. These data should cover not just daily hydrological characteristics, but also indicators of water use and abstraction.	Upgrade existing and establish new river gauges for monitoring flows. River flow gauges spaced at not more than 10 km intervals downstream of the intake weirs and upstream of Masinga Reservoir. Establish systems for daily reporting of these data to a central system.
Monitoring of water use and abstraction	Monitoring of downstream water use by communities and industries is required. 1. Household use 2. Agricultural use 3. Industrial/commercial use	Up-to-date information on all abstractions from the rivers, including both licensed and unlicensed abstractions for all uses. Obtain data on volumes of water required as well as monthly or seasonal changes in requirements, and methods of abstraction.
Rural Water Supplies	Collection of up-to-date information on the status of rural water supplies to households as well as the numbers of households connected and not connected to rural water supplies.	Develop proposals for development of rural water supplies to ensure that as many as possible of the rural households in those areas downstream of the Maragua, Gikigie and Irati intakes are connected.

Information Requirements		Actions, Surveys or Data Recording
	Consideration should be given to ensure that all communities traversed by the pipelines are fully provided with piped water supplies, as a priority.	Provide adequate local, rural and urban water supplies along pipeline routes
Data for monitoring aquatic and riparian fauna	Monitoring for the EMP requires a set of accurate and comprehensive baseline data on which to base subsequent surveys, compare changes, and determine required actions. Where possible, surveys should include involvement of personnel from the National Museum.	Surveys of aquatic fauna, including fish species in the rivers and in Thika Reservoir. Development of detailed plans and designs for fish passes or fish ladders as integral components of each of the intake weirs. Surveys in the riparian zone of bird species and population numbers.
Resettlement Action Plan	The installation of the pipeline may result in displacement of households.	A Resettlement Action Plan should be prepared. Involuntary displacement should be avoided
Data on land use / land cover	Detailed information on the land use and land cover will be required as part of the EMP for all areas adjacent to the intake sites, outfall and other access sites for: 1. Northern Collector tunnel 2. Pipeline routes	Detailed land use and land cover surveys. These will form a baseline for environmental and social monitoring components of the Environmental Management Plan.
Disposal of excavated material	Instead of considering the excavated material as “spoil”, requiring disposal, it should be used as raw material for a range of activities such as road repair and construction, and for use as building material.	Selection of suitable sites for long-term storage of excavated material. It is suggested that disused quarries should be used for storage of excavated material. It is also recommended that disposal of excavated material is integrated with the regeneration and rehabilitation of disused quarries.
Storage areas for excavated material	Construction of temporary on-site storage of material excavated from the tunnels will be required. Storage will need to be within fully bunded structures so as to prevent erosion and siltation in rivers.	Selection of suitable sites for temporary storage of excavated material. Purchase of the land and compensation of households for loss of future earnings from these areas. Storage sites will need to be constructed with at least 40 m buffer zone between the bunded storage area and the edge of the river.
Ambient air quality	Active sampling methods to determine air quality will be required.	Baseline sampling to determine ambient air quality will be carried out prior to the commencement of construction activities.

Information Requirements		Actions, Surveys or Data Recording
Baseline noise levels	Noise level measurements will be need to be carried out as per ISO standards.	Baseline sampling to determine noise levels will be carried out prior to the commencement of construction activities.
Technical committee	A technical committee, including environmental assessment personnel, needs to be established with the remit to assess any damage caused and assess required compensation or mitigation measures during construction and operational phases.	Establish technical committee and review the collection of baseline monitoring data. Ensure that contracts for the construction phase include reference to supervision by the technical committee. Ensure that all local communities are fully aware of the details of upcoming activities.

Construction Phase

Where the household property or productive assets (e.g. plantation tea) adjacent to the construction or operational sites are to be infringed upon or otherwise impacted, they should be sufficiently and promptly compensated for. Similarly, where property or productive assets are impacted by trucks or other transport associated with construction and excavation activities, sufficient compensation should be given. National guidelines for compensation rates should be followed as minimum compensation, including rates provided by the Ministry of Agriculture for the value of crops and trees. The value of tea plantation should also take account of the long term value of tea to household incomes in this area.

During the construction phase, the role of the contractor is critical. With specific reference to the Environment Management Plan (EMP), the role of the Contractor will be to:

- Implement, manage and maintain the construction elements of the EMP for the duration of the contract;
- Designate, appoint and/or assign tasks to personnel who will be responsible for managing the relevant components of the construction EMP, and assign appropriate authority, accountability and necessary equipment and facilities for these personnel to carry out their duties;
- Ensure that all sub-contractors and other workers appointed by the Contractor are aware of their environmental responsibilities while on site or during the provision of their services off site, and ensure that they comply with and implement the construction EMP during the duration of their specific contracts;
- Provide appropriate resources, including budgets, equipment, personnel and training, for effective control and management of all environmental risks associated with the construction phase.

Table 8-25: Environmental, Safety and Health Issues during Construction Phase

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Technical committee	Continue the technical committee and review the collection of baseline monitoring data. Ensure that the technical committee is able to review information from continued environmental monitoring activities as well as all ongoing construction activities.	All involved Authorities and Construction management
River flows	Continued daily monitoring of flows upstream and downstream of all diversion structures on a daily basis, including at all new sites installed during pre-construction phase on Maragua, Gikigie and Irati Rivers. Monitoring of sediment transport at all river gauges.	Data collection
Water Quality	Monitoring of water quality, including tests for biological contamination that may be related to potential human health issues. Monitoring to be carried out at all river gauge sites.	Data collection, Health & Safety
Loss of land and changes in land cover	Monitor changes in land use and land cover, including: • Riparian vegetation • Forest and woodland, and individual trees • Smallholder tea plantation • Other agricultural areas, and areas that are suitable for and used by grazing livestock (e.g. sheep owned by the community) • Household land and adjacent community areas • Roads and tracks, including footpaths used by the community • Loss of access to land as a result of pipeline wayleave • Change in vegetation cover and land use along pipeline routes • Change in vegetation cover and land use in and adjacent to proposed Ngorongo Water Treatment Works.	Data collection
Establishment of Buffer Zones	Ensure that all construction activities are confined to within defined buffer zones.	Administrative
Awareness	Ensure that all construction personnel and supervision personnel are aware of the environmental requirements and are equipped to deal with these requirements. This should include relevant health and safety requirements.	Administrative

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Site management	All areas should be securely fenced at least 3 m from the edge of operational areas using chain link fencing of at least 1.5 m high. Warning notices / signs erected at all entrances. All roads and tracks to be safely accessible. All footpaths and access to tea plantation lands to be safely accessible by local communities and landowners.	Administrative
Workmen's camps and Settlements	Ensure careful planning and location of both temporary campsites, and more permanent workmen's camps. Provide local employment. Provision of adequate sewage and waste disposal facilities, and adequate resources, including water supplies and household fuel. There may also be health risks and increased requirements for health services, including both first aid facilities and medical centres.	Construction management Administrative, Health & Safety
Health and Safety	Relevant protective gear and equipment should be used by all construction personnel, including: • Protective helmets • Gloves • Protective footwear • Safety goggles • Dust masks • Overalls/dust coats All blasting materials and all other potentially dangerous materials to be acquired, stored and used subject to relevant permits.	Administrative, Health & Safety
Safety Training	Operators to be trained on safety, health and environmental issues. Each construction site should have a person in charge of safety, and Safety, Health and Environment Committees should be established at each construction site. These should report to the Technical Committee.	Administrative, Health & Safety
Waste Disposal	Waste collection and disposal pathways and sites will be identified for all major waste types expected from construction activities. Mineral construction waste will be separated from general refuse, organic, liquid and chemical wastes by onsite-sorting and stored in appropriate containers. There will be no open burning of waste materials at the sites.	Administrative, Health & Safety
Welfare	Adequate welfare facilities to be provided at all sites, including clean water and sanitation, first aid kit with trained first aiders.	Administrative
Access Roads to NC tunnel access sites	Road maintenance to be carried out on a regular basis to ensure continued access for all local services. Road maintenance should make maximum use of material excavated from the tunnel.	Administrative

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Pipelines and Access Roads	Impacts may occur where transmission pipelines cross roads. These impacts should be prepared for and included in detailed designs. Required mitigation measures should be incorporated in designs and action plans.	Construction management
Pipeline Access for Maintenance	Long-term access to the pipelines will be required for routine checking and maintenance. Careful location of pipelines will be required, and access incorporated in detailed designs.	Construction management
Noise Levels	Regular monitoring of noise levels. Reporting of unacceptable noise levels.	Data collection
Air Quality	Regular monitoring of air quality, including monitoring of dust levels near all excavated material storage sites, and reporting of unacceptable air quality levels so that appropriate actions can be taken by construction management.	Data collection
Habitat Restoration Required as a result of Clearance of Vegetation	Minimize clearance of natural vegetation. Ensure a buffer zone of a minimum of 30 metres between all construction sites or related activities and the riparian zone along the rivers. The only exception to this will be the construction of the intake weirs and associated structures. For every tree cut or felled, ensure that a minimum of five trees are planted and maintained elsewhere in suitable sites nearby along the river, either upstream or downstream of the intake sites. Creation of wildlife corridors to replace all areas where removal of trees or other vegetation has resulted in disruption to existing wildlife corridors. Habitat restoration in areas impacted by clearance of vegetation along the transmission pipeline routes.	Construction management
Monitoring of Habitat Restoration	All areas impacted by clearance of vegetation will require habitat restoration. This restoration should be monitored to ensure success and feedback of these findings must be provided to construction management to enable improvements where necessary.	Data collection and Construction management
Erosion	Monitor erosion and ensure adequate erosion control measures are in place	Data collection and Construction management
Pollution	Monitoring of pollution, including dust and noise pollution. Contamination from wastes and oil/fuel spills may also occur. All sites where oil or fuel may be stored should be protected by fully bunded structures to contain all potential spills. Such sites will require to be constructed with a buffer zone of at least 40 m between the fuel storage area and the edge of the river.	Construction management

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Excavated Material	Finalise the construction of temporary on-site storage facilities for material excavated from the tunnels. Storage will need to be within fully bunded structures so as to prevent erosion and siltation in rivers.	Construction management
Storage of Excavated Material	On-site storage of excavated material will require the construction of fully bunded structures to contain all of the excavated material so as to prevent erosion and siltation in the rivers, constructed at least 40 m buffer zone between the bunded storage area and the edge of the river. Storage areas should avoid areas being close to tea plantations due to the potential problems related to contamination of tea with dust from excavations. Storage areas should avoid being located on steep slopes due to the potential problems of erosion.	Construction management
Transport of Excavated Material	Ensure that there is sufficient transport to enable transfer of excavated material from temporary on-site storage areas to permanent facilities that have been prepared elsewhere.	Construction management
Hydrogeology	Tunnelling may result in changes to underground drainage as a result of underground fractures. This will require detailed investigation during construction. The wider impacts of changes in underground drainage on groundwater resources will also need to be investigated, and suitable mitigation measures developed and implemented.	Data collection and Construction management

Operational Phase

Impacts that can be expected from operation of the intake weirs are listed in Table 8-23 on page 8-97. Primary environmental impacts resulting from operation of the intake weirs and Northern Collector Tunnel are related to the significant change in downstream hydrology. These will result from changes to water flow patterns, changes in quantity (in particular the loss of flood events), and also from a deterioration in water quality. Changes in water quality are themselves a direct response to the changes in flow. In addition, the normal or base flows will, after installation of the intake weirs and abstraction of water, change to the flows similar to those currently classified as “extreme low flows”, or to the lower range of flows classified as low flows, or base flows.

The provision of adequate downstream environmental flows, as a component of Reserve Flows, is considered to be essential for all rivers, as described under “Downstream Reserve Flows”. Similarly, provision of adequate compensation flows is viewed as being critically important for all downstream communities.

An important consideration will be the cumulative impact arising from the combined operation and release of downstream Reserve Flows from all three weirs at Maragua, Gikigie and Irati. Cumulative impacts are likely to include the following factors (see also section 6 on Cumulative Impacts):

- Less flow available for rural household water supplies;

- Less flow available for use in current and future agricultural activities, especially for use during dry seasons, in order to provide food required by the increasing population of Nairobi;
- Reduction in the flow reaching Masinga Reservoir;
- Short periods or single days with zero flow, preceded and/or followed by further periods with extreme low flow.

Up-to-date information on all downstream abstractions from the rivers, including both licensed and unlicensed abstractions for all uses (including: household, agricultural / irrigation, industrial uses, and methods of abstraction) should continue to be obtained, following on from the collection of this information as part of the EMP during pre-construction phase. These data will need to be monitored and updated on a regular basis and the requirements for downstream Reserve Flows modified accordingly.

Monitoring surveys initiated as part of the EMP during the pre-construction phase should continue to be conducted on a regular basis. These include surveys to determine changes that may occur within aquatic and riparian habitats. Where such changes are related to reduced downstream flows, it may be necessary to either adjust the levels and timing of environmental flows accordingly, e.g. though the provision of high flow pulses, or to carry out alternative mitigation or preservation measures.

In those cases where there are a number of different relevant Authorities for management or control of specific issues raised by the Environment Monitoring and Management Plan, it will be necessary to establish Technical Committees and Working Parties with representatives from each of the different authorities. Examples may for example include the monitoring of downstream flows and the setting of or modifying Reserve Flows, which by definition require to include both Environmental Flows and Compensation Flows. In this case, different Authorities or Departments may be responsible for the monitoring and recording of daily flows, for Nairobi water supplies, for the licensing of abstractions (and recording of all licensed and unlicensed abstractions), for the use of water for irrigation of smallholder and/or commercial agriculture, household and rural water supplies, and for environmental flow requirements, as well as for downstream hydropower use at Masinga Dam or mini-hydro schemes and other downstream needs.

Table 8-26: Environmental Issues during Operational Phase

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
River Flows	Continued daily monitoring of flows upstream and downstream of all diversion structures on a daily basis, including at all new sites installed during pre-construction phase on Maragua, Gikigie and Irati Rivers. Monitoring of sediment transport at all river gauges.	Data collection
Reserve Flow Requirements	Continued assessment of the abstractions by downstream water users (both licensed and unlicensed) will be required on a regular basis, including monthly or seasonal abstraction requirements.	Data collection
Rural Water Supplies	Ensure that all abstraction sites for rural water supply systems are supplied with adequate flows.	Management of the Intake Sites.

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Irrigation Requirements	Ensure that downstream irrigation requirements are supplied with adequate flows.	Management of the Intake Sites
Groundwater levels	As a result of reduced downstream flows there may be a reduction of recharge to groundwater from the impacted rivers. Changes in groundwater levels may also occur as a result of extraction of water that the proposed well fields. It will be necessary to install an increased network of river gauges and recording stations in order to cover the potentially impacted areas. Regular, daily monitoring and reporting of these river gauges will be necessary. Existing springs and dug water supply wells in the areas within the geological strata affected by the proposed groundwater well fields will need to be identified and mapped. The yields from these sources will need to be recorded and monitored. Alternative, piped, water supplies will need to be provided in those cases where these water sources are impacted by reduced groundwater levels resulting from abstraction	Data collection.
Provision of Downstream Reserve Flows	Based on the assessment of downstream water use requirements, adjust the provision of Reserve Flows to ensure adequate provision of water resources for all downstream users, whilst at the same time maintaining adequate environmental flows. Ensure that there are no unnecessary periods with unacceptable low flows or zero flows in downstream reaches of the rivers. At such times, increased release of flows at the intake sites (derived from forested areas of the Aberdares) is likely to correct these potential problems. In some cases it may be necessary to restrict abstractions by selected downstream users in order to ensure maximum provision of water resources to downstream communities.	Management of the Intake Sites.
Water Quality	Monitoring of water quality, including tests for pollutants and biological contamination that may be related to potential human health issues. Monitoring to be carried out at all river gauge sites on a regular monthly basis (or more frequently).	Data collection, Health & Safety
	Detailed monitoring of water quality should also be carried out at the proposed Ngorongo Water Treatment Works.	Data collection, Health & Safety
	Reduced nutrient availability in downstream areas, resulting from the reduction in downstream flows, may result in a reduction in productivity of downstream systems, including cultivation in alluvial and other riparian areas downstream. In such cases it may be necessary to carry out mitigation or corrective measures, for example through the release of high flow pulses or flood events to induce sediment transport.	Data collection. Actions to be taken by Relevant Authorities.

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
	Reduced water quality as a result of reduced flows may result in increased health risks for downstream communities especially for those households dependant on untreated river water. A change in faecal bacterial concentrations and waterborne pathogens as a result reduced flows and from inflow of contaminants from upstream is likely and needs to be monitored.	Monitoring of diarrheal and other diseases in rural households. Actions by Relevant Authorities.
	All water quality data to be analysed and made available on a regular basis to all authorities involved with the management of the water resources and related issues.	Relevant Authorities.
Changes to Aquatic and Riparian Habitats	It will be necessary to continue regular monitoring of riparian habitats, and surveys of aquatic fauna and bird populations in riparian zones. Results of these surveys will provide indication of potential changes or loss of habitat downstream as a result of changed hydrological regimes, including cumulative downstream impacts. Depending on the nature and specific locations of observed changes, those management authorities concerned with the maintenance of riparian zones will need to propose and carry out mitigation or corrective measures. These may for example include release of environmental flows that include high flow pulses.	Data collection. Actions to be taken by Relevant Authorities.
Increased Settlement	Increased permanent settlement is likely to result from activities during the operational phase. In addition to operational staff, induced settlement is likely to occur in the surrounding area, creating potential stress on local resources and facilities, including fuelwood.	Intake Site Management Authorities.
Impact from presence of pipelines	Long-term access to the pipelines will be required for routine checking and maintenance. Assuming that most of the pipeline length is buried with limited surface structures, the overall impacts can be expected to be relatively low. However, leaks are highly likely to occur along transmission and distribution pipelines, and possibly at treatment works. Contamination of supply pipes may also occur at these sites. Leakages may result in health risks, e.g. Malaria, Cholera, Typhoid, Dysentery, Diarrhoea and other water-borne or water-related diseases. All leaks should be monitored and controlled accordingly. Regular monitoring and maintenance is considered essential. Early detection of leaks reduces the possibility of public health risks.	Pipeline Management Authorities.

7 Project Costs and Implementation Schedule

The Water Sources Options Review (September 2011) prepared for the Nairobi City Water Supply Master Plan investigated and evaluated four main potential investment scenarios and two sub-scenarios that were identified for the development of additional water resources for Nairobi's water supply for the time horizon of 2035. These six scenarios included key water resources investment sub-projects and corresponded to different alternatives for supplying additional raw water, and their particular capital expenditures, O&M costs, and investment schedules

A multicriteria least cost analysis was carried out to compare each of the potential water resources development scenarios. As each alternative provides a different raw water output, a normalization procedure was applied to allow for comparison of costs of the scenarios for a similar water output with the results expressed as the Average Incremental Economic Cost of water (AIEC). Four key sustainability issues were used for the multicriteria analysis taking account of natural resources, economic performance, environmental issues and social sustainability.

The results of the multicriteria analysis indicated that Scenario 3A was the preferred option for the development of Nairobi's water supply having an AIEC of US$0.61 (KES55) per m^3 of water compared to Scenario 2, the next best option, with an AIEC of US$0.74 (KES67), and scoring the highest in the multicriteria analysis (see the Executive Summary and Chapter 12 in Water Sources Option Review Report). Consequently Scenario 3A was selected as the preferred option for the development of Nairobi's water supply to 2035, and for the development of the Preliminary Design and Feasibility study of the investment required to meet the year 2017 water demand for Nairobi City.

Stage 1 of the investment programme covering the years 2012 to 2017 includes: the Northern Collector tunnel and weirs to abstract water from three rivers to divert water to Thika Dam, the construction of a new water high-level treatment works at Ngorongo, a new raw water transfer main from Thika Dam to Ngorongo WTW and a new treated water main from Ngorongo WTW to Kabete reservoir. In this regard Scenario 3A and Scenario 2 have the same investment programme for stage 1; the main difference in the overall programme is that Scenario 3A includes construction of Maragua 4 Dam (scheduled for 2016-2020) at the beginning of the next stage which eliminates the need for the Chania-Komu transfer scheme needed for Scenario 2, which would involve high pumping cost contributing to its higher AIEC.

This chapter presents the project costs and implementation schedule for Stage 1 2012 – 2017 only.

7.1 Assumptions for Project Costs

The costs include (i) initial capital costs, (ii) replacement costs and (iii) future O&M costs (fixed and variable costs).

The following assumptions are used:

- Costs are expressed in US$ using the rates applicable in January 2012, and where necessary foreign costs are converted to KES at the rate of KES 90 = US$1.0 and KES117 = 1.0 Euro.
- Costs are assumed to be free of Kenyan customs and excise duty, unless stated otherwise.
- Costs are assumed to be free of VAT of 16%, unless stated otherwise

- An allowance of 15% is applied to all construction costs to allow for preliminaries and general items.
- An allowance of 9% of construction costs is applied to allow for engineering and works supervision services.
- A physical contingency of 10% is applied to all construction costs to allow for underestimation in bill of quantities and unforeseen costs.
- Price escalation (financial contingency) is included at the rate of 1% per year for foreign costs and 5% per year for local costs over the five year capital investment period.

7.2 Cost Estimates

The costs have been prepared using COSTAB, the project costing software that is used by the World Bank and other multilateral development agencies. It allows the incorporation of physical and price contingencies and production of summary tables in a standardised format.

Details of the main cost components are presented in the Appendix to this report. The following sections describe how the main component costs have been prepared from the unit rates.

7.2.1 Wellfields

a) Individual Private Wells

Increased groundwater extraction from individual private tubewells of 1,000m^3/day each year 2012 – 2035 is assumed to require an additional five wells to be developed each year with a yield of 10m^3/hr. At current rates a 200 m borehole costs US$50,000, including drilling, lining, screens, pump installation and pipe work. This assumes that 3-phase power is available to the location. As this development will be funded entirely by the private sector no costs are allocated to the publically-funded Stage 1 Project.

b) Groundwater Resources Investigation

Prior to the development of the two new Wellfields planned at Ruiru and Kiunyu, a ground water investigation is proposed to be undertaken to determine and confirm the characteristics of the aquifer and the extent of the actual groundwater resources. A total of US$3 million is included in the cost estimates for this investigation.

c) Ruiru Wellfield

The Ruiru Wellfield is planned to produce 30,000m^3/day involving the installation of 15 tubewells, with each well yielding a minimum of 90m^3/h. The boreholes will be 500 m deep equipped with a submersible pump with a life of five years. The 15 boreholes will be connected to a 60,000m^3 reservoir through a 5 km manifold piping system with an attached chlorination unit. From the reservoir, water will be transferred through a 15 km long trunk main with the capacity of 350 l/s from Ruiru to Nairobi, most probably to the Gigiri storage/distribution tank. Details of the unit costs are shown in Table 8-27 on page 8-119.

Table 8-27: Unit Rates for Ruiru Wellfield

Item	Unit	Unit Cost (US$)
Boreholes	each	300,000
Pumps	each	10,000
Motors	Each	15,000
Manifold pipe system (5 km, 25 l/s)	set	4,765,000
Reservoir	60,000 m^3	6,780.000
Chlorination unit	Unit	50,000
Treated water pump station		
- Pump house	Each	9,000
- Pumps & motors	Set	54,000
Transmission main (DN600mm, 350 l/s, 25 km)	km	290,000
Preliminaries and general		15%
Engineering services (drilling works, distribution and storage)		9%

d) Kiunyu Wellfield

The Kiunyu Wellfield is planned to produce 35,000m^3/day requiring the installation of 25 200 m deep tubewells equipped with submersible pumps with a five year life. Each well would yield a minimum of 60m^3/h. The wellfield will be connected to a 70,000 m^3reservoir and associated chlorination unit through a 7km pipe manifold system designed with a capacity of 20l/s. From the reservoir treated water will be transferred to Nairobi through a 45km transfer main with a capacity of 400 l/s. A pumping station will be required to transfer water from the Kiunyu Wellfield at an altitude of 1,600 masl to Nairobi (1,650 masl). The unit rates used for the costing are as follows.

Table 8-28: Unit Rates for Kiunyu Wellfield

Item	Unit	Unit Cost (US$)
Boreholes (200 m)	Each	120,000
Pumps and Motors	Each	12,500
Manifold Pipe System (7 km, 20 l/s)	Set	3,960,000
Collector Tank / Reservoir	70,000 m^3	7,780,000
Chlorination Unit	Unit	50,000
Treated Water Pump Station		
- Pump house	Each	9,000
- Pumps & motors	Set	57,000
Transmission Main (DN700mm, 400 l/s, 50 km)	Km	360,000
Preliminaries and General		15%
Engineering Services (drilling works, distribution and storage)		9%

7.2.2 Northern Collector Tunnel - Phase 1

The proposed 12km Northern Collector Tunnel will abstract water from three Rivers (Maragua, Gikigie and Irati) and transfer water to Thika Dam. Unit rates for tunnels have been estimated for a 3.2m diameter lined tunnel using the drill and blast construction method. Intakes and shafts costs are based on BOQ and local unit costs. An allowance of 15% contractor's preliminaries and general expenses and 9% engineering works and supervision are added to the unit rate in the estimates.

Table 8-29: Unit rates for tunnels

Item	Unit	Unit Cost (US$)
Driving and Lining (drill & blast)	m	5,500
Intakes	each	1,111,111
Irati Shaft (46m)	set	1,020,000
Thika Outfall	set	550,000
Contractor's Preliminaries and General		15%
Engineering Services (drilling works, distribution and storage)		9%

7.2.3 Water Transfer Pipelines

New transfer water mains with capacity of 1.4m^3/s will be constructed to transfer raw water from Thika Dam 44km (in two sections) to the new Ngorongo high level water treatment works and a further 17.6 km from the water treatment works to Kabete reservoir. The following base costs in KES and US$ have been prepared to estimate the capital costs for the two pipelines. Contactors preliminaries and general at 15% and engineering supervision (9%) and a 10% physical contingency is added to these costs. A summary is provided in Table 8-30 below.

Table 8-30: Base Costs for Water Transfer Pipelines

Thika Dam - Ngorongo WTW Raw Water Gravity Main (44km)			
Class	**Description**	**KES'000**	**US$**
A	General	19,820	220,222
E	Earth works	23,974	266,378
F	In situ concrete	218,928	2,432,533
G	Concrete ancillaries	115,571	1,284,122
I	Pipe work - supply and laying	2,556,081	28,400,900
J	Pipe work - joints, fittings & valves	485,159	5,390,656
K	Pipe work - chambers and ancillaries	19,196	202,178
L	Pipe work - support and protection	339,191	3,768789
M	Structural Steel work	23,500	277,778
	Total	**3,801,420**	**42,238,000**
Ngorongo WTW - Kabete Reservoir Treated Water Gravity Main (18km)			
A	General	8,235	91,500
E	Earth works	5,515	61,278
F	In situ concrete	11,624	129,156
G	Concrete ancillaries	9,621	106,900
I	Pipework - supply and laying	806,353	8,959,478
J	Pipework - joints, fittings & valves	172,346	1,914,956
K	Pipework - chambers and ancillaries	5,611	62,344
L	Pipework - support and protection	177,077	1,967,522
M	Structural Steel work	2,250	25,000
	Total	**1,198,632**	**13,318,133**

7.2.4 Ngorongo Water High-level Water Treatment Works

A new water treatment works will be built at Ngorongo with capacity of 100,000 ml/day. The new plant will include staff housing, school and community services. A summary of the capital base costs are shown in Table 8-31 on page 8-121. The same percentage rates of 15% for preliminary and general, 9% for engineering supervision and 10% physical contingency are applied to these costs.

Table 8-31: Base Costs for Ngorongo High Level Water Treatment Works

No.	Description	KES'000	US$'000
1	**Ngorongo Water Treatment Works**		
	Treatment works and pipelines	2,251,583	25,018
	Buildings	162,932	1,810
	Site and ancillary works	140,521	1,561
	Sub-total	**2,555,036**	**28,389**
2	**Staff Housing**		**-**
	Houses	106,927	1,188
	Site and ancillary works	51,507	572
	Sub-total	**158,434**	**1,760**
3	**Primary School**		**-**
	Buildings	58,815	654
	Site and ancillary works	51,733	575
	Sub-total	**110,548**	**1,228**
4	**Total Base Costs**	**2,824,018**	**31,378**
	Electro-Mechanical components (15%	423,603	4,707
	Sub-total	**3,247,621**	**36,085**
	Miscellaneous items (12%)	389,715	4,330
	Grand Total	**3,637,336**	**40,415**

7.2.5 Other Associated Costs

The rehabilitation and upgrading of Nairobi's water supply and sewerage network during stage 1 will also require additional capital investment that is not included in the costs discussed above, which are limited to the increased bulk supply of additional treated water to the Kabete reservoir from the Northern Collector. Currently there are several other studies investigating the need for the rationalisation, rehabilitation, and expansion of the water delivery network which is expected to result in further capital investment during the time period of the Stage 1 investment programme. A summary of these works are as follow.

a) Nairobi Network Modification

A study to develop hydraulic models for Nairobi water supply distribution system is currently being prepared to optimise the network down to the 150mm distribution system level and for the construction of Karen, Kikuyu and Loresho water reservoir tanks. Capital investment of €30 million, equivalent to US$39 million, is planned for a three year investment programme 2012 to 2014 most probably funded by KfW, the German government-owned development bank. During a second phase of this programme a further investment of around US$27.5 million is proposed for expanding the network.

b) Nairobi Tertiary Network Expansion and Connections

Similarly, an investment programme for the rehabilitation and expansion of the Nairobi water supply tertiary network is planned over the period 2012 to 2016 with an expansion in the number of individual connections and upgrade of the distribution system in the informal settlements. Total capital investment costs of €22 million (US$28.6 million) are scheduled), to be funded by AFD, EU and a US$6.5 million contribution from the Kenya Government.

c) Sewage Ponds Methane Gas Production

The World Bank is funding a US$15 million project to develop the capacity to produce methane from Nairobi's sewage treatment ponds. The gas would be used to generate electricity which would be sold to KenGen at the relevant feed-in tariff rate. These costs and benefits are included as the investment and income would come within the operation of the Nairobi City Water and Sewage Company and impact on their financial performance.

7.2.6 Summary of Cost Estimates

A summary of the capital investment costs for the period 2012 to 2017 is shown in the Table 8-32 below. The total costs of the investment programme for stage 1 from 2012 to 2017 is KES33.885 billion (US$376,507 million) including contingencies. Included in this total are the associated costs for the Nairobi distribution network amounting to US$67.6 million including contingencies as discussed above.

The detailed cost estimates for each component are included in **Appendix 8.11**.

Table 8-32: Summary of Costs for Stage 1 – 2012 – 2017

Nairobi Water Supply Master Plan Stage 1 - 2012 - 2017

Components Project Cost Summary	(KES '000)			(US$ '000)			% Foreign Exchange	% Total Base Costs
	Local	Foreign	Total	Local	Foreign	Total		
A. Wellfield Development								
1. Groundwater investigation	135,000	135,000	270,000	1,500	1,500	3,000	50	1
2. Kiunyu wellfield	1,071,533	2,545,702	3,617,235	11,906	28,286	40,192	70	12
3. Ruiru wellfield	860,902	1,562,213	2,423,115	9,566	17,358	26,924	64	8
Subtotal	2,067,435	4,242,915	6,310,350	22,972	47,144	70,115	67	21
B. Northern Collector Phase I								
1. Tunnell	1,832,476	5,497,427	7,329,903	20,361	61,083	81,443	75	24
2. River Offtakes and Shafts	110,325	330,975	441,300	1,226	3,677	4,903	75	1
Subtotal	1,942,801	5,828,402	7,771,203	21,587	64,760	86,347	75	26
C. Ngorongo Highlevel Water Treatment Works and Water Mains								
1. Ngorongo WTW	1,872,045	2,626,206	4,498,251	20,800	29,180	49,981	58	15
2. Transfer mains	1,557,033	4,643,031	6,200,063	17,300	51,589	68,890	75	20
Subtotal	3,429,077	7,269,237	10,698,314	38,101	80,769	118,870	68	35
D. Nairobi City Network Modification	1,313,497	1,818,294	3,131,790	14,594	20,203	34,798	58	10
E. Nairobi City Tertiary Network								
1. Tertiary distribution system	539,388	809,082	1,348,470	5,993	8,990	14,983	60	4
2. Individual metered connections	270,000	270,000	540,000	3,000	3,000	6,000	50	2
3. Informal settlements upgrade	270,000	270,000	540,000	3,000	3,000	6,000	50	2
Subtotal	1,079,388	1,349,082	2,428,470	11,993	14,990	26,983	56	8
Total BASELINE COSTS	9,832,197	20,507,930	30,340,127	109,247	227,866	337,113	68	100
Physical Contingencies	693,051	1,453,174	2,146,225	7,701	16,146	23,847	68	7
Price Contingencies	894,742	504,567	1,399,309	9,942	5,606	15,548	36	5
Total PROJECT COSTS	**11,419,991**	**22,465,671**	**33,885,662**	**126,889**	**249,619**	**376,507**	**66**	**112**

7.3 Operation and Maintenance Costs

7.3.1 Annual Maintenance Costs – Fixed Items

Rates for the annual maintenance and replacement, intervals for fixed items associated with water supply based on the guidelines of the Design Manual for Water Supply Services in Kenya, MoWI, 2005 are shown in Table 8-33 on page 8-123. Where appropriate these rates have been used for the estimation of annual maintenance and replacement costs for the capital assets.

Table 8-33: Annual Maintenance Rates

Asset part		Economic Lifetime	Fixed Annual Maintenance Costs (i)
		Years	% per year
1	Dams	40	0.5
2	Intake works (ii)	40	1.0
3	Earthworks	40	1.0
4	Boreholes and wells	20	1.0
5	Pumps	10	5.0
6.	Electric motors, cables and switch gears	10	5.0
7.	Pipes (all types)	30	1.0
8.	Treatment works	30	1.0
9.	Reservoirs	30	
10.	Storage tanks in masonry or reinforced concrete	30	1.0
11.	Storage tanks , sectional steel incl. Towers	10	2.0
12.	Buildings	30	1.0
13.	Gantries, steelworks	20	2.0
14.	Permanent tools and plant	10	2.0
15.	Chemical apparatus	10	5.0
15.1.	Chemical dosing gear	10	5.0
15.2.	Instruments & testing apparatus	5	5.0
13.	Roads	30	1.0
Source: MoWI, Practice Manual for water supply services in Kenya, Dec. 2005			
(i) Calculated as a % of construction costs			
(ii) intake works: including boreholes: mass concrete structures, intakes, underground pits, culverts, etc			

Annual fixed maintenance cost for tunnels is estimated at 0.5% of the initial capital cost. An economic lifetime of 40 years is considered for tunnels.

Replacement costs for all investments are considered at 90% of the initial capital investment costs and occur at the end of the economic lifetime of the asset.

7.3.2 Variable Operation & Maintenance Costs

a) Water Treatment Works

For the water treatment works the following variable operating costs are derived from: (i) the average 2010 variable operation costs of NCWSC for its existing water treatment plants, namely Ngethu WTW, Kabete / Kikuyu WTW and Sasumua WTW, and (ii) other relevant WTW operation costs in Kenya.

The variable operation costs of NCWSC operations (staffing, electricity, chemicals and repairs and maintenance etc) based on information in the company's annual accounts and other information sources. In 2010, the average variable costs per m^3 of water produced of all NCWSC WTW was KES2.20/m^3 including the costs of chemicals, personnel and electricity/fuel oil costs.

b) Pumps Variable Operating Costs

Costs of pumping for boreholes have been estimated based on the lift (head) and the pump discharge with the electricity requirement based on a pump efficiency of 70%.

Energy cost has been calculated at a rate of KES 20/KWh (US$0.20) corresponding to the 2010 industrial rate for electricity provided by Kenya Power and Lighting Company (KPLC).

7.4 Implementation Schedule

7.4.1 Stage 1 Capital Works 2012 – 2017

The implementation schedule for the implementation of Stage 1 capital works is shown in Table 8-34 below. The work is scheduled to begin in the later part of 2012 and to be completed by end of 2016. The Kiunyu well field will come into operation in 2014 followed by Ruiru in 2015 with the Northern Collector and the Ngorongo WTW and transfer main completed and commissioned in 2016. The table below presents the schedule of expenditure 2012 to 2017.

Table 8-34: Summary of Implementation 2012 – 2017

	Totals Including Contingencies						US$'000	Euro'000	
Project Components by Year	2012	2013	2014	2015	2016	2017	Total	Total	1.3
A. Wellfield Development									
1. Groundwater investigation	1,520	1,560	-	-	-	-	3,080	2,369	
2. Kiunyu wellfield	-	15,660	29,428	-	-	-	45,088	34,683	
3. Ruiru wellfield	-	2,654	27,888	-	-	-	30,542	23,494	
Subtotal	1,520	19,874	57,316	-	-	-	78,710	60,546	
B. Northern Collector Phase I								-	
1. Tunnell	13,029	29,612	27,388	20,661	-	-	90,691	69,762	
2. River offtakes and shafts	-	2,499	3,060	-	-	-	5,559	4,276	
Subtotal	13,029	32,111	30,448	20,661	-	-	96,250	74,038	74,038
C. Ngorongo Highlevel Water Treatment Works and Water Mains								-	
1. Ngorongo WTW	-	12,259	22,479	21,744	-	-	56,481	43,447	
2. Transfer mains	-	15,852	31,661	29,948	-	-	77,461	59,585	
Subtotal	-	28,110	54,140	51,692	-	-	133,942	103,032	103,032
D. Nairobi City Network Modification	8,387	18,303	12,311	-	-	-	39,001	30,001	30,001
E. Nairobi City Tertiary Network								-	
1. Tertiary distribution system	2,272	5,417	7,911	-	-	-	15,601	12,000	12,000
2. Individual metered connections	-	1,560	1,603	1,647	1,692	-	6,502	5,001	5,001
3. Informal settlements upgrade	-	1,560	1,603	1,647	1,692	-	6,502	5,001	5,001
Subtotal	2,272	8,538	11,116	3,293	3,385	-	28,604	22,003	22,003
Total PROJECT COSTS	**25,208**	**106,937**	**165,332**	**75,646**	**3,385**	**-**	**376,507**	**289,621**	**229,075**

Note. US$: Euro exchange rate of Euro 1.0 = US$1.30

8 Financial Analysis

This Section presents an analysis of the financial impact on the Stage 1 development programme of Nairobi's water supply system covering six years 2012 to 2017. The financial analysis is conducted from the point of view of the Nairobi City Water Supply Company (NCWSC), the entity responsible for managing the delivery of water and sewerage services to Nairobi city. The sector development costs discussed in the previous chapter and the water demand and supply projections prepared as part of the study have been used to model the financial situation for NCWSC over a 10 year period 2012 to 2022, using an excel-based purpose-made financial model that allows all CAPEX and OPEX parameters to be factored in to the model and the production of financial performance summary tables.

The purpose of the financial analysis is to show the impact the stage 1 development programme will have on the financial performance of NCWSC and to indicate the level of tariffs necessary for the company to produce an acceptable financial return and to be able to operate as a sustainable entity.

8.1 Water Sector Organisation Structure

The Kenyan water sector underwent far-reaching reforms through the Water Act No. 8 of 2002. Previously, service provision had been the responsibility of a single National Water Conservation and Pipeline Corporation as well as of a few local utilities established since 1996. After the passage of the Act service provision was gradually decentralized to 117 Water Service Providers (WSPs). These are linked to eight regional Water Services Boards (WSBs) in charge of asset management through Service Provision Agreements (SPAs). The Act also created a national regulatory board (WASREB) that carries out performance benchmarking and is in charge of approving SPAs and tariff adjustments. The Ministry of Water and Irrigation (MOWI) is in charge of policies for water supply and the Ministry of Public Health and Sanitation (MPHS) is in charge of policies for sanitation. The structure of the water sector is portrayed in the diagram in Figure 8-34.

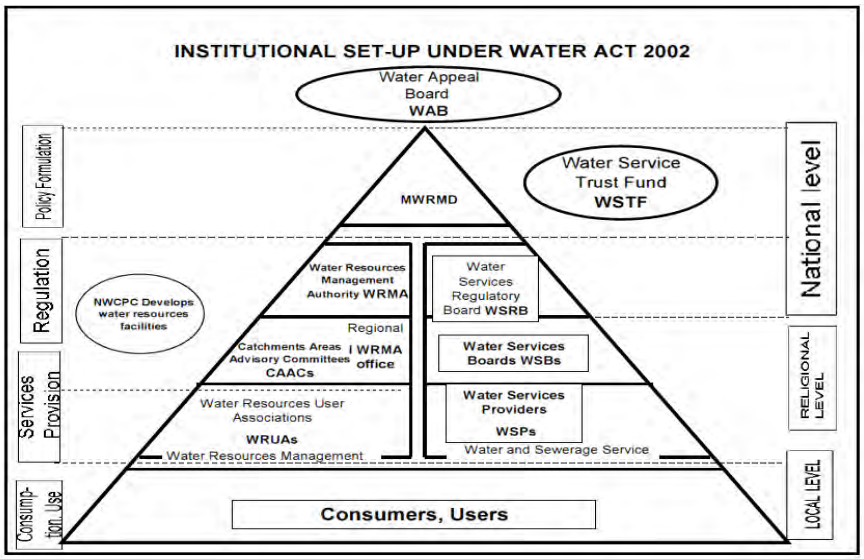


Figure 8-34: Structure of Kenya Water Sector

a) Nairobi City Water Supply and Sewerage

The responsibility for water supply and sewerage in Nairobi City is shared between an asset holding company, Athi Water Services Board (AWSB), and an operating company, the Nairobi City Water and Sewer Company (NCWSC) that operates under contract with the AWSB to provide water and sewerage services to the City. Ten other Water Service Providers (WSPs) operate under the AWSB in localities near Nairobi that are located outside of Nairobi Province. Service standards are set and monitored by a national water regulatory agency called the Water Services Regulatory Board (WASREB).

b) Athi Water Services Board

AWSB, which is located in The Africa Re-Centre building, Hospital Road, Nairobi, comes under the authority of the MOWI and covers its costs through a Regulatory Levy collected from the WSPs. The Minister of MOWI appoints the 8-member Board of AWSB.

c) Nairobi City Water & Sewerage Company

NCWSC was established in 2003 during the reform process and its physical assets were transferred to AWSB as the asset holding company, which signed a performance contract with the new operating utility. The reform was designed to allow utilities to offer higher salaries to qualified staff, to insulate decisions about tariff adjustments from political interference, to improve the financial viability of utilities, and to ultimately improve service quality

The company, which has its headquarters on Kampala Road, Nairobi, is owned by the City and has a supervisory Board of 12 Directors from the Private Sector, Professional Associations, NGOs and the City Council. The day to day business of the company is run by a Managing Director and executive staff. The Company is structured into six administrative regions and is ISO 9001 Certified.

8.1.1 Tariffs

Water tariffs are identical for all Water Service Providers under Contract with the AWSB. Tariff increases are approved by WASREB. In May 2010 a tariff adjustment took effect, bringing residential and commercial tariffs to the level shown in the table below. If there is a sewer connection, there is a sewer surcharge of 75% of the relevant water tariff. Other associated charges for meter rental, tanker water, septic tank evacuation etc. are also shown in the table.

Water kiosks and standpipes in the informal settlements are billed at a lower flat rate of KES15/m^3 independently of consumption, if the kiosk owners are properly registered. Nevertheless, residents in the informal settlements end up paying much more for water. A 20-litre jerry can of water typically sells for KES3 to 5 corresponding to KES150 to KES250 per m^3. This is more than 16 times the water tariff for kiosks and standpipes of KES15/m^3.During droughts prices in the informal settlements rise to KES10 to KES20 per 20l jerry can, corresponding to over KES500per m^3, a very high rate compared to the NCWSC tariff.

a) Tariff Adjustments

Tariff setting is the responsibility of WSBs and WSPs according to operation and maintenance costs. Tariffs have to be approved by WASREB, which can also mandate a WSB to formulate a tariff adjustment. There are three types of tariff adjustments, as described in the Tariff Guidelines: (i) Regular Tariff Adjustments based on the WSPs' business plan; (ii) Extraordinary Tariff Adjustments when the cost structure undergoes significant changes; and (iii) Automatic Tariff Adjustments every 12 months which might be part of a service provision agreement with a WSP.

In 2008 an Extraordinary Tariff Adjustment was granted to all WSPs as an interim measure to assist WSPs to meet their operation and maintenance costs. Tariffs for sewerage services are part of tariff adjustments and the aim is to reach full cost recovery also for sanitation, although it is acknowledged that full cost recovery tariffs for sewerage for certain systems would make the service provision unaffordable for many connected households.

It is proposed by AWSB that there should be tariff adjustment in 2012 to take account of the increase in costs since the last increase and also to provide an increase in income for NCWSC to enable it to pay the increasing debt servicing costs as the grace period of the

development loans come to an end and repayment of principal starts. It is also proposed to increase the sewerage tariff to be the same as the water tariff.

Table 8-35: Current Water and Sewerage Tariffs for Nairobi City

Water

Customer Category	Consumption range (m^3)	Tariff Kshs/m^3
Kiosk & standpipes	Flat rate	15.0
Domestic/Residential, Commercial/Industrial, Government Institutions and Schools	0 to 10 11 to 30 31 to 60 >60	18.71 28.07 42.89 53.80
Bulk sale to WSPs for resale	0 to 10 11 to 30 31 to 60 >60	27
Meter rentals		various

Sewerage

Customer Category	Consumption range (m^3)	Tariff Kshs/m^3
Domestic/Residential, Commercial/Industrial, Government Institutions and Schools	0 to 10 11 to 30 31 to 60 >60	75% of the water tariff of corresponding consumption block

Table 8-36: Other Water and Sewerage Charges

Meter Rent per Month	
Size	**KES**
½ inches	50
¾ inches	100
1 inch	180
1 ½ inch	300
2 inches	450
3 inches	600
4 Inches	750
5 inches	1,000
6 Inches	1,250
7 inches	1,500
Over 8 inches	2,000

Refundable Deposits	
Account type	**KES**
Domestic	2,500
Kiosk	5,000
Commercial	25,000
Industry	50,000
Commercial/	50,000
Construction	600

Other Charges

Size	KES
Connection fee 1/2 to 1 inch	2,500
Connection fee 1/2 to 1 inch	7,500
Connection fee 1/2 to 1 inch	15,000
Reconnection fee - normal	500 and double deposit for every default up to a maximum 2.5 times of your bill
Reconnection fee - all mains	5,000 and double deposit or the cost of reconnection, whichever is higher
Illegal connection - commercial, industry, construction (fraud)	30,000 and double deposit
Illegal connection - domestic (fraud)	15,000 and double deposit
Tanker 8000 litres	2,500 per tanker supplied within the city of Nairobi
Replacement of stolen or damaged metres	200% of the market cost of the metre
Exhauster services	5,000 for other customers and 4000 for informal settlements

8.2 Nairobi Water Supply Development Costs

8.2.1 Capital Development Costs

a) Stage 1 Costs

The capital development costs for stage 1 2012 – 2017 including physical and financial contingencies are the same as detailed in Chapter 12. The costs total US$ 376.507 million made up of US$ 78.7 million for the development of the Kiunyu and Ruiru Wellfields and the groundwater investigation; US$96.250 for northern collector stage 1; US$133.94 million for the Ngorongo WTW and transfer mains; US$39.0 million for the rationalisation and upgrading of the Nairobi distribution network, and a further US$28.6 million for the rehabilitation of the distribution system and increase in the number of individual connections.

It is assumed that under the Stage 1 programme the Northern Collector tunnel and structures will be funded by a World Bank loan while the Ngorongo water treatment works and the transfer pipeline will be funded by AFD. The associated capital investment in rationalising and upgrading of the distribution network down to 150mm pipes will be funded by KfW and the rehabilitation and expansion of the tertiary distribution network and new connections will be funded by the EU and AFD with the Government of Kenya contributing US$6.5 million to the development programme as grant funding to NCWSC.

The World Bank is also funding the construction of a methane gas and power generation facility for the sewerage ponds to the amount of US$15.63 million. This debt will also be allocated to NCWSC. The revenue generated by electricity produced from the methane gas is included in NCWSC's financial projections.[9]

The cost of the development of the private boreholes which assumed to contribute an additional 1000m^3/day per year is not included in the cost estimates. This cost amounts to around US$125,000 per year for an increase in water supply of 1,000 m^3/d.

For the financial analysis the additional capital investment costs over the full programme from 2018 to year 2035 are not included as the financial analysis has a shorter time horizon relating to Stage 1 only. For the economic analysis (described in chapter 14) the full programme costs to year 2035 are allowed for, including the cost of the privately–funded boreholes.

8.2.2 Operation and Maintenance Costs

Operation and maintenance costs for the new infrastructure are included in the financial projections for NCWSC based on historical costs and allowing for the specific electricity costs for the Kiunyu and Ruiru Wellfields, WTWs and extra staff required for the operation of the new assets. The O&M costs have been calculated as unit rate per m^3 of water abstracted and treated.

[9]This facility may also generate revenue through carbon credits, but they have not been included in the analysis.

8.3 Water Supply and Demand Projections

8.3.1 Supply

In Chapter 4, Section 3 details of the water supply projection are presented for the preferred development option Scenario 3A, which allows for the increased contribution from the Ruiru and Kiunyu Well fields, private groundwater development, and the Northern Collector Phase 1. A summary of the projected water supply over the time period 2011 to 2020 corresponding to Stage 1 development phase is shown in the table below. Total available water resources are projected to increase from 541,700 m^3/d in 2011 to 723,500 m^3/d by 2020 to match the projected demand. This is a 33.6 % increase in supply over the time period.

Table 8-37: Nairobi City Projected Water Supply

year		2011	2012	2013	2014	2015	2016	2017	2020
Available Existing Water Resources (m^3/day):									
Kikuyu springs		4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Ruiru Dam		21,000	21,000	21,000	21,000	21,000	21,000	21,000	21,000
Sasumua Dam		56,000	56,000	56,000	56,000	56,000	56,000	56,000	56,000
Thika / Chania / Ngethu System [1]		414,700	414,700	414,700	414,700	414,700	414,700	414,700	414,700
Groundwater Sources from Private Wells [2]		46,000	47,000	48,000	49,000	50,000	51,000	52,000	55,000
Total Existing Water Resources (m^3/day):		**541,700**	**542,700**	**543,700**	**544,700**	**545,700**	**546,700**	**547,700**	**550,700**
Additional Water Resources from Northern Collector	**m^3/s**								
Wellfield in Kiunyu	0.40				34,560	34,560	34,560	34,560	34,560
Wellfield in Ruiru	0.35					30,240	30,240	30,240	30,240
Northern Collector Tunnel Phase I to Thika Dam [3]	1.25						108,000	108,000	108,000
Total New Water Resources (m^3/day):					34,560	64,800	172,800	172,800	172,800
Total All Water Resources (m^3/day):		**541,700**	**542,700**	**543,700**	**579,260**	**610,500**	**719,500**	**720,500**	**723,500**

Source: Consutants estimates

Notes:
1. 98% WEAP and HH Compensation Flow
2. Increasing at 1,000m^3/day per year
3. CF 1xQ95

8.3.2 Demand

Water demand projections for Nairobi city were prepared for the period 2010 to 2035 based on the combination of factors: projected population growth (based on a medium population growth rate); percentage of the population/households supplied by individual connections (IC), and without individual connections (NIC); demand according to income levels (high, medium and low), and industrial water demand. A summary of the net (delivered) projected water demand for the period 2011 to 2020 is shown in Table 8-38 on page 8-130.

Table 8-38: Nairobi City Projected Water Demand (Medium Population Growth)

Year		2011	2012	2013	2014	2015	2016	2017	2020
Population Growth		3.2%	3.2%	3.2%	3.2%	3.2%	3.2%	3.2%	2.9%
Population		3,352,948	3,458,797	3,567,988	3,680,625	3,796,818	3,916,680	4,040,325	4,403,791
Number of HHs	*6*	558,825	576,466	594,665	613,438	632,803	652,780	673,388	733,965
% Pop. supplied by IC		65%	65%	66%	66%	67%	67%	68%	72%
Income levels	(No. / HH)								
High (IC)		6%	6%	6%	6%	6%	6%	6%	6%
No. of HH	*6*	33,529	34,588	35,680	36,806	37,968	39,167	40,403	44,038
Medium (IC)		50%	50%	50%	50%	50%	50%	50%	50%
No. of HH	*6*	279,412	288,233	297,332	306,719	316,402	326,390	336,694	366,983
Low (IC)		9%	9%	10%	10%	11%	11%	12%	16%
No. of HH	*6*	50,294	51,882	59,466	61,344	69,608	71,806	80,807	117,434
Low (NIC)		35%	35%	34%	34%	33%	33%	32%	28%
No. of HH	*6*	195,589	201,763	202,186	208,569	208,825	215,417	215,484	205,510
Total HHs		**558,825**	**576,466**	**594,665**	**613,438**	**632,803**	**652,780**	**673,388**	**733,965**
Domestic Water Demand (m^3/d)	lpcd								
High (IC)	200	40,235	41,506	42,816	44,168	45,562	47,000	48,484	52,845
Medium (IC)	120	201,177	207,528	214,079	220,838	227,809	235,001	242,420	264,227
Low (IC)	60	18,106	18,678	21,408	22,084	25,059	25,850	29,090	42,276
Low (NIC)	30	35,206	36,317	36,393	37,542	37,589	38,775	38,787	36,992
Total Domestic WD		**294,724**	**304,028**	**314,697**	**324,631**	**336,018**	**346,626**	**358,781**	**396,341**
Other Water Demand (Commercial etc.)		96,409	100,169	104,075	108,134	112,352	116,733	121,286	137,219
Net Water Demand	**m^3/d**	**391,133**	**404,197**	**418,772**	**432,765**	**448,370**	**463,359**	**480,067**	**533,560**

Source: Consultants estimates

Total net water demand is projected to increase from 391,133 m^3/d in 2011 to 533,560 m^3/d by 2020, an increase of 36%.

8.3.3 Unaccounted for Water

Unaccounted for Water (UfW) is made up of physical losses through water distribution, transmission and treatment and when added to the total net water demand represents the gross demand for water at source. This does not allow for non-revenue water: taken and used but not paid for. Distribution losses are projected to decrease from 40% to 25% by 2020, as a result of rehabilitation of the distribution system, better leak detection etc., while transmission losses and treatment losses are projected to remain at 4% and 5% respectively. A summary of the projected losses 2011 to 2020 and the gross water demand is shown in the table below. UfW as a percentage of production is projected to decrease from 35% to 27% over this period. Consequently, allowing for this improvement in UfW, gross water demand is projected to increase from 598,964 m^3/d in 2011 to 728,309 m^3/d by 2020, an increase of 22%.

Table 8-39: Nairobi City Projected UfW

Year		2011	2012	2013	2014	2015	2016	2017	2020
Net Water Demand	**m^3/d**	**391,133**	**404,197**	**418,772**	**432,765**	**448,370**	**463,359**	**480,067**	**533,560**
Percent physical losses									
Distribution Losses	**%**	40%	37%	36%	34%	32%	30%	28%	25%
Transmission Losses	**%**	4%	4%	4%	4%	4%	4%	4%	4%
Treatment Losses	**%**	5%	5%	5%	5%	5%	5%	5%	5%
UfW (as % of net demand)		**53%**	**50%**	**48%**	**46%**	**44%**	**42%**	**40%**	**37%**
Losses (m3/day)	**% of UfW**								
Distribution Losses	76%	156,453	151,019	148,794	145,840	142,887	139,178	134,419	133,390
Transmission Losses	11%	21,903	22,209	22,703	23,144	23,650	24,101	24,579	26,678
Treatment Losses	14%	28,474	28,871	29,513	30,087	30,745	31,332	31,953	34,681
Total Physical losses	100%	**206,831**	**202,099**	**201,010**	**199,072**	**197,283**	**194,611**	**190,951**	**194,749**
UfW (as percentage of demand)		53%	50%	48%	46%	44%	42%	40%	37%
UfW (as percentage of production)		35%	33%	32%	32%	31%	30%	28%	27%
Gross Water Demand (m^3/d)		**597,964**	**606,296**	**619,782**	**631,837**	**645,653**	**657,970**	**671,018**	**728,309**

Source: Consultants estimates

8.3.4 Water Balance

A comparison of the gross water demand shown in Table 8-39 and the projected supply in Table 8-37 shows that the supply will begin to fully meet demand in 2016 when the Northern Collector and Kiunyu and Ruiru Wellfields are fully operational. Projected demand will then be fully met until 2020 by the investment in Stage 1.

8.4 Financial Model for NCWSC

The methodology for the financial analysis uses a purpose-made financial model developed for modelling the performance of a water supply company, such as NCWSC. This model was developed by the Asian Development Bank for the financial and economic analysis of water supply and sanitation projects. It has been used by the Consultant for the evaluation of several other water and sanitation development projects and specifically adapted and modified by the Consultant to model the investment programme for NCWSC. The excel-based model applied allows for all the important parameters affecting financial performance to be modelled over a 15 year time period. The main components factored into the model are: capital investment costs (CAPEX), economic factors (exchange rate and projected inflation), debt service parameters, revenue and all operating costs (OPEX).

All costs in the financial model are expressed in KES and an exchange rate of KES 90 to US$1.0 has used to convert foreign costs to local costs. The rate of inflation for Kenya is assumed to be 5% per year.

Output from the model presents the usual financial statements and projections: income, cash flow, profit and loss account, balance sheet etc., and a range of financial performance indicators, including the unit cost structure, tariffs and performance indicators. The model has the facility to calculate the level and increase in the tariffs necessary to achieve profitability over the future time period.

The model can be simply updated with the latest financial accounts from NCWSC and could be used on an on-going basis as a financial planning tool for AWSB NCWSC and other WSPs.

8.4.1 NCWSC Accounts

The latest available annual report and financial accounts for NCWSC for the years ended 30th June 2009 and 2010 and the draft accounts for the year ended 30th June 2011 are used to set up the model and as a basis for establishing the annual operating expenses.

a) Operating Income

NCWSC's gross operating income is over KES 5 billion per year with around 55% derived from water sales, 35% from sewerage services and the remaining 10% from meter rental and miscellaneous charges (meter rental, septic tank exhauster services, sale of tanker water etc.). A summary for the last three years is shown in Table 8-40.

Table 8-40: NCWSC Operating Income

KES Million			
Item	**2011**	**2010**	**2009**
Water sales	3,209.6	2,710.3	2,211.5
Sewer services	2,035.0	1,802.1	870.7
Meter rental	181.1	177.8	94.1
Miscellaneous	311.9	361.2	296.3
Total	**5,737.6**	**5,051.4**	**3,472.6**

Source: NCWSC Annual Accounts

b) Maintenance Costs

Annual maintenance costs from NCWSC's annual accounts are shown in Table 8-41.

Table 8-41: NCWSC Maintenance costs

KES Million			
Item	**2011**	**2010**	**2009**
Ground	5,169.2	0.4	4,189.7
Plant and machinery	34,116.2	22,771.3	31,598.9
Buildings	4,416.8	1,588.6	3,137.3
Equipment	24,310.3	6,964.9	7,120.9
Motor vehicles	71,412.2	63,986.8	38,197.6
Furniture and fittings	1.4	0.5	1,321.3
Software	0.2	0.8	0.3
Water fittings and accessories	160,349.3	114,956.7	116,493.6
Water meters	41,158.9	26,057.8	31,297.9
Total	**342,514.5**	**238,139.2**	**233,669.0**

Source: NCWSC Annual Accounts

A summary of operating costs for the three years 2009, 2010 and 2011 is shown in Table 8-42 on page 8-133.

The licensing, lease and levy expenses comprise lease fees payable to AWSB for the use of assets belonging to Nairobi City Council based on the guidelines from the WSRB.

In the last year's accounts for the years ended 30th June 2011 total operating expenses were KES1.923 billion equivalent to US$21 million. The largest item in the operating expenses is for licensing, lease and levy accounting for 35% of the total. Excluding this item and the cost of asset renewal, the remaining contribution of the other costs are as follows:

Item	Average cost/year (2009 – 2011)	% of total
Chemicals	179,180,073	20%
Electricity	194,831,527	22%
Vehicle & Equipment expenses	80,996,453	9%
Office & Admin expenses	436,274,786	49%
Total	**891,282,839**	**100%**
Licensing, lease and levy	573,328,742	
Asset Renewal(AWSB)	166,666,667	
Grand Total	**1,631,278,248**	

Table 8-42: NCWSC Operating Expenses

Year ended 30th June (Kshs)	2011	2010	2009
Chemicals	175,565,750	203,780,440	158,194,028
Electricity	211,000,808	203,137,091	170,356,682
Vehicle & Equipment expenses			
Fuel, oil and lubricants	75,946,206	66,674,198	65,483,529
Hire of equipment and Vehicles	10,735,948	0	
Tyres and related accessories	10,391,143	5,848,114	7,910,221
Total Vehicle & Equipment	**97,073,297**	**72,522,312**	**73,393,750**
Office & Admin expenses			
Office supplies	32,754,548	30,103,879	35,332,483
Postal and couriers	57,042,585	37,149,399	53,483,266
Insurance	65,379,719	60,208,228	47,545,032
Rent and rates	24,808,560	13,047,501	11,310,100
Telecommunications	38,052,550	26,059,584	21,897,791
Bank charges	7,668,928	7,118,720	8,790,639
Security	39,715,049	22,268,111	24,246,854
Publicity and advertising	50,826,522	58,453,407	43,295,699
Library	2,950	3,174	77,893
Water and conservancy	2,270,248	5,658,450	266,333
AGM Expenses	1,505,375	8,000,000	8,000,000
Audit fees	3,058,300	2,768,000	2,781,331
Legal fees	19,300,730	5,000,705	12,871,057
Claims, damages and compensation	1,794,524	216,600	114,900
Miscellaneous expenses	1,001	3,541,725	5,026,607
Donations/Corporate Social Responsibility	10,759,632	577,843	621,658
Corporate year end party	3,393,172	0	
Board remuneration	4,742,494	7,445,390	10,302,712
Consultancy	18,422,219	12,934,376	21,887,133
Uniforms and protective clothing	13,364,129	8,431,146	9,946,419
Travelling and subsistence - local	50,246,611	21,930,636	13,639,976
Travelling and subsistence - external	12,641,384	4,652,474	3,119,384
Staff development	44,231,477	54,552,715	20,831,466
Commissions	10,547,557	32,745,832	14,000,858
Sports and recreation	14,796,241	0	
Total Office and Admin	**516,566,873**	**422,867,895**	**369,389,591**
Licensing, lease and levy	673,187,540	526,227,562	520,571,124
Asset Renewal(AWSB)	250,000,000	250,000,000	0
Total	**1,923,394,268**	**1,678,535,300**	**1,291,905,175**

Source: NCWSC annual accounts 2009, 2010, 2011

Office and administration expenses contribute 49% to these costs followed by electricity and chemicals at 22% and 20% respectively.

Staff costs in 2011 were a total of KES2.085 billion, and with an average cost of KES997,057 per staff member. A breakdown of staff costs is shown in the Table 8-43 on page 8-134.

Table 8-43: NCWSC Staff Costs 2009 - 2011

KES			
Item	**2011**	**2010**	**2009**
Salaries and Wages	1,029,506,715	822,904,364	650,979,391
House Allowances	299,940,214	272,298,642	222,031,294
Leave Allowances	71,542,979	22,292,048	19,154,042
Bonus	8,365,153	13,527,804	14,843,716
Overtime	141,330,866	94,176,788	79,035,823
Retirement Benefits	209,777,508	115,456,846	93,553,273
Other Allowances	170,231,948	131,906,309	86,278,597
Medical Expenses	37,813,144	20,905,574	25,513,097
Staff Awards	3,366,000	340,000	142,000
Leave Pay Provision	92,660,107	38,732,243	38,883,560
Welfare	20,311,076	7,554,406	3,005,151
Total	**2,084,845,710**	**1,540,095,024**	**1,233,419,944**
Number of Staff	2,091	1,972	1,956
Average Cost per Staff	**997,057**	**780,981**	**630,583**

8.4.2 Capital Investment

The projected capital investment in increasing the water supply for Nairobi over the 2012 – 2020 time period and the associated investment in the rehabilitation, rationalisation of the water distribution system and the increase in the number and percentage of consumers with individual connections will be funded by development loans from several sources, according to the capital investment costs schedule discussed above. A summary of the likely source of the capital development and debt servicing commitments for AWSB / NCWSC for different packages is shown in Table 8-44. These parameters have been used in the NCWSC financial model, but will be subject to further negotiation and clarification when the funding arrangements are confirmed.

Table 8-44: Capital Investment Source and Conditions- Stage 1

Source	CAPEX 2012-2017 (US$ mill)	Euro (mill)	Loan Conditions	Interest Rate
World Bank			32 year term including 8 year grace period	1.50%
Wellfield Development	$75			
Northern Collector 1	$95			
Sewage Power Plant	$15			
AFD			25 year term including 8 year grace period Commitment fee 0.5%	2.44%
Ngorongo WTW	$56	€43.5		
Transfer Main	$77	€60.0		
Tertiary system	$22.1	€17		
KfW Nairobi City Network Modification	$39	€30.0	30 year term including 5 year grace period	2.30%
Govt of Kenya Nairobi City Distribution Network & Connections	$6.5	€5.0	Grant funds	–

8.4.3 Water Supply Connections

Of Nairobi's 3.25 million inhabitants only about 50 % have direct access to piped water through an individual connection. The rest obtain water from kiosks, vendors, illegal connections or from wells. Only about 40% of those with access to piped water receive water 24 hours per day

In Kibera and other informal settlements of Nairobi water is supplied through water kiosks, almost all of which are privately owned and financed by the owners with construction of the kiosks and the pipes connecting to the water mains. Currently only about 2% are operated by community-based organizations or NGOs.

The number of connections divided between individual (IC) and non individual (NIC) and the assumed increase in ICs per year for high, medium and low households consumption bands over the period 2011 to 2020 is shown in the Table 8-45. These data are used in the financial model to project the income stream for NCWSC.

Table 8-45: Projected Water Supply Connections for Nairobi City

Year		2010	2011	2012	2013	2014	2015	2016	2017	2020
Number of Connections										
IC - Individual Connections	No. of hhs	352,120	363,236	374,703	392,479	404,869	423,978	437,363	457,904	528,455
NIC - No Individual Connections	"	189,603	195,589	201,763	202,186	208,569	208,825	215,417	215,484	205,510
Total HH		**541,723**	**558,825**	**576,466**	**594,665**	**613,438**	**632,803**	**652,780**	**673,388**	**733,965**
Low Income Households										
No. of low income HHs	Low IC	48,755	245,883	253,645	261,652	269,913	278,433	287,223	296,291	322,945
(at 6 members per HH)	Low NIC	189,603	195,589	201,763	202,186	208,569	208,825	215,417	215,484	205,510
	Total	**238,358**	**441,472**	**455,408**	**463,838**	**478,481**	**487,258**	**502,641**	**511,775**	**528,455**
Increase in IC / year										
	High		1,026	1,058	1,092	1,126	1,162	1,199	1,236	3,635
No. of new connections per year	Med		8,551	8,821	9,099	9,386	9,683	9,988	10,304	30,289
	Low		1,539	1,588	7,585	1,877	8,265	2,197	9,001	36,628
	Total		**11,116**	**11,467**	**17,776**	**12,390**	**19,109**	**13,385**	**20,541**	**70,551**

Source: Consultants' Estimates

8.4.4 Financial Analysis

The Excel financial model produces several summary tables as outputs. Table 8-46 on page 8-137 provides a summary of the projections for the period 2010 to 2025 showing: Income Statements, Cash Flow Statement (source and application of funds), Balance Sheets, and Financial Ratios. The other main summary tables which provide more details are included in the following sections.

Performance indicators

Net income after meeting operating expenses, depreciation, interest payments and tax is shown to remain positive throughout the period.

In terms of the three main financial ratios shown in the summary tables the financial projections indicate the following.

Cost Recovery Ratio (CRR): This is the ratio of revenue to total operating costs, and is a key indicator of financial performance. If it equals 1.0 the operation as a whole is breaking even; if it exceeds 1.0 it is earning a surplus, while if it is below 1.0 the operation is losing

money. Typical cost recovery ratios for a profitable business operation lie between 1.1 and 1.15.

For NCWSC the CRR turns below 1.0 from 2013 to 2015 but rises to a healthier 1.5 before reducing to 1.3 in 2020 when the debt repayment for the loans begins.

Debt Service Ratio (DSR). This is the ratio of cash available for debt servicing of interest, principal and lease payments. It is used in the measurement of an entity's ability to produce enough cash to cover its debt (including lease) payments. The higher this ratio is, the better the situation.

For NCWSC the DSR is very healthy throughout the period indicating that the entity can cover it debt serving obligations but begins to deteriorate after 2020 when the main loan repayments begin.

Debt – Asset Ratio (DAR). The debt/asset ratio shows the proportion of a company's assets which are financed through debt. If the ratio is less than 0.5, most of the company's assets are financed through equity. If the ratio is greater than 0.5, most of the company's assets are financed through debt, indicating that the company is “highly leveraged."

In NCWSC’s case the ratio shows the company is highly leveraged with most of the assets funded through debt. This is largely brought about by the situation that most of the original assets are not being held by the company for which it pays a lease fee to AWSB for the use of the assets, therefore the situation is distorted.

Table 8-46: NCWSC Summary Projections 2010 – 2025

Summary Financial Projections
(KES million - current prices)

	Actual/Estimated		Projected													
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Income Statements																
Operating Revenue	5,051.4	5,736.5	6,151.9	6,640.3	7,619.2	8,765.6	10,237.9	13,244.3	15,367.8	16,804.9	19,410.2	17,253.4	17,761.1	18,284.2	18,823.0	19,351.0
Operating Expenses	3,466.6	4,360.6	4,583.1	4,816.9	5,472.8	6,130.1	6,011.7	6,362.6	6,942.9	7,573.5	8,211.7	8,655.0	8,878.3	9,107.3	9,342.3	9,583.3
Depreciation	177.9	191.7	30.8	54.5	303.6	556.5	895.5	899.3	899.3	899.3	899.3	899.3	899.3	899.3	899.3	899.3
Operating Income	1,406.8	1,184.2	1,538.1	1,768.9	1,842.7	2,078.9	3,330.7	5,982.4	7,525.5	8,332.0	10,299.2	7,699.1	7,983.5	8,277.5	8,581.4	8,868.4
Operating Subsidies	10.1	(37.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net Non-Operating Expenses	1,188.2	164.9	173.1	470.3	493.8	518.5	544.4	571.6	600.2	630.2	661.8	686.6	703.7	721.3	739.4	757.8
Interest & Other Financial Expenses	72.9	57.6	143.7	429.8	803.4	1,240.3	1,594.8	1,814.8	1,954.1	2,011.5	2,132.5	2,245.7	2,283.4	2,211.0	2,031.8	1,743.1
Income Tax	0.0	0.0	244.3	173.8	109.1	64.0	238.3	719.2	994.2	1,138.0	1,501.0	953.4	999.3	1,069.0	1,162.0	1,273.5
Net Income	145.7	924.7	977.0	695.1	436.4	256.1	953.2	2,876.7	3,976.9	4,552.2	6,004.0	3,813.5	3,997.1	4,276.1	4,648.1	5,093.9
Cash Flow Statements																
Sources																
Internal Cash	400.8	1,166.3	1,151.5	1,179.4	1,543.4	2,053.0	3,443.4	5,590.9	6,830.4	7,463.0	9,035.8	6,958.5	7,179.9	7,386.5	7,579.3	7,736.4
Debt	14.0	0.0	4,135.6	11,003.1	16,339.5	9,080.7	2,239.4	1,575.0	800.0	210.0	1,200.0	1,085.0	80.0	0.0	0.0	0.0
Equity Contributions	0.0	160.0	64.3	187.0	257.1	40.9	35.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	160.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	414.8	1,486.3	5,351.4	12,369.4	18,140.0	11,174.5	5,717.9	7,165.9	7,630.4	7,673.0	10,235.8	8,043.5	7,259.9	7,386.5	7,579.3	7,736.4
Applications																
Capital Investments	0.0	0.0	2,472.9	9,890.1	15,320.6	6,486.6	154.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Working Capital Increase (Decrease)	0.0	530.3	(1,947.5)	(761.4)	(341.8)	756.4	813.3	(33.4)	(225.9)	(261.9)	(182.6)	52.5	62.7	125.4	(9.3)	(17.9)
Interest	72.9	57.6	288.3	596.2	891.5	1,259.6	1,594.8	1,814.8	1,954.1	2,011.5	2,132.5	2,245.7	2,283.4	2,211.0	2,031.8	1,743.1
Debt Repayment	65.0	120.0	0.0	0.0	0.0	0.0	0.0	140.4	140.4	140.4	916.3	1,599.1	1,599.1	2,349.1	3,299.1	4,174.1
Other	0.0	0.0	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.3	0.3	0.3	0.3
Total	137.9	708.0	814.2	9,725.3	15,870.8	8,502.9	2,563.0	1,922.3	1,869.1	1,890.6	2,866.8	3,897.8	3,945.6	4,685.9	5,322.1	5,899.7
Cash Changes	277	778	4,537	2,644	2,269	2,672	3,155	5,244	5,761	5,782	7,369	4,146	3,314	2,701	2,257	1,837
Ending Cash Balance	621	1,239	5,776	8,420	10,689	13,361	16,516	21,760	27,521	33,303	40,672	44,818	48,132	50,833	53,090	54,927
Balance Sheets																
Assets																
Current Assets	3,636	5,047	7,639	10,426	12,981	15,985	19,566	24,924	30,748	36,596	44,184	47,990	51,397	54,193	56,548	58,481
Net Fixed Assets	576	384	1,304	10,599	21,026	22,321	33,286	32,387	31,487	30,588	29,689	28,789	27,890	26,991	26,091	25,192
Work in Progress	0	0	1,667	2,374	7,052	11,706	0	0	0	0	0	0	0	0	0	0
Other Assets	12	8	8	9	9	10	10	11	11	12	12	13	13	13	14	14
Total	4,224	5,439	10,618	23,408	41,068	50,021	52,862	57,321	62,247	67,196	73,885	76,792	79,300	81,197	82,653	83,687
Liabilities and Equity																
Current Liabilities	1,932	2,075	3,804	6,008	7,912	10,122	11,996	13,718	14,807	16,121	18,405	19,098	19,208	18,427	16,835	14,374
Long Term Debt	711	785	2,545	12,248	27,312	33,758	33,737	33,596	33,456	32,539	30,940	29,341	27,742	26,143	24,544	22,945
Equity	1,580	2,580	4,269	5,151	5,845	6,142	7,130	10,007	13,984	18,536	24,540	28,353	32,350	36,626	41,275	46,368
Total	4,224	5,439	10,618	23,408	41,068	50,021	52,862	57,321	62,247	67,196	73,885	76,792	79,300	81,197	82,653	83,687
Financial Ratios																
Cost Recovery Ratio	1.1	1.1	1.5	0.9	0.9	0.9	1.1	1.4	1.5	1.5	1.5	1.2	1.2	1.2	1.3	1.3
Debt Service Ratio	2.9	6.6	4.0	2.0	1.7	1.6	2.2	2.9	3.3	3.5	3.0	1.8	1.8	1.9	2.1	2.3
Debt - Asset Ratio	0.2	0.2	0.4	0.7	0.8	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4

Table 8-47: NCWSC Key Performance Indicators 2010– 2025

Key Performance Indicators	Actual/Estimated		Projected													
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Operating Data																
Net Water Supplied (1000 m^3/d)	353.68	354.33	361.80	367.36	396.75	423.96	463.36	480.07	494.05	508.44	533.56	540.26	541.00	541.73	542.46	543.19
Population Served (IC & NIC) (1000s)	3,250.34	3,352.95	3,458.80	3,567.99	3,680.63	3,796.82	3,916.68	4,040.33	4,158.02	4,279.14	4,403.79	4,525.22	4,650.00	4,778.22	4,909.97	5,007.27
Actual Water Production (1000 m^3/d)	540.70	541.70	542.70	543.70	579.26	610.50	657.97	671.02	690.56	710.68	728.31	737.46	738.46	739.46	740.46	741.46
Non Revenue Water (% of production)	35%	35%	33%	32%	32%	31%	30%	28%	28%	28%	27%	27%	27%	27%	27%	27%
Average Water Consumption (All lpcd)	116	117	117	117	118	118	118	119	119	119	121	122	123	123	124	126
Average Tariffs (KES/m3 - current prices)																
Expressed on Basis of Water Consumed:																
Accrual Basis	0.00	34.33	36.08	37.89	39.82	41.82	43.95	46.16	48.47	50.89	53.53	55.05	56.62	58.23	59.89	61.49
Cash Basis	21.00	24.81	24.88	26.64	28.48	30.27	32.02	34.47	37.14	39.96	43.20	45.37	46.64	47.94	49.28	50.60
Cost Recovery & Profitability																
Operating Ratio (%)	72%	79%	79%	76%	77%	77%	70%	60%	58%	57%	55%	61%	61%	61%	61%	61%
Working Ratio (%)	69%	76%	78%	75%	73%	71%	61%	53%	52%	52%	50%	56%	56%	56%	56%	56%
Return on Equity	10.0%	44.1%	28.5%	14.8%	7.9%	4.3%	14.4%	33.6%	33.2%	28.0%	27.9%	14.4%	13.2%	12.4%	11.9%	11.6%
Collection Performance																
Average Collection Performance (%)	61%	72%	71%	72%	73%	74%	75%	77%	79%	81%	83%	83%	83%	83%	83%	83%
Accounts Receivable (Days Worth of Billings	190	207	100	100	100	100	100	80	70	65	60	60	60	60	60	60
Cost Efficiency & Effectiveness (KES/m3 - current prices)																
Cash O&M	17.57	22.05	23.14	24.27	25.88	27.51	25.03	25.98	27.55	29.20	30.89	32.15	32.94	33.74	34.57	35.41
Depreciation Expense	0.90	0.97	0.16	0.27	1.44	2.50	3.73	3.67	3.57	3.47	3.38	3.34	3.34	3.33	3.33	3.32
Liquidity & Cash Flow																
Cash (Days Worth of Cash O&M)	65	104	460	638	713	796	1,003	1,248	1,447	1,605	1,808	1,890	1,979	2,037	2,074	2,092
Cash (Days Worth of Cash Obligations)	48	92	400	563	642	727	887	1,019	1,158	1,282	1,315	1,375	1,442	1,401	1,332	1,270
Current Ratio	1.9	2.4	2.0	1.7	1.6	1.6	1.6	1.8	2.1	2.3	2.4	2.5	2.7	2.9	3.4	4.1
Debt - Asset Ratio	0.22	0.17	0.41	0.66	0.77	0.82	0.81	0.78	0.73	0.67	0.62	0.59	0.55	0.51	0.46	0.40
Self Financing Ratio (%) - Annual	NA	NA	108%	9%	1%	-19%	-362%	NA	NA	NA	NA	NA	NA	NA	NA	NA
Self Financing Ratio (%) - 3 Year Average	NA	NA	65%	10%	2%	-16%	-25%	NA	NA	NA	NA	NA	NA	NA	NA	NA
Covenant Compliance																
Cost Recovery Ratio 1	1.05	1.21	1.16	1.10	1.09	1.10	1.22	1.38	1.45	1.46	1.45	1.22	1.23	1.18	1.14	1.10
Cost Recovery Ratio 2	1.07	1.06	1.50	0.92	0.86	0.85	1.07	1.41	1.51	1.53	1.49	1.23	1.23	1.24	1.28	1.31
Debt Service 1 (Total Debt)	2.91	6.57	3.99	1.98	1.73	1.63	2.16	2.86	3.26	3.47	2.96	1.81	1.85	1.62	1.42	1.31
Debt Service 2 (Long-Term Debt)	2.91	6.57	3.99	1.98	1.73	1.63	2.16	2.86	3.26	3.47	2.96	1.81	1.85	1.94	2.09	2.31
Depreciation Covered (%)	891	718	5,099	3,344	707	474	472	765	937	1,026	1,245	956	988	1,020	1,054	1,086
Return on Net Fixed Assets (%)	211.64	246.74	182.26	29.72	11.65	9.59	11.98	18.22	23.56	26.84	34.17	26.33	28.17	30.17	32.33	34.59

a) Tariffs and Unit Costs

The following two tables show the tariff structure over the period and the unit cost structure, in current and constant prices. For current prices the model allows for annual inflation so the tariffs increase over the period by the annual inflation rate (5% per year) while in constant prices they remain more or less the same with changes in the weighted average tariff over time due to the changing mix of consumption bands. The model allows for changes to be made to the tariff levels which would them show as a change in the tariff level in constant prices, or real terms, in this summary table.

The unit costs show the average unit cost per m^3 of water produced for the main cost items over the period, in current and constant prices. These costs can be compared to the average water tariff to indicate if the average tariff on a cash basis is sufficient to meet the production cost, although the additional revenue from sewage services and income from electricity generated from the sewage ponds also contribute to revenue.

As can be seen salary expenses are the largest cost component contributing almost half to O&M costs.

8.4.5 Conclusion and Discussion

The financial analysis of NCWSC shows that the company can maintain profitability and produce acceptable financial returns according to the projections in the model. However an overriding aspect of this performance is the assumed increase in efficiency in reducing the UfW and increasing the number of individual connections which contributes to better performance and revenue generation.

The most useful aspect of the model is its potential for use on monitoring the performance of NCWSC with regular revision to accommodate changes in the pricing structure and key unit rates. The model can be used to quickly test for changes in the tariff structure in a “what if” fashion and be used to determine changes in the tariff necessary to maintain financial viability and sustainability.

Table 8-48: NCWSC Actual and Projected Water Tariffs 2010 – 2020

Actual & Projected Water Tariffs

	Actual/Estimated		Projected								
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
By Consumption Block											
(KES/m3 water consumed - current prices)											
0 -10 m^3/month											
Tariff - Beginning of Year	0.00	18.71	18.71	19.65	20.63	21.66	22.74	23.88	25.07	26.33	27.64
Tariff - End of Year	0.00	18.71	19.65	20.63	21.66	22.74	23.88	25.07	26.33	27.64	29.03
Weighted Average Tariff	18.71	18.71	19.65	20.63	21.66	22.74	23.88	25.07	26.33	27.64	29.03
11 -30 m^3/month											
Tariff - Beginning of Year	0.00	28.07	28.07	29.47	30.95	32.49	34.12	35.83	37.62	39.50	41.47
Tariff - End of Year	0.00	28.07	29.47	30.95	32.49	34.12	35.83	37.62	39.50	41.47	43.55
Weighted Average Tariff	28.07	28.07	29.47	30.95	32.49	34.12	35.83	37.62	39.50	41.47	43.55
31 - 60 m^3 /month											
Tariff - Beginning of Year	0.00	42.89	42.89	45.03	47.29	49.65	52.13	54.74	57.48	60.35	63.37
Tariff - End of Year	0.00	42.89	45.03	47.29	49.65	52.13	54.74	57.48	60.35	63.37	66.54
Weighted Average Tariff	42.89	42.89	42.90	45.04	47.30	49.66	52.14	54.75	57.49	60.36	63.38
>60 m^3 /month											
Tariff - Beginning of Year	0.00	53.80	53.80	56.49	59.31	62.28	65.39	68.66	72.10	75.70	79.49
Tariff - End of Year	0.00	53.80	56.49	59.31	62.28	65.39	68.66	72.10	75.70	79.49	83.46
Weighted Average Tariff	53.80	53.80	53.80	56.49	59.31	62.28	65.39	68.66	72.10	75.70	79.49
Kiosks											
Tariff - Beginning of Year	0.00	15.00	15.00	15.75	16.54	17.36	18.23	19.14	20.10	21.11	22.16
Tariff - End of Year	0.00	15.00	15.75	16.54	17.36	18.23	19.14	20.10	21.11	22.16	23.27
Weighted Average Tariff	15.00	15.00	15.75	16.54	17.36	18.23	19.14	20.10	21.11	22.16	23.27
Weighted Average Tariff (KES/m^3 water consumed)											
Expressed on Accrual Basis - current prices:											
Tariff - Beginning of Year	0.00	34.33	34.36	36.08	37.93	39.83	41.86	43.96	46.16	48.47	50.98
Tariff - End of Year	0.00	34.33	36.08	37.89	39.82	41.82	43.95	46.16	48.47	50.89	53.53
Weighted Average Tariff	0.00	34.33	36.08	37.89	39.82	41.82	43.95	46.16	48.47	50.89	53.53
Expressed on Accrual Basis - constant prices:											
Tariff - Beginning of Year	0.00	34.33	32.73	32.73	32.76	32.77	32.80	32.80	32.80	32.80	32.86
Tariff - End of Year	0.00	34.33	34.36	34.37	34.40	34.40	34.44	34.44	34.44	34.44	34.51
Weighted Average Tariff	0.00	34.33	34.36	34.37	34.40	34.40	34.44	34.44	34.44	34.44	34.51
Expressed on Cash Basis:											
Current prices	21.00	24.81	24.88	26.64	28.48	30.27	32.02	34.47	37.14	39.96	43.20
Constant prices	21.00	24.81	23.70	24.16	24.60	24.90	25.09	25.73	26.40	27.04	27.85

Table 8-49: NCWSC Unit Cost Structure (Current and Constant Price Basis) 2010 – 2020

Unit Cost Structure
(KES/m^3 water produced)

	Actual/Estimated		*Projected*							
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Current Price Basis										
Operating & Maintenance Expenses										
Salary Expense	7.80	10.54	11.05	11.58	11.50	11.54	11.60	11.89	12.13	12.37
Electricity Expense	1.03	1.07	1.12	1.18	2.70	4.03	1.36	1.53	2.41	3.34
Chemicals Expense	1.03	0.89	0.93	0.98	1.03	1.08	1.13	1.19	1.25	1.31
Operation & Maintenance Expenses	1.57	2.22	2.33	2.45	2.50	2.56	2.60	2.71	2.81	2.91
Asset Replacement Charges	1.27	1.26	1.33	1.39	1.46	1.54	1.61	1.69	1.78	1.87
Office and Admin.	2.14	2.61	2.74	2.88	2.93	3.01	3.05	3.18	3.30	3.42
Resource Cost of Raw Water	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.07
Lease fee payment to AWSB	2.67	3.40	3.57	3.75	3.71	3.70	3.61	3.72	3.81	3.89
Total Operating & Maintenance	**17.57**	**22.05**	**23.14**	**24.27**	**25.88**	**27.51**	**25.03**	**25.98**	**27.55**	**29.20**
Depreciation	0.90	0.97	0.16	0.27	1.44	2.50	3.73	3.67	3.57	3.47
Interest Expense	0.37	0.29	0.73	2.17	3.80	5.57	6.64	7.41	7.75	7.75
Total	**18.84**	**23.32**	**24.02**	**26.71**	**31.12**	**35.57**	**35.40**	**37.06**	**38.87**	**40.42**
Constant Price Basis										
Operating & Maintenance Expenses										
Salary Expense	7.80	10.54	10.52	10.51	9.93	9.49	9.09	8.87	8.62	8.38
Electricity Expense	1.03	1.07	1.07	1.07	2.33	3.32	1.07	1.14	1.71	2.26
Chemicals Expense	1.03	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Operation & Maintenance Expenses	1.57	2.22	2.22	2.22	2.16	2.11	2.04	2.02	1.99	1.97
Asset Replacement Charges	1.27	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Office and Admin.	2.14	2.61	2.61	2.61	2.53	2.47	2.39	2.37	2.34	2.32
Resource Cost of Raw Water	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lease fee payment to AWSB	2.67	3.40	3.40	3.40	3.20	3.04	2.83	2.78	2.71	2.63
Total Operating & Maintenance	**17.57**	**22.05**	**22.04**	**22.02**	**22.36**	**22.63**	**19.61**	**19.39**	**19.58**	**19.76**
Depreciation	0.90	0.97	0.15	0.25	1.24	2.05	2.92	2.74	2.54	2.35
Interest Expense	0.37	0.29	0.69	1.96	3.28	4.58	5.20	5.53	5.51	5.25
Total	**18.84**	**23.32**	**22.87**	**24.23**	**26.88**	**29.27**	**27.74**	**27.65**	**27.62**	**27.36**

Table 8-50: NCWSC Income Statements 2010 – 2020

Income Statements
(KES million - current prices)

	Actual/Estimated		Projected								
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Operating Revenue											
Sales Revenue	5,051.4	5,736.5	6,151.9	6,640.3	7,619.2	8,765.6	10,237.9	13,244.3	15,367.8	16,804.9	19,410.2
Water	2,710.3	3,208.6	3,285.6	3,571.9	4,123.8	4,683.5	5,414.8	6,040.7	6,698.0	7,415.2	8,413.7
Sewerage	1,802.0	2,035.0	2,287.0	2,438.6	2,768.1	3,106.2	3,568.2	5,823.4	7,157.9	7,734.8	9,148.2
Other (meter rent, connections, tankers)	539.0	492.9	579.4	629.9	727.2	825.9	954.8	1,065.2	1,181.1	1,307.6	1,483.7
Electricity generation	-	-	-	-	-	150.0	300.0	315.0	330.8	347.3	364.7
Less: VAT & Other Taxes	-	-	-	-	-	-	-	-	-	-	-
Total Operating Revenue	**5,051.4**	**5,736.5**	**6,151.9**	**6,640.3**	**7,619.2**	**8,765.6**	**10,237.9**	**13,244.3**	**15,367.8**	**16,804.9**	**19,410.2**
Operating Expenses											
Salary Expense	1,540.1	2,084.8	2,189.1	2,298.5	2,430.8	2,570.5	2,785.6	2,911.5	3,057.0	3,209.9	3,370.4
Electricity Expense	203.1	211.0	222.0	233.5	571.1	898.5	327.1	374.7	606.3	866.9	1,120.2
Chemicals Expense	203.8	175.6	184.7	194.3	217.3	240.5	272.2	291.4	314.9	340.3	366.2
Operation & Maintenance Expenses	310.7	439.6	462.4	486.4	527.9	570.2	623.8	662.7	707.5	755.6	805.1
Asset Replacement Charges	250.0	250.0	263.0	276.6	309.5	342.5	387.6	415.0	448.4	484.6	521.4
Office and Admin.	422.9	516.6	543.4	571.6	620.4	670.1	733.1	778.7	831.4	887.9	946.1
Resource Cost of Raw Water	9.9	9.9	10.4	10.9	12.2	13.5	15.3	16.4	17.7	19.2	20.6
Lease fee payment to AWSB	526.2	673.2	708.2	744.9	783.6	824.3	867.1	912.1	959.5	1,009.3	1,061.7
Sales tax	-	-	-	-	-	-	-	-	-	-	-
Total Operating Expenses	**3,466.6**	**4,360.6**	**4,583.1**	**4,816.9**	**5,472.8**	**6,130.1**	**6,011.7**	**6,362.6**	**6,942.9**	**7,573.5**	**8,211.7**
US$ million	*38.52*	*48.45*	*50.92*	*53.52*	*60.81*	*68.11*	*66.80*	*70.70*	*77.14*	*84.15*	*91.24*
Income before Depreciation	**1,584.7**	**1,375.9**	**1,568.9**	**1,823.4**	**2,146.3**	**2,635.5**	**4,226.2**	**6,881.8**	**8,424.9**	**9,231.3**	**11,198.5**
Depreciation	177.89	191.66	30.8	54.5	303.6	556.5	895.5	899.3	899.3	899.3	899.3
Operating Income	**1,406.84**	**1,184.22**	**1,538.1**	**1,768.9**	**1,842.7**	**2,078.9**	**3,330.7**	**5,982.4**	**7,525.5**	**8,332.0**	**10,299.2**
Operating Subsidies	10.06	-36.97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Operating Revenue (Grant income)	10.39	261.69	274.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Operating Expenses (prov for bad debts)	1,198.60	426.57	447.9	470.3	493.8	518.5	544.4	571.6	600.2	630.2	661.8
Interest & Other Financial Expenses	72.9	57.6	143.7	429.8	803.4	1,240.3	1,594.8	1,814.8	1,954.1	2,011.5	2,132.5
Other Financial Expenses (int on cust deposits)	5.75	7.71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Profit Before Income Tax	**150.0**	**917.0**	**1,221.3**	**868.8**	**545.5**	**320.1**	**1,191.5**	**3,595.9**	**4,971.2**	**5,690.2**	**7,505.0**
Income Tax	0.00	0.00	244.3	173.8	109.1	64.0	238.3	719.2	994.2	1,138.0	1,501.0
Net Income	**150.0**	**917.0**	**977.0**	**695.1**	**436.4**	**256.1**	**953.2**	**2,876.7**	**3,976.9**	**4,552.2**	**6,004.0**

Income Statements
(KES million - current prices)

	Actual/Estimated		Projected								
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Operating Revenue											
Sales Revenue	5,051.4	5,736.5	6,151.9	6,640.3	7,619.2	8,765.6	10,237.9	13,244.3	15,367.8	16,804.9	19,410.2
Water	2,710.3	3,208.6	3,285.6	3,571.9	4,123.8	4,683.5	5,414.8	6,040.7	6,698.0	7,415.2	8,413.7
Sewerage	1,802.0	2,035.0	2,287.0	2,438.6	2,768.1	3,106.2	3,568.2	5,823.4	7,157.9	7,734.8	9,148.2
Other (meter rent, connections, tankers)	539.0	492.9	579.4	629.9	727.2	825.9	954.8	1,065.2	1,181.1	1,307.6	1,483.7
Electricity generation	-	-	-	-	-	150.0	300.0	315.0	330.8	347.3	364.7
Less: VAT & Other Taxes	-	-	-	-	-	-	-	-	-	-	-
Total Operating Revenue	**5,051.4**	**5,736.5**	**6,151.9**	**6,640.3**	**7,619.2**	**8,765.6**	**10,237.9**	**13,244.3**	**15,367.8**	**16,804.9**	**19,410.2**
Operating Expenses											
Salary Expense	1,540.1	2,084.8	2,189.1	2,298.5	2,430.8	2,570.5	2,785.6	2,911.5	3,057.0	3,209.9	3,370.4
Electricity Expense	203.1	211.0	222.0	233.5	571.1	898.5	327.1	374.7	606.3	866.9	1,120.2
Chemicals Expense	203.8	175.6	184.7	194.3	217.3	240.5	272.2	291.4	314.9	340.3	366.2
Operation & Maintenance Expenses	310.7	439.6	462.4	486.4	527.9	570.2	623.8	662.7	707.5	755.6	805.1
Asset Replacement Charges	250.0	250.0	263.0	276.6	309.5	342.5	387.6	415.0	448.4	484.6	521.4
Office and Admin.	422.9	516.6	543.4	571.6	620.4	670.1	733.1	778.7	831.4	887.9	946.1
Resource Cost of Raw Water	9.9	9.9	10.4	10.9	12.2	13.5	15.3	16.4	17.7	19.2	20.6
Lease fee payment to AWSB	526.2	673.2	708.2	744.9	783.6	824.3	867.1	912.1	959.5	1,009.3	1,061.7
Sales tax	-	-	-	-	-	-	-	-	-	-	-
Total Operating Expenses	**3,466.6**	**4,360.6**	**4,583.1**	**4,816.9**	**5,472.8**	**6,130.1**	**6,011.7**	**6,362.6**	**6,942.9**	**7,573.5**	**8,211.7**
US$ million	*38.52*	*48.45*	*50.92*	*53.52*	*60.81*	*68.11*	*66.80*	*70.70*	*77.14*	*84.15*	*91.24*
Income before Depreciation	**1,584.7**	**1,375.9**	**1,568.9**	**1,823.4**	**2,146.3**	**2,635.5**	**4,226.2**	**6,881.8**	**8,424.9**	**9,231.3**	**11,198.5**
Depreciation	177.89	191.66	30.8	49.6	280.3	524.3	862.6	866.0	866.0	866.0	866.0
Operating Income	**1,406.84**	**1,184.22**	**1,538.1**	**1,773.8**	**1,866.0**	**2,111.2**	**3,363.6**	**6,015.8**	**7,558.8**	**8,365.3**	**10,332.5**
Operating Subsidies	10.06	-36.97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Operating Revenue (Grant income)	10.39	261.69	274.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-Operating Expenses (prov for bad debts)	1,198.60	426.57	447.9	470.3	493.8	518.5	544.4	571.6	600.2	630.2	661.8
Interest & Other Financial Expenses	72.9	57.6	142.3	422.3	788.0	1,221.7	1,576.1	1,796.6	1,936.6	1,994.7	2,071.6
Other Financial Expenses (int on cust deposits)	5.75	7.71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Profit Before Income Tax	**150.0**	**917.0**	**1,222.7**	**881.2**	**584.1**	**371.0**	**1,243.1**	**3,647.5**	**5,022.0**	**5,740.3**	**7,599.1**
Income Tax	0.00	0.00	244.5	176.2	116.8	74.2	248.6	729.5	1,004.4	1,148.1	1,519.8
Net Income	**150.0**	**917.0**	**978.1**	**704.9**	**467.3**	**296.8**	**994.4**	**2,918.0**	**4,017.6**	**4,592.3**	**6,079.3**

Table 8-51: NCWSC Cash Flow Statements 2010 – 2020

Cash Flow Statements
(KES million - current prices)

	Actual/Estimated		Projected								
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Sources											
Net Income	150.0	917.0	977.0	695.1	436.4	256.1	953.2	2,876.7	3,976.9	4,552.2	6,004.0
Operating Interest	72.92	57.65	143.7	429.8	803.4	1,240.3	1,594.8	1,814.8	1,954.1	2,011.5	2,132.5
Depreciation	177.9	191.7	30.8	54.5	303.6	556.5	895.5	899.3	899.3	899.3	899.3
Total Internal Cash	400.8	1,166.3	1,151.5	1,179.4	1,543.4	2,053.0	3,443.4	5,590.9	6,830.4	7,463.0	9,035.8
Short-Term Debt	13.97	0.00	1,727.0	1,300.0	1,276.0	2,635.0	2,120.0	1,575.0	800.0	210.0	1,200.0
Long-Term Debt											
Development loan	0.00	0.00	1,522.6	4,567.9	7,613.1	1,522.6	0.0	0.0	0.0	0.0	0.0
Domestic Loans	0.00	0.00	886.0	5,135.2	7,450.3	4,923.0	119.4	0.0	0.0	0.0	0.0
Total	**0.00**	**0.00**	**2,408.6**	**9,703.1**	**15,063.5**	**6,445.7**	**119.4**	**0.0**	**0.0**	**0.0**	**0.0**
Government Contributions	0.00	0.00	64.3	187.0	257.1	40.9	35.1	0.0	0.0	0.0	0.0
Other Capital Contributions	0.00	160.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Proceeds from Disposal of Fixed Assets	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Sources	**414.80**	**1,326.31**	**5,351.4**	**12,369.4**	**18,140.0**	**11,174.5**	**5,717.9**	**7,165.9**	**7,630.4**	**7,673.0**	**10,235.8**
Applications											
Capital Investments											
WB Project	0.00	0.00	1,522.6	4,567.9	7,613.1	1,522.6	0.0	0.0	0.0	0.0	0.0
Other Projects	0.00	0.00	950.3	5,322.2	7,707.4	4,963.9	154.4	0.0	0.0	0.0	0.0
Total	0.00	0.00	2,472.9	9,890.1	15,320.6	6,486.6	154.4	0.0	0.0	0.0	0.0
Increase (Decrease) in Working Capital	0.0	530.3	(1,947.5)	(761.4)	(341.8)	756.4	813.3	(33.4)	(225.9)	(261.9)	(182.6)
Short-Term Debt Repayment	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Operating Interest											
WB Project	0.00	0.00	11.4	57.1	148.5	217.0	228.4	228.4	228.4	228.4	223.6
Other Projects	72.92	57.65	132.3	372.7	655.0	1,023.4	1,366.4	1,586.5	1,725.7	1,783.1	1,908.8
Total	72.92	57.65	143.7	429.8	803.4	1,240.3	1,594.8	1,814.8	1,954.1	2,011.5	2,132.5
IDC & Commitment Fees											
Project	0.00	0.00	144.6	114.2	53.3	7.6	0.0	0.0	0.0	0.0	0.0
Other Projects	0.00	0.00	0.0	52.2	34.8	11.6	0.0	0.0	0.0	0.0	0.0
Total	0.00	0.00	144.6	166.4	88.1	19.2	0.0	0.0	0.0	0.0	0.0
Long-Term Debt Repayment											
Project	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	634.4
Other Projects	65.00	120.00	0.0	0.0	0.0	0.0	0.0	140.4	140.4	140.4	281.9
Total	65.00	120.00	0.0	0.0	0.0	0.0	0.0	140.4	140.4	140.4	916.3
Total Long-Term Debt Service											
Project	0.00	0.00	156.1	171.3	201.7	224.6	228.4	228.4	228.4	228.4	858.1
Other Debt	137.92	177.65	132.3	424.9	689.8	1,035.0	1,366.4	1,726.9	1,866.1	1,923.5	2,190.7
Total	137.92	177.65	288.3	596.2	891.5	1,259.6	1,594.8	1,955.2	2,094.5	2,151.9	3,048.8
Dividends	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Applications	0.00	0.00	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6
Total Applications	**137.9**	**708.0**	**814.2**	**9,725.3**	**15,870.8**	**8,502.9**	**2,563.0**	**1,922.3**	**1,869.1**	**1,890.6**	**2,866.8**
Net Increase (Decrease) in Cash	**276.9**	**618.3**	**4,537.2**	**2,644.1**	**2,269.2**	**2,671.6**	**3,154.9**	**5,243.6**	**5,761.3**	**5,782.5**	**7,369.0**
Cash at Beginning of Year	**343.7**	**620.6**	**1,238.9**	**5,776.1**	**8,420.2**	**10,689.5**	**13,361.0**	**16,515.9**	**21,759.5**	**27,520.8**	**33,303.3**
Cash at End of Year	**620.6**	**1,238.9**	**5,776.1**	**8,420.2**	**10,689.5**	**13,361.0**	**16,515.9**	**21,759.5**	**27,520.8**	**33,303.3**	**40,672.3**

Table 8-52: NCWSC Balance Sheets 2010 – 2020

Balance Sheets
(KES million - current prices)

	Actual/Estimated		Projected								
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Assets											
Current Assets											
Cash and Bank	620.6	1,238.9	5,776.1	8,420.2	10,689.5	13,361.0	16,515.9	21,759.5	27,520.8	33,303.3	40,672.3
Accounts Receivable	2,633.9	3,258.6	1,685.5	1,819.3	2,087.4	2,401.5	2,804.9	2,902.9	2,947.2	2,992.6	3,190.7
Other Accounts Receivable	121.6	126.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inventory	260.3	423.2	177.3	186.5	204.2	222.1	245.5	261.4	280.1	300.2	320.9
Accounts Prepaid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prepaid Expenses	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Current Assets	**3,636.3**	**5,047.3**	**7,638.9**	**10,426.0**	**12,981.1**	**15,984.7**	**19,566.3**	**24,923.8**	**30,748.2**	**36,596.2**	**44,183.9**
Non Current Assets											
Fixed Assets	1,230.8	1,230.8	2,181.1	11,531.1	22,261.9	24,112.9	35,973.8	35,973.8	35,973.8	35,973.8	35,973.8
Accumulated Depreciation	-655.0	-846.7	-877.5	-932.0	-1,235.6	-1,792.2	-2,687.7	-3,587.0	-4,486.3	-5,385.7	-6,285.0
Net Fixed Assets	575.8	384.1	1,303.6	10,599.1	21,026.2	22,320.8	33,286.2	32,386.8	31,487.5	30,588.1	29,688.8
Work in Progress	0.0	0.0	1,667.3	2,373.8	7,051.7	11,706.5	0.0	0.0	0.0	0.0	0.0
Intangible and Deferred Assets	11.6	7.9	8.3	8.7	9.1	9.6	10.0	10.5	11.1	11.6	12.2
Long-Term Investments	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Non-Current Assets	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Non Current Assets	**587.4**	**392.0**	**2,979.2**	**12,981.6**	**28,087.1**	**34,036.8**	**33,296.2**	**32,397.4**	**31,498.5**	**30,599.7**	**29,701.0**
Total Assets	**4,223.7**	**5,439.3**	**10,618.1**	**23,407.6**	**41,068.1**	**50,021.5**	**52,862.5**	**57,321.2**	**62,246.7**	**67,195.9**	**73,884.9**
Liabilities & Equity											
Current Liabilities											
Accounts Payable	682.2	530.3	581.0	611.2	745.3	877.7	773.5	827.3	936.9	1,057.5	1,177.9
Other Accounts Payable	0.0	0.0	0.0	826.6	1,266.5	534.7	12.7	0.0	0.0	0.0	0.0
Accrued Payroll and Welfare	38.7	92.7	119.9	125.9	133.2	140.8	152.6	159.5	167.5	175.9	184.7
Taxes Payable	0.0	0.0	66.9	47.6	29.9	17.5	65.3	197.0	272.4	311.8	411.2
Short-Term Loans	114.0	114.0	1,841.0	3,141.0	4,417.0	7,052.0	9,172.0	10,747.0	11,547.0	11,757.0	12,957.0
Current Portion of Long-Term Debt	120.0	0.0	0.0	0.0	0.0	0.0	140.4	140.4	140.4	916.3	1,599.1
Other Current Liabilities	977.5	1,337.7	1,194.7	1,255.6	1,319.7	1,499.4	1,679.5	1,647.0	1,743.2	1,902.2	2,074.9
Total Current Liabilities	**1,932.4**	**2,074.7**	**3,803.5**	**6,007.9**	**7,911.5**	**10,122.2**	**11,996.0**	**13,718.3**	**14,807.4**	**16,120.7**	**18,404.8**
Long-Term Debt											
WB Loan	0.0	0.0	1,522.6	6,090.5	13,703.7	15,226.3	15,226.3	15,226.3	15,226.3	14,591.9	13,957.4
Other Loans (Domestic)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Loans (Long-Term Debt)	711.1	784.9	1,022.7	6,157.9	13,608.2	18,531.3	18,510.3	18,369.9	18,229.5	17,947.6	16,982.8
Total Long-Term Debt	**711.1**	**784.9**	**2,545.3**	**12,248.4**	**27,311.9**	**33,757.6**	**33,736.6**	**33,596.2**	**33,455.8**	**32,539.4**	**30,940.3**
Equity											
Equity	446.1	446.1	1,181.4	1,368.3	1,625.4	1,666.3	1,701.4	1,701.4	1,701.4	1,701.4	1,701.4
Retained Earnings	982.7	2,031.3	2,985.5	3,680.5	4,116.9	4,373.0	5,326.2	8,202.9	12,179.8	16,732.0	22,736.0
Other (Capital Grant)	151.5	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4
Total Equity	**1,580.2**	**2,579.7**	**4,269.2**	**5,151.2**	**5,844.7**	**6,141.7**	**7,129.9**	**10,006.7**	**13,983.6**	**18,535.8**	**24,539.8**
Total Liabilities + Equity	**4,223.7**	**5,439.3**	**10,618.1**	**23,407.6**	**41,068.1**	**50,021.5**	**52,862.5**	**57,321.1**	**62,246.7**	**67,195.9**	**73,884.9**

9 Economic Analysis

This Section presents the economic analysis for the development of Nairobi's water supply for the period 2012 – 2035. The economic analysis is constructed from the perceptive of the national economy; quantifying the economic costs and benefits of increasing the water supply to meet Nairobi's projected demand over the planning period. This is in contrast to the financial analysis in the previous chapter which shows financial projections for NCWSC, the entity responsible for providing water and sanitation services to the City, for Stage 1 of the development period limited to 2012 to 2020.

9.1 Methodology

The methodology used to assess the economic impact and returns is a conventional cost: benefit analysis whereby the capital and O&M costs in economic terms over the project life 2012 – 2035 are compared to the economic benefits from increased water supply with the annual cash flows discounted to present values at a discount rate representing the opportunity cost of capital. The net incremental benefits are calculated on the *future with project minus future without project* basis. The results are presented as the Economic Internal Rate of Return (EIRR), Net Present Value (NPV), and Benefit Cost Ratio (BCR). The main benefits from the project in meeting the increasing demand for potable water from the growing population are the saving in costs of providing essential water from alternative more expensive sources, and other associated benefits including saved time in collecting water, saved costs of disinfection from less safe water supplies, and the health benefits gained through having a more reliable and cleaner supply of water. The increased consumption of water per capita and per household brought about from the improved supply is valued in economic terms based on the opportunity cost of the alternative sources of supply, and average willingness to pay (WTP) for incremental consumption resulting from the programme. All costs and benefits are expressed in constant 2012 prices, and project life span for the analysis is assumed to be 30 years, from 2012 to 2042.

9.2 Costs

The costs presented in Section 7 are used for the economic analysis. The costs include the detailed costs estimates for Stage 1 2012 – 2017 and the preliminary cost estimates for the remainder of the study period 2018 to 2035, based on Scenario 3A, allowing for the construction of Maragua 4 Dam. In addition, the anticipated costs of expanding the water supply distribution and sewage network and the cost of new individual connections are included. The total cost for the capital expenditure associated with increasing the bulk water supply is estimated to be US$963.27 million, plus US$95 million for allowed for expanding and rationalising the network, making a total of US$1,058.27 million. A summary is provided in Table 8-53 on page 8-147.

Table 8-53: Nairobi Water Supply Development Capital Costs 2012 – 2035

US$ million 2012 Constant Prices		Total Capital Cost
Item	**Component and Phase**	**US$ million**
1.	**Groundwater Well Fields (2013-2015)**	
1.1.	Groundwater investigation	3.00
1.2.	Ruiru and Kiunyu well fields	73.40
	Subtotal	**76.40**
2.	**Northern Collector - Phase 1 (2013 - 2015)**	
2.1.	Tunnels and shafts, intakes	95.78
2.2	**Ngorongo WTW and Thika - Ngorongo TW - Kabete Transfer (2013 - 2015)**	
2.2	Thika - Ngorongo TW water transfer Phase	76.53
2.4	Ngorongo HL WTW phase 1	52.45
	Subtotal	**128.98**
	Total Stage 1	**301.16**
2.3	**Ngorongo WTW and Thika - Ngorongo TW water transfer Phase 2 (2023 - 2025)**	
2.31	Thika - Ngorongo TW water transfer Phase 2	66.69
2.32	Ngorongo HL WTW phase 2 (103,680m3/d)	48.70
	Subtotal	**115.40**
3.	**Maragua 4 Dam (2017 - 2020)**	
3.1.	Maragua 4 Dam	81.74
3.2.	Raw + Treated water transmission main to Gigiri Phase 1	60.57
3.3.	WTW Ndunyu Chege - phase 1	60.69
	Subtotal	**203.00**
4.	**Thika Dam - Ndunyu Chege Transfer Main (2018 - 2020)**	
4.1	Raw water transmission pipe D700, 23 km (Phase 1)	**2.51**
5.	**South Mathioya Collector/Diversion (2019 - 2020)**	
5.1	Tunnels and shafts, intakes	**28.41**
6.	**Northern Collector - Phase 2 (2022 - 2025)**	
6.1	Tunnels and shafts, intakes	**66.24**
7.	**Ndaragu 1 Dam (2025 - 2028)**	
7.1	Ndaragu Dam	58.85
7.2	Raw water main + Treated water main to Gigiri Phase 1	73.80
7.3	Pumping stations Nadrugu -Gigiri - Phase 1	20.25
7.4	WTW Nadarugu - Phase 1	93.66
	Subtotal	**246.56**
8.	**Nairobi Network Rehabilitation (2012 - 2014), 2016-2020)**	
8.1	Hydraulic rationalisation and new storage etc Phase 1	39.00
8.2	Hydraulic rationalisation and new storage etc Phase 2	27.4
	Subtotal	**66.40**
9.	**Nairobi Tertiary Development (2120- 2016)**	
9.1	Tertiary distribution system	15.60
9.2	Individual metered connections	6.50
9.3	Informal settlements upgrade	6.50
	Subtotal	**28.60**
	TOTAL	**1,058.27**

Notes *(i) all capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision*

(ii) no financial contingencies included

9.2.1 Assumptions and Conversion to Economic Process

The capital costs shown in the table above have been converted to their economic values in constant 2012 price terms by using a standard conversion factor of 0.84 to allow for the removal of tax and duties included in the cost estimates and the shadow value of unskilled labour. The foreign exchange element of the capital costs is relatively high and the proportional cost of unskilled labour relatively low. The annual O&M and capital replacement costs have also been converted to economic values through applying a similar conversion factor. This is shown in the Table 8-54.

Table 8-54: Nairobi Water Supply Economic Cost Conversion

(KES million –2012 constant prices)			
Particulars	**Financial Costs**	**Conversion factor**	**Economic Costs**
A. Capital Costs[/a]			
Traded components (SERF) (70%)	61,909	1.00	61,909
Non-traded components:			
Domestic M&E (SWRF)	13,334	1.00	13,334
Unskilled labour (SWRF) 90%	4,286	0.80	3,429
Skilled labour (SERF) 10%	476	1.00	476
Land acquisition (SERF)	952	1.00	952
Taxes and duties (15%)	14,287	0.00	0
Subtotal (A)	**95,244**	**0.84**	**80,101**
B. Operation and Maintenance Costs	1	0.84	0.84
Capital costs excluding IDC and replacements			

Incremental O&M costs in economic terms are based on the cost schedule generated by the NCWSC financial and economic model, converted to constant 2012 prices and allowing for the economic conversion factor noted above.

9.2.2 Cost Summary and Implementation Schedule

The annual cash flows for capital and O&M costs allowing for replacement of pumps etc. and a remaining salvage value at the end of the period are shown in the Table 8-55 on page 8-149.

Table 8-55: Nairobi Water Supply Cost Summary and Schedule

(KES million, Constant 2012 Prices)

Year	% distrib	CAPEX	Replacement	Salvage	Tot CAPEX	O&M cost
2011						
2012	1%	800	-		800	-
2013	9%	7,560	-		7,560	-
2014	15%	12,077	-		12,077	270.26
2015	8%	6,402	-		6,402	507.79
2016	0%	130	-		129.88	220.25
2017	4%	3,534	-		3,533.97	406.60
2018	7%	5,234	121.10		5,355.38	564.83
2019	8%	6,170	-		6,170.31	711.77
2020	4%	3,370	-		3,369.69	840.09
2021	1%	603	-		603.10	471.05
2022	2%	1,355	-		1,355.20	510.58
2023	4%	3,579	121.10		3,700.32	547.45
2024	7%	5,638	-		5,638.27	736.84
2025	7%	5,918	756.90		6,675.02	955.12
2026	5%	4,106	507.12		4,612.73	762.26
2027	9%	6,905	-		6,904.89	805.36
2028	8%	6,718	121.10		6,839.38	975.72
2029	0%	-	-		-	1,426.39
2030	0%	-	-		-	1,830.72
2031	0%	-	567.68		567.68	2,191.37
2032	0%	-	-		-	2,596.11
2033	0%	-	121.10		121.10	3,046.09
2034	0%	-	-		-	3,442.01
2035	0%	-	-		-	3,751.46
2036		-	-		-	3,751.46
2037		-	-		-	3,751.46
2038		-	121.10		121.10	3,751.46
2039		-	-		-	3,751.46
2040		-	-		-	3,751.46
2041		-	-		-	3,751.46
2042		-	-	(2,670.02)	(2,670.02)	3,751.46
	100.0%	**80,100.52**	**2,437.22**	**(2,670.02)**	**79,867.72**	**53,830.37**

9.3 Benefits

9.3.1 Water Demand and Supply

The water demand and supply projections prepared for the time period 2012 to 2035 form the basis of the analysis. Water demand projections are based on the medium population projections for Nairobi City based on five consumption groups with different demand (lpcd) and allow for an improving UfW decreasing from 40% in 2012 to 25% by 2035. The projections are based on three categories of household income - high, medium and low - with individual connections, and low income households without individual connections, who rely on standpipes, kiosks and water vendors for their source of water. Most households in the informal

settlements are in this category. In addition there is demand from the non-domestic sector representing the commercial, industrial and institutional uses. This represents the future with project situation with the development of new water sources and improvements to the water distribution network to meet the projected demand. Average water consumption per capita for all demand including the commercial sector is projected to increase from 117 lpcd in 2012 to 137 lpcd by 2035. A summary of the distribution of demand is shown in Table 8-56 below.

Table 8-56: Nairobi Water Demand 2010 – 2035

Year		2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035
Population Growth		3.6%	3.2%	3.2%	3.2%	3.2%	3.2%	3.2%	3.2%	2.9%	2.8%	2.6%	2.5%
Population		3,250,338	3,352,948	3,458,797	3,567,988	3,680,625	3,796,818	3,916,680	4,040,325	4,403,791	5,007,274	5,693,457	6,444,969
Number of HHs	6	541,723	558,825	576,466	594,665	613,438	632,803	652,780	673,388	733,965	834,546	948,909	1,074,162
% Pop. supplied by IC		65%	65%	65%	66%	66%	67%	67%	68%	72%	74%	78%	80%
Income levels	(No. / HH)												
High (IC)		6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
No. of HH	6	32,503	33,529	34,588	35,680	36,806	37,968	39,167	40,403	44,038	50,073	56,935	64,450
Medium (IC)		50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
No. of HH	6	270,862	279,412	288,233	297,332	306,719	316,402	326,390	336,694	366,983	417,273	474,455	537,081
Low (IC)		9%	9%	9%	10%	10%	11%	11%	12%	16%	18%	22%	24%
No. of HH	6	48,755	50,294	51,882	59,466	61,344	69,608	71,806	80,807	117,434	150,218	208,760	257,799
Low (NIC)		35%	35%	35%	34%	34%	33%	33%	32%	28%	26%	22%	20%
No. of HH	6	189,603	195,589	201,763	202,186	208,569	208,825	215,417	215,484	205,510	216,982	208,760	214,832
Total HHs		**541,723**	**558,825**	**576,466**	**594,665**	**613,438**	**632,803**	**652,780**	**673,388**	**733,965**	**834,546**	**948,909**	**1,074,162**
Domestic Water Demand (m^3/d)	lpcd												
High (IC)	200	39,004	40,235	41,506	42,816	44,168	45,562	47,000	48,484	52,845	60,087	68,321	77,340
Medium (IC)	120	195,020	201,177	207,528	214,079	220,838	227,809	235,001	242,420	264,227	300,436	341,607	386,698
Low (IC)	60	17,552	18,106	18,678	21,408	22,084	25,059	25,850	29,090	42,276	54,079	75,154	92,808
Low (NIC)	30	34,129	35,206	36,317	36,393	37,542	37,589	38,775	38,787	36,992	39,057	37,577	38,670
Total Domestic WD		**285,705**	**294,724**	**304,028**	**314,697**	**324,631**	**336,018**	**346,626**	**358,781**	**396,341**	**453,659**	**522,659**	**595,515**
Other Water Demand (Commercial etc.)		92,790	96,409	100,169	104,075	108,134	112,352	116,733	121,286	137,219	175,130	223,515	287,505
Net Water Demand	**m^3/d**	**378,495**	**391,133**	**404,197**	**418,772**	**432,765**	**448,370**	**463,359**	**480,067**	**533,560**	**628,789**	**746,174**	**883,020**
Percent physical losses													
Distribution Losses	**%**	40%	40%	37%	36%	34%	32%	30%	28%	25%	25%	25%	25%
Transmission Losses	**%**	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Treatment Losses	**%**	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
UfW (as % of net demand)		**53%**	**53%**	**50%**	**48%**	**46%**	**44%**	**42%**	**40%**	**37%**	**37%**	**37%**	**37%**
Losses (m3/day)	**% of UfW**												
Distribution Losses	76%	151,398	156,453	151,019	148,794	145,840	142,887	139,178	134,419	133,390	157,197	186,544	220,755
Transmission Losses	11%	21,196	21,903	22,209	22,703	23,144	23,650	24,101	24,579	26,678	31,439	37,309	44,151
Treatment Losses	14%	27,554	28,474	28,871	29,513	30,087	30,745	31,332	31,953	34,681	40,871	48,501	57,396
Total Physical losses	100%	**200,148**	**206,831**	**202,099**	**201,010**	**199,072**	**197,283**	**194,611**	**190,951**	**194,749**	**229,508**	**272,354**	**322,302**
UfW (as percentage of demand)		53%	53%	50%	48%	46%	44%	42%	40%	37%	37%	37%	37%
UfW (as percentage of production)		35%	35%	33%	32%	32%	31%	30%	28%	27%	27%	27%	27%
Gross Water Demand (m^3/d)		**578,643**	**597,964**	**606,296**	**619,782**	**631,837**	**645,653**	**657,970**	**671,018**	**728,309**	**858,297**	**1,018,528**	**1,205,322**

9.3.2 Water Supply and Demand Balance

The overall water balance is calculated matching the projected demand allowing for UfW (non revenue water) with the increased supply from the new investment in infrastructure allowing for the construction schedule and when new water supplies come on stream. The water balance model shows that the system should meet all projected demand from 2016 when the Northern Collector I comes on stream and to maintain surplus capacity to meet the average projected demand for the remainder of the planning period until 2035. The Kiunyu and Ruiru well fields are projected to only be required to provide supplemental water on an intermittent basis to meet the projected demand when the other infrastructure has not yet come on stream. Details of the water balance calculation showing the water demand and supply projections are shown in table 8-57 on page 8-151.

This water balance represents the future with project situation when all projected demands are met from the new infrastructure.

Table 8-57: Nairobi Water Balance Supply and Demand 2011 – 2035

	Actual/Estimated		Projected											
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
NRW & Water Production														
Non-Revenue Water (Existing)		35%	33%	32%	32%	31%	30%	28%	28%	28%	27%	27%	27%	27%
Non-Revenue Water (New)		35%	33%	32%	32%	31%	30%	28%	28%	28%	27%	27%	27%	27%
Required Production (1000 m^3/d) (From existing	0.00	541.70	542.70	543.70	544.70	545.70	546.70	547.70	548.70	549.70	550.70	551.70	552.70	553.70
Required Production (1000 m^3/d) (From new)		56.26	63.60	76.08	87.14	99.95	111.27	123.32	141.86	160.98	177.61	201.19	225.68	251.12
Total Required Production		**597.96**	**606.30**	**619.78**	**631.84**	**645.65**	**657.97**	**671.02**	**690.56**	**710.68**	**728.31**	**752.89**	**778.38**	**804.82**
Actual Production Existing (1000 m^3/d)	0.00	541.70	542.70	543.70	544.70	545.70	546.70	547.70	548.70	549.70	550.70	551.70	552.70	553.70
Actual Production New (1000 m^3/d)		0.00	0.00	0.00	34.56	64.80	111.27	123.32	141.86	160.98	177.61	201.19	225.68	251.12
Total Actual Production		**541.70**	**542.70**	**543.70**	**579.26**	**610.50**	**657.97**	**671.02**	**690.56**	**710.68**	**728.31**	**752.89**	**778.38**	**804.82**
Unsatisfied Gross Demand (with project)	**1000 m^3/d**	56.26	63.60	76.08	52.58	35.15	(74.49)	(62.44)	(43.90)	(24.78)	(8.15)	(116.76)	(92.27)	(66.83)
(negative value means excess capacity)														
Actual Production per year mm^3	-	197.72	198.09	198.45	211.43	222.83	240.16	244.92	252.06	259.40	265.83	274.80	284.11	293.76
Production Capacity (1000 m^3/d)		*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*
Existing System	538.70	541.70	542.70	543.70	544.70	545.70	546.70	547.70	548.70	549.70	550.70	551.70	552.70	553.70
New System														
Wellfield in Kiunyu (2014)					34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56
Wellfield in Ruiru (2015)						30.24	30.24	30.24	30.24	30.24	30.24	30.24	30.24	30.24
Northern Collector Phase I (2016)							120.96	120.96	120.96	120.96	120.96	120.96	120.96	120.96
S. Mathioya Transfer to Thika Dam (2021)												51.84	51.84	51.84
Maragua Dam (33Mm3) (2021)												80.35	80.35	80.35
Northern Collector Tunnel Phase II to Thika Dam (2026)														
Ndarugu Dam with Natural Inflow (2029)														
Total New System	-	-	-	-	**34.56**	**64.80**	**185.76**	**185.76**	**185.76**	**185.76**	**185.76**	**317.95**	**317.95**	**317.95**
Total capacity (m^3/day)	**538.70**	**541.70**	**542.70**	**543.70**	**579.26**	**610.50**	**732.46**	**733.46**	**734.46**	**735.46**	**736.46**	**869.65**	**870.65**	**871.65**
Actual Production (1000 m^3/d)														
Existing System	-	541.7	542.7	543.7	544.7	545.7	546.7	547.7	548.7	549.7	550.7	551.7	552.7	553.7
New System	-	-	-	-	34.56	64.80	111.27	123.32	141.86	160.98	177.61	201.19	225.68	251.12
Wellfield in Kiunyu (2014)	-	-	-	-	34.6	34.6	-	2.4	20.9	34.6	34.6	-	-	-
Wellfield in Ruiru (2015)	-	-	-	-	-	30.2	-	-	-	5.5	22.1	-	-	-
Northern Collector Phase I (2016)	-	-	-	-	-	-	111.3	121.0	121.0	121.0	121.0	121.0	121.0	121.0
S. Mathioya Transfer to Thika Dam (2021)			-	-	-	-	-	-	-	-	-	51.8	51.8	51.8
Maragua Dam (33Mm3) (2021)			-							-	-	28.4	52.9	78.3
Northern Collector Tunnel Phase II to Thika Dam (2026)										-	-	-	-	-
Ndarugu Dam with Natural Inflow (2029)										-	-	-	-	-
Total Actual Production	**-**	**541.7**	**542.7**	**543.7**	**579.3**	**610.5**	**658.0**	**671.0**	**690.6**	**710.7**	**728.3**	**752.9**	**778.4**	**804.8**

Table 8-58: Nairobi Water Balance Supply and Demand 2011 – 2035 continued

	ctual/Estimate	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
NRW & Water Production													
Non-Revenue Water (Existing)		27%	27%	27%	27%	27%	27%	27%	27%	27%	27%	27%	27%
Non-Revenue Water (New)		27%	27%	27%	27%	27%	27%	27%	27%	27%	27%	27%	27%
Required Production (1000 m^3/d) (From existing	0.00	554.70	555.70	556.70	557.70	558.70	559.70	560.70	561.70	562.70	563.70	564.70	565.70
Required Production (1000 m^3/d) (From new)		277.54	302.60	331.76	362.06	393.52	423.94	457.83	490.50	524.43	562.18	598.87	639.62
Total Required Production		**832.24**	**858.30**	**888.46**	**919.76**	**952.22**	**983.64**	**1,018.53**	**1,052.20**	**1,087.13**	**1,125.88**	**1,163.57**	**1,205.32**
Actual Production Existing (1000 m^3/d)	0.00	554.70	555.70	556.70	557.70	558.70	559.70	560.70	561.70	562.70	563.70	564.70	565.70
Actual Production New (1000 m^3/d)		277.54	302.60	331.76	362.06	393.52	423.94	457.83	490.50	524.43	562.18	598.87	639.62
Total Actual Production		**832.24**	**858.30**	**888.46**	**919.76**	**952.22**	**983.64**	**1,018.53**	**1,052.20**	**1,087.13**	**1,125.88**	**1,163.57**	**1,205.32**
Unsatisfied Gross Demand (with project)	**1000 m^3/d**	(40.41)	(15.36)	(106.28)	(75.99)	(44.52)	(230.11)	(196.22)	(163.55)	(129.62)	(91.86)	(55.18)	(14.43)
(negative value means excess capacity)													
Actual Production per year mm^3	-	303.77	313.28	324.29	335.71	347.56	359.03	371.76	384.05	396.80	410.95	424.70	439.94
Production Capacity (1000 m^3/d)		*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*	*2031*	*2032*	*2033*	*2034*	*2035*
Existing System	538.70	554.70	555.70	556.70	557.70	558.70	559.70	560.70	561.70	562.70	563.70	564.70	565.70
New System													
Wellfield in Kiunyu (2014)		34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56	34.56
Wellfield in Ruiru (2015)		30.24	30.24	30.24	30.24	30.24	30.24	30.24	30.24	30.24	30.24	30.24	30.24
Northern Collector Phase I (2016)		120.96	120.96	120.96	120.96	120.96	120.96	120.96	120.96	120.96	120.96	120.96	120.96
S. Mathioya Transfer to Thika Dam (2021)		51.84	51.84	51.84	51.84	51.84	51.84	51.84	51.84	51.84	51.84	51.84	51.84
Maragua Dam (33Mm3) (2021)		80.35	80.35	80.35	80.35	80.35	80.35	80.35	80.35	80.35	80.35	80.35	80.35
Northern Collector Tunnel Phase II to Thika Dam (2026)				120.10	120.10	120.10	120.10	120.10	120.10	120.10	120.10	120.10	120.10
Ndarugu Dam with Natural Inflow (2029)							216.00	216.00	216.00	216.00	216.00	216.00	216.00
Total New System	-	**317.95**	**317.95**	**438.05**	**438.05**	**438.05**	**654.05**	**654.05**	**654.05**	**654.05**	**654.05**	**654.05**	**654.05**
Total capacity (m^3/day)	**538.70**	**872.65**	**873.65**	**994.75**	**995.75**	**996.75**	**1,213.75**	**1,214.75**	**1,215.75**	**1,216.75**	**1,217.75**	**1,218.75**	**1,219.75**
Actual Production (1000 m^3/d)													
Existing System	-	554.7	555.7	556.7	557.7	558.7	559.7	560.7	561.7	562.7	563.7	564.7	565.7
New System	-	277.54	302.60	331.76	362.06	393.52	423.94	457.83	490.50	524.43	562.18	598.87	639.62
Wellfield in Kiunyu (2014)	-	24.4	34.6	-	-	20.3	-	-	-	-	-	9.6	34.6
Wellfield in Ruiru (2015)	-	-	14.9	-	-	-	-	-	-	-	-	-	15.8
Northern Collector Phase I (2016)	-	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0
S. Mathioya Transfer to Thika Dam (2021)		51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
Maragua Dam (33Mm3) (2021)		80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4
Northern Collector Tunnel Phase II to Thika Dam (2026)		-	-	78.6	108.9	120.1	120.1	120.1	120.1	120.1	120.1	120.1	120.1
Ndarugu Dam with Natural Inflow (2029)		-	-	-	-	-	50.7	84.6	117.2	151.2	188.9	216.0	216.0
Total Actual Production	**-**	**832.2**	**858.3**	**888.5**	**919.8**	**952.2**	**983.6**	**1,018.5**	**1,052.2**	**1,087.1**	**1,125.9**	**1,163.6**	**1,205.3**

9.3.3 Future Without Project Situation

In the future-without project situation it is assumed that there is no further increase in the NCWSC water supply from the existing production capacity in 2012 of 540,720m^3 per day. This will result in an increasing unsatisfied demand for water by consumers as the population grows and lpcd rates increase, meaning that there will be an increasing reliance on other alternative sources of water, such as boreholes and water delivered by tanker from other sources. Actual per capita consumption of water from all sources in the future-without project situation can be expected to be less than in the projected future-with project situation as demand will change in response to an increase in the effective cost of alternative sources of water, that is, there is a negative price elasticity of demand for water. Water is fundamental to life and wellbeing and there is an absolute minimum required to meet the basic needs for drinking and cooking and hygiene, which is generally accepted to be around 15 – 20 lpcd. The demand for water follows a hierarchy of needs with increasing levels of consumption used for other purposes after the basics needs including clothes washing, cleaning, sanitation, garden watering etc., as is portrayed in Figure 8-35.

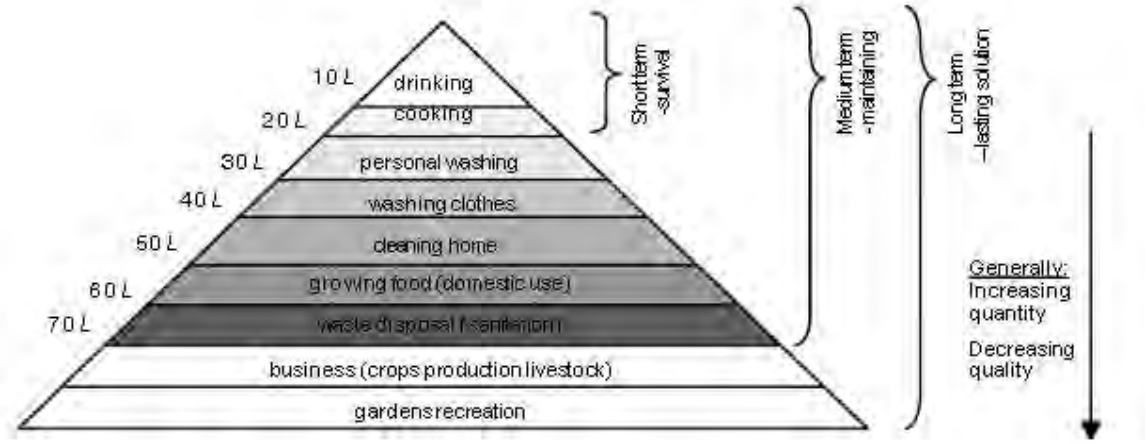


Figure 8-35 : Hierarchy of Water Requirements
(after Abraham Maslow's (1908-1970) hierarchy of needs)

The demand for water from alternative sources in the future-without situation to make up the deficit in supply will vary according to the consumer groups according to their level of income and their resources. It can be expected that high level income households will be more able to afford to meet future needs by developing their own independent supply through installing a borehole/tubewell or by purchasing water from tanker suppliers when their supply runs short. The commercial, industrial and institutional sector is also most likely to satisfy most of their future needs by developing their own sources, (as happens now where many large consumers and apartment blocks have their own bores to enable them to be self-sufficient).

The sector that is less able to afford meeting their full demand is the low income sector that does not have individual connections, for which the projected demand is 30 lpcd. These households, which predominantly make up the informal settlements, face the highest cost for water having to rely on kiosks and water vendors purchasing small quantities on an as needed basis for a current price of around KES3- 5 per 20 l. (equivalent of KES 150 – 250 per m^3). Further restrictions to supply and shortages could be expected to drive up the price and curtail future demand.

The unsatisfied demand for the different groups has been adjusted for the assumed reduction in demand with the result that overall 70% of the projected unsatisfied demand is assumed to be met by alternative sources of water as shown in Table 8-59 below.

Table 8-59: Unsatisfied Water Demand

Structure of Demand (% of demand)	Design Lpcd	% of Total Demand	% of Unsatisfied Demand Met	Lpcd 2020	Lpcd 2035
Residential - High income (IC)	200	10%	75%	188	172
- Medium income (IC)	120	51%	70%	111	100
- Low income (IC)	60	5%	50%	52	44
Low income NIC (NCWSC)	30	9%	30%	25	18
Other Users (Commercial, institutional)		25%	90%	30	42
Total		**100%**			**100%**

This shows that the low income NIC group of consumers would reduce their average consumption from a projected rate of 30 lpcd in 2012 to 18 lpcd by 2035.

9.3.4 Non Revenue Water and Technical and Non-technical Losses

Unaccounted for water, or non-revenue water, is projected to reduce from 33% of production in 2012 to 27% by 2035 as a result of the capital investment in improving the distribution system, better maintenance, leak detection etc. The non-revenue water can be further divided into technical and non-technical losses. Technical losses being water that is lost through leakage and failure of the system, while non-technical losses represent water that is lost (stolen) from the network through illegal connections but is still consumed. (This is in addition to water that is supplied to consumers, billed but not paid for). Non-technical water still has an economic value as it is consumed, and so the value of this additional water is included as an economic benefit to the project.

9.3.5 Valuation of Benefits

a) Opportunity Costs of Alternative Water Sources

The opportunity cost of water for the future situation without the project is based on three alternative sources of water to meet the unsatisfied demand for water: boreholes, tanker supply, and kiosks and water vendors.

Boreholes

Currently most of the water boreholes in Nairobi are operated by the larger private consumers (industrial enterprises, hotel complexes, apartment blocks etc.) or by individual residential owners in parts of the city that receive only intermittent supply (e.g. Langata, Karen). Wells are often shared with neighbours or water is sold for distribution by tankers at high prices. Many private well owners are also connected to the mains water-supply network (which provides cheaper water) but use groundwater as a back-up supply; which explains why in 2005 it was stated that installed well capacity of 300,000 – 350,000m^3/d was much larger than actual

abstraction of 85,000m^3/d[10]. As the aquifer under Nairobi is at a relatively deep depth requiring a considerable capital investment there is low potential for the middle and low income consumers to develop their own source of groundwater by using shallow wells and boreholes, so they would have to become more reliant on a shared borehole, using tankers and water vendors to meet their needs when the mains network cannot meet the demand .

Typically boreholes in the Nairobi area have a depth of over 200 m and a capacity of 10m^3/h. The current cost of installing a new well is around KES20,000 per m allowing for all costs including drilling lining, screens, pumps and pipes, or around the equivalent of around US$50,000 per well. Storage and piping adds an estimated US$6,500 to make a total cost per tubewell of US$56,500. In economic pricing terms this cost can be adjusted by a standard conversion factor of 0.85 making an economic cost of US$45,000. At an assumed utilisation rate of 16 hours pumping per day with a well life of 20 years, a pump life of 5 years and a cost of electricity of US$0.20/kWh the average cost per m^3 of water is calculated to be KES21/m^3.

Tanker Supply

Currently many consumers rely on tankers to deliver water to supplement the mains water when supply is intermittent and during time of shortages. The current set rate for tanker delivery by the NCWSC is KES2,500 for 8,000 l delivered within the Nairobi area (equivalent to KES312 /m^3). However the NCWSC services are limited and many consumers have to use private operators for delivering tanker water at a much higher cost per m^3. But there is likely to be excessive costs for the services due to inefficiencies and poorly functioning market in this service delivery. Therefore for the purpose of the economic analysis an average cost of KES300 /m^3 has been used.

Vendors and Kiosks

Most of the households in the low income sector in the informal settlements who do not have an individual connection to the mains supply rely on getting their basic water needs from standpipes, kiosks and water vendors, many of which are also supplied by water tanker. Although two thirds of the kiosks have water reservoirs, their capacity is insufficient and often water is not available due to supply interruptions. A higher percentage of kiosk users report scarcity than households with mains connections, suggesting that in times of scarcity kiosks are less likely to receive water than domestic connections. According to various reports water is often highly contaminated, smells, is discoloured and contains sediment, because old, rusty pipes often break and water is polluted by the open drainage lines and sewage lines which run parallel to the water network. The current cost for a 20 l container of water is KES3- KES5, equivalent to KES150 – 250/m^3 , many times the set tariff for supply from NCWSC. During times of severe water shortages the price increases markedly. For the purpose of the economic analysis the opportunity cost of this source of supply is taken as KES200/m^3.

b) Average Opportunity Cost of Water

Combining the combination of the alternative sources of water for the five different categories of consumers produces the weighted average cost which varies from KES62.9/m^3 for the high income households to KES200/m^3 for low income households without an individual connection who would have to rely entirely on water vendors and kiosks to meet the shortfall in supply in the future-without project situation. Non-residential consumers (commercial, industrial and

[10]Sustainable Groundwater Management Lessons from Practice, "Kenya: The Role of Groundwater in the Water-Supply of Greater Nairobi", Case Profile Collection Number 13, The World Bank, March 2005

institutional) are assumed to source 95% of their extra water from private bores, with an average cost of KES35/m^3. The calculations are shown in table below. Overall the weighted average cost for all consumer groups is KES82.6/m^3. This value is adjusted by a factor of 72% representing the actual value of the utilisation of alternative sources of water rather than the projected unsatisfied demand, (actual use will be less than the projected deficit through the negative price elasticity demand for water as discussed above).

Table 8-60: Average Opportunity Cost of Water

Category		Private Borehole 200m	Tanker Supply	Water Vendor etc	Weighted Average Cost KES/m^3
	Cost/m^3 KES	*21*	*300*	*200*	82.6
Residential - High income (IC)	100%	85%	15%		62.9
- Medium income (IC)	100%	60%	10%	30%	102.6
- Low income (IC)	100%	10%	5%	85%	187.1
Low income NIC (NCWSC)	100%		0%	100%	200.0
Other Users (Commercial, institutional)	100%	95%	5%		35.0

These costs for each category are combined with net demand for extra non-mains water for each category over the time period and represents the economic benefit gained from substituting non-incremental water in the future-with project situation. The average value of this water varies over the time period from KES83.6m^3 in 2015 to KES79.7/m^3 in 2035, (the change is brought about by a changing mix in the demand by consumer category over time).

c) Health Benefits

Improvement of the water supply and sanitation system and increased water supply to meet the projected demand can be expected to generate significant health benefits, particularly in the low income households without individual connections living in the informal settlements. These households rely of various sources of water supplied by standpipes, kiosks, and water vendors at a high cost, and often of poor quality, contaminated, involving considerable time for collecting water, and extra expenditure on disinfection to make it fit for consumption. The health benefits would materialise as a reduction in sickness; thereby reducing household expenditure on medicine and health care, work days lost from sickness and time spent having to care for sick family members. A more healthy population is also more productive, people are more productive, children have fewer days off school etc. Various studies have attempted to quantify the impact of improved water supply and sanitation services. A recent compilation of the various variables and costs associated with quantifying improved water supply and sanitation based on data from World Health Organisation and other development agencies is shown in Table 8-61 on page 8-157.

Unfortunately no information is available on the level on direct expenditure on health problems brought about by poor water and sanitation in Nairobi, nor days lost through sickness or having to care for sick relatives etc.

Table 8-61: Factors Concerned with Benefits of Improved Water Supply and Sanitation

Benefit by sector	Variable	Data source	Data values (+ range)
1. Health sector			
Direct expenditures avoided, due to less illness from diarrhoeal disease	Unit cost per treatment	WHO regional unit cost data	US$4.3-US$9.7 (cost per visit) US$16.1-US$39.7 (cost per day) *Varying by WHO region*
	Number of cases	WHO BoD data	Variable by region
	Visits or days per case	Expert opinion	1 outpatient visit per case (0.5-1.5) 5 days for hospitalised cases (3-7)
	Hospitalisation rate	WHO data	91.8% of cases ambulatory 8.2% of cases hospitalised
2. Patients			
Direct expenditures avoided, due to less illness from diarrhoeal disease	Transport cost per visit	Assumptions	US$0.50 per visit
	% patients use transport	Assumptions	50% of patients use transport (0-100%)
	Non-health care patient costs	Assumptions	US$0.50 ambulatory (US$0.25-1.00) US$2.00 hospitalisation (US$1.0-3.0)
	Number of cases	WHO BoD data	Variable by region
	Visits or days per case	Expert opinion	1 outpatient visit per case (0.5-1.5) 5 days for hospitalised cases (3-7)
	Hospitalisation rate	WHO data	91.8% of cases ambulatory 8.2% of cases hospitalised
Income gained, due to days lost from work avoided	Days off work/ episode	Expert opinion	2 days (1-4)
	Number of people of working age	WHO population data 2002	Variable by region
	Opportunity cost of time	World Bank data	Minimum wage rate (GNP per capita – value added in manufacturing)
Days of school absenteeism avoided	Absent days / episode	Expert opinion	3 (1-5)
	Number of school age children (5-14)	WHO population data 2002	Variable by region
	Opportunity cost of time	World Bank data	Minimum wage rate (GNP per capita – value added in manufacturing)
Productive parent days lost avoided, due to less child illness	Days sick	Expert opinion	5 (3-7)
	Number of babies (0-4)	WHO population data 2002	Variable by region
	Opportunity cost of time	World Bank data	50% minimum wage rate (50% GNP per capita – 50% value added in manufacturing)
Value of loss-of-life avoided (life expectancy, discounting future years at 3%)	Discounted productive years lost (0 – 4 years)	WASH study [16]	16.2 years (9.5 – 29.1)
	Discounted productive years lost (5 – 14 years)	WASH study [16]	21.9 years (15.2 – 33.8)
	Discounted productive years lost (15+ years)	WASH study [16]	19.0 years (16.3 – 22.7)
	Opportunity cost per year of life lost	World Bank data	Minimum wage rate
3. Consumers			
'Convenience' – time savings	Water collection time saved per household per day for better external access	Expert opinion	0.5 hours (0.25-1.0)
	Water collection time saved per household per day for piped water	Expert opinion	1.5 hours (1.0-2.0)
	Sanitation access time saved per person	Expert opinion	0.5 hours (0.25-0.75)
	Average household size	WHO population data 2002	6 people (4-8)
	Opportunity cost of time	World Bank data	Minimum wage rate (GNP per capita – value added in manufacturing)

An important benefit, as highlighted in the above table, is the value of loss-of-life avoided through improved access to water, particularly a reduction in infant mortality for the under-fives, the most vulnerable group. To quantify this economic benefit the value of a child's life saved is expressed as the 2011 level of GNP per working-age population, assumed constant over the project life. (The GNP, as opposed to GDP, encompasses a weighted average of "all futures" in terms of individual earnings potential - wages, subsistence, and remittances). The annual GNP amount is applied to the child's 50 working years (ages 15 to 65) and discounted back to the birth of the child using a discount rate of 3%.[11] In the case of Kenya with a GNP per capita of KES38,461 in 2012 (US$427), this represents a present value of a life saved of KES654,237.

This approach has been applied for this economic analysis. Children under the age of five make up 16% of Kenya's population and within this cohort there is a death rate of 2% per year, according to UNICEF.[12] Applying these rates to the estimated population of 1.2 million people in 2012 residing in the informal settlements of Nairobi without an individual water connection indicates that there would be around 3,800 deaths in the under-five age group per year. In the future-without project situation with a deteriorating supply and quality of water this percentage could be expected to increase over time; and for the analysis it is assumed that the actual number of child deaths increases by 1% of the total per year. In the future-with project situation it is assumed that there would be a reduction in the number of deaths; increasing from 5% per year during the period 2015-2019 and progressively increasing to a 25% reduction in annual deaths by 2035, reflecting the deteriorating water supply situation in the without project situation. In terms of numbers this represents almost 200 saved lives in 2019 increasing to over 1000 per year by 2035. Consequently the annual benefits increase from KES123 million in 2015 when the project first has an impact to over KES600 million per year in 2035.

d) Time Savings and Water Disinfection

A consumer and social protection assessment conducted in Nairobi's informal settlements by AWSB in 2007 gathered information about access to water, time taken for collecting water, methods used for disinfection etc. The survey showed that 48% of the sampled households were connected to NCWSC network, although only 38% said that they received water all the time, the rest only received water on a varying number of days per month. The survey showed that for households not connected to the NCWSC network most got water from water vendors, kiosks and boreholes. Based on the results it is calculated that households spent an average of 18 minutes a day collecting water, which at a basic opportunity cost for their time of KES5 per hour (allowing for the less productive family members children, the unemployed etc.) represents an annual cost per household of KES560 per year. When grossed up to represent the estimated 200,000 households involved this indicates a total opportunity cost of KES112 million per year.

The majority of households also disinfect their drinking water by various means – boiling, filtering and treating with bleach. The estimated cost for treating a minimum amount of water for drinking amounts to a similar cost per household of KES500 or around KES100 million per year for all the households in this sector. Improved supply of clean water and better access as a

[11] *Water and Sanitation to Reduce Child Mortality: The Impact and Cost of Water and Sanitation Infrastructure*, The World Bank Development Economics Prospects Group, Policy Research Working Paper 5618, March 2011

[12] http://www.unicef.org/infobycountry/kenya_statistics.html

result of the project should result in a reduction in collection time and disinfection costs. For the purpose of the analysis this benefit has been taken as a 50% reduction in cost to produce a progressive benefit rising to KES120 million per year by 2025.

e) Willingness to Pay

Recent information of Willingness to Pay (WTP) for improved supply and access to water for the Nairobi City area is not available. The assessment conducted by AWSB in 2007 concerned with consumer and social protection mentioned above also asked about WTP, but as this survey was limited to the informal settlements it is not representative of attitudes for all groups of consumers in the supply network. However the results of the survey did indicate that in terms of WTP, 51% of the households said they were not willing to pay more for water if services were improved, 33% said that they were willing and 16 % were undecided. As most of the households are already paying considerably more that the applicable NCWSC tariff, as they get mostly water from other more expensive sources, this result is ambiguous and is not consistent with the expected reaction when consumers have the alternative of receiving an improved and cheaper supply from the mains network.

In the absence of good information on WTP in the Nairobi area the average tariff of KES35/m^3 has been used to value the incremental supply of water in the economic analysis.

9.4 Economic Analysis

9.4.1 Cost-Benefit Cash Flow Summary

The resources and costs and benefit flows for the project are presented in the followed table for the 30-years project evaluation period.

9.4.2 Results of Economic Analysis

Table 8-62 that follows below shows the results of the economic analysis and the sensitivity analysis. The base case Economic Internal Rate of Return (EIRR) is 7.3% with a Net Present Value (NPV) at a discount rate of 12% of –KES11,557 million. The project does not meet the commonly accepted hurdle of an EIRR of 12% but the result is considered to be acceptable for long term investment in the water supply and sanitation sector.

9.4.3 Sensitivity Analysis

Table 8-63 on page 8-161 also shows the results of the sensitivity analysis with a 20% variation in the main parameters – capital costs, O&M costs, benefits and a delay in benefits by one year. A 20% reduction in the capital investment costs increases the EIRR to 9.7% while a 20% increase in the benefits results in an EIRR of 9.8%. A 20% reduction in O&M costs and a delay in one year in the benefits stream do not have such a significant effect on the economic results.

The switching value (a measure of the change in cost or benefits to achieve the opportunity cost of capital) shows that capital costs would have to reduce by 38% and the benefits to also increase by 38% to achieve an EIRR of 12%. The sensitivity indicator shows that the EIRR is most sensitive to changes in capital costs and benefits rather than changes in O&M costs and delay in the timing of the benefits.

Table 8-62: Economic Cost-Benefit Resource Cash Flows 2012 – 2042

Year	Incremtl Prodn	Incremtl Unaccounted-for-Water			Water Sold Incremental			Total	Economic Benefits						Econ	Net
		NTL	TL	Total	Non-incr	Incr	Total all	Consump	Non-incr	Incr	NTL	Other	Health	Total	Cost	Benefit
	m^3 mill/yr	m3 mill	m3 mill	m3 mill	m3 mill	m3 mill	m3 mill	m3 mill	KES mill	KES mill	KES mill	KES mill	KES mill	KES mill	KES mill	KES mill
2012	-	-	-	-	-	-	-	132.06	0	0	0			0	800	-800
2013	-	-	-	-	-	-	-	134.09	0	0	0			0	7,560	-7,560
2014	12.61	0.44	3.54	3.97	8.64	-	8.64	144.82	714	0	15			729	12,347	-11,618
2015	23.65	0.79	6.43	7.23	16.43	-	16.43	154.74	1,357	0	28	0	123	1,508	6,910	-5,402
2016	40.61	1.32	10.69	12.01	20.33	8.27	28.60	169.13	1,680	289	46	12	125	2,152	350	1,802
2017	45.01	1.41	11.40	12.81	22.90	9.30	32.20	175.22	1,892	326	49	24	126	2,417	3,941	-1,524
2018	51.78	1.62	13.11	14.74	26.34	10.70	37.05	180.33	2,176	375	57	36	127	2,771	5,920	-3,149
2019	58.76	1.84	14.88	16.72	29.89	12.14	42.04	185.58	2,470	425	64	48	128	3,135	6,882	-3,747
2020	64.83	1.91	15.43	17.33	33.85	13.64	47.49	194.75	2,797	477	67	60	254	3,655	4,210	-555
2021	73.43	2.16	17.48	19.64	38.41	15.39	53.80	201.32	3,173	539	76	72	251	4,110	1,074	3,036
2022	82.37	2.42	19.60	22.03	43.15	17.20	60.35	208.14	3,565	602	85	84	245	4,581	1,866	2,715
2023	91.66	2.70	21.81	24.51	48.09	19.06	67.15	215.21	3,973	667	94	96	239	5,070	4,248	822
2024	101.30	2.98	24.11	27.09	53.24	20.98	74.21	222.54	4,398	734	104	108	234	5,578	6,375	-797
2025	110.45	3.25	26.28	29.53	58.13	22.78	80.91	229.51	4,803	797	114	120	407	6,240	7,630	-1,390
2026	121.09	3.56	28.82	32.38	63.84	24.88	88.71	237.57	5,274	871	125	120	397	6,786	5,375	1,411
2027	132.15	3.89	31.45	35.34	69.77	27.04	96.81	245.94	5,764	946	136	120	388	7,355	7,710	-356
2028	143.64	4.22	34.18	38.41	75.96	29.27	105.23	254.62	6,275	1,024	148	120	379	7,946	7,815	131
2029	154.74	4.55	36.83	41.38	81.96	31.40	113.36	263.02	6,771	1,099	159	120	370	8,520	1,426	7,093
2030	167.11	4.92	39.77	44.68	88.66	33.76	122.42	272.35	7,325	1,182	172	120	652	9,451	1,831	7,620
2031	179.03	5.27	42.61	47.87	95.16	36.00	131.16	281.36	7,862	1,260	184	120	637	10,063	2,759	7,304
2032	191.42	5.63	45.55	51.18	101.94	38.29	140.23	290.70	8,422	1,340	197	120	622	10,701	2,596	8,105
2033	205.20	6.04	48.83	54.87	109.47	40.85	150.33	301.06	9,044	1,430	211	120	607	11,413	3,167	8,246
2034	218.59	6.43	52.02	58.45	116.84	43.30	160.14	311.14	9,653	1,515	225	120	593	12,106	3,442	8,664
2035	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	3,751	9,124
2036	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	3,751	9,124
2037	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	3,751	9,124
2038	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	3,873	9,003
2039	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	3,751	9,124
2040	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	3,751	9,124
2041	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	3,751	9,124
2042	233.46	6.87	55.56	62.43	125.02	43.30	168.32	322.30	10,328	1,515	240	120	671	12,875	1,081	11,794

Table 8-63: Economic Cost-Benefit Analysis Results

Year	Benefit KES mill	Economic Cost Investmt KES mill	Economic Cost O&M KES mill	Economic Cost Total KES mill	Net Benefit (Cost) Base Case KES mill	Net Benefit (Cost) Investmt -20% KES mill	Net Benefit (Cost) O&M -20% KES mill	Net Benefit (Cost) Benefit 20% KES mill	1-yr Delay in Benefit KES mill
2012	0	800	0.0	800	-800	-640	-800	-800	-800
2013	0	7,560	0.0	7,560	-7,560	-6,048	-7,560	-7,560	-7,560
2014	729	12,077	270.3	12,347	-11,618	-9,203	-11,564	-11,472	-12,347
2015	1,508	6,402	507.8	6,910	-5,402	-4,122	-5,300	-5,100	-6,181
2016	2,152	130	220.3	350	1,802	1,828	1,846	2,232	1,158
2017	2,417	3,534	406.6	3,941	-1,524	-817	-1,443	-1,041	-1,789
2018	2,771	5,355	564.8	5,920	-3,149	-2,078	-3,037	-2,595	-3,504
2019	3,135	6,170	711.8	6,882	-3,747	-2,513	-3,604	-3,120	-4,111
2020	3,655	3,370	840.1	4,210	-555	119	-387	176	-1,074
2021	4,110	603	471.0	1,074	3,036	3,157	3,130	3,858	2,581
2022	4,581	1,355	510.6	1,866	2,715	2,986	2,817	3,631	2,244
2023	5,070	3,700	547.4	4,248	822	1,562	931	1,836	333
2024	5,578	5,638	736.8	6,375	-797	331	-649	319	-1,305
2025	6,240	6,675	955.1	7,630	-1,390	-55	-1,199	-142	-2,052
2026	6,786	4,613	762.3	5,375	1,411	2,334	1,564	2,769	865
2027	7,355	6,905	805.4	7,710	-356	1,025	-194	1,115	-924
2028	7,946	6,839	975.7	7,815	131	1,499	326	1,721	-460
2029	8,520	0	1,426.4	1,426	7,093	7,093	7,378	8,797	6,520
2030	9,451	0	1,830.7	1,831	7,620	7,620	7,986	9,510	6,689
2031	10,063	568	2,191.4	2,759	7,304	7,417	7,742	9,316	6,691
2032	10,701	0	2,596.1	2,596	8,105	8,105	8,624	10,245	7,467
2033	11,413	121	3,046.1	3,167	8,246	8,270	8,855	10,528	7,534
2034	12,106	0	3,442.0	3,442	8,664	8,664	9,353	11,086	7,971
2035	12,875	0	3,751.5	3,751	9,124	9,124	9,874	11,699	8,355
2036	12,875	0	3,751.5	3,751	9,124	9,124	9,874	11,699	9,124
2037	12,875	0	3,751.5	3,751	9,124	9,124	9,874	11,699	9,124
2038	12,875	121	3,751.5	3,873	9,003	9,027	9,753	11,578	9,003
2039	12,875	0	3,751.5	3,751	9,124	9,124	9,874	11,699	9,124
2040	12,875	0	3,751.5	3,751	9,124	9,124	9,874	11,699	9,124
2041	12,875	0	3,751.5	3,751	9,124	9,124	9,874	11,699	9,124
2042	12,875	-2,670	3,751.5	1,081	11,794	11,260	12,544	14,369	11,794
2043	0	0		0	0	0	0	0	12,875
		Discount Rate @ 12%		**EIRR**	7.3%	9.7%	7.8%	9.8%	6.4%
				ENPV	-11,557	-4,647	-10,426	-5,828	-14,627
		Sensitivity Indicator		**EIRR**		2.6	0.6	2.6	1.6
				ENPV		3.0	0.5	2.5	2.5
		Switching Value		**EIRR**		38%	173%	38%	61%
				ENPV		33%	204%	40%	40%

9.4.4 Conclusion

The economic analysis of the development of Nairobi's water supply to fully meet the projected needs until 2035 shows that the economic performance, although not meeting the hurdle of an opportunity cost of capital of 12% does show a reasonable performance with an EIRR of 7.3%. The economic evaluation is based on a conservative estimation of the benefits, especially for the health benefits as in the absence of reliable data on the impact of improved water supply and sanitation a broad-brush approach was applied, which may underestimate the long term impact. Considerable benefits can be expected to arise from the capital investment, but the economic performance is tempered by the relatively large scale of the investment of over US$1 billion needed to increase water supply to meet projected demand.

Scenario 3A, on which the economic evaluation is based, was shown by the multicriteria analysis of the four main investment scenarios to be the most economically viable and favoured option, and so represents the least-cost option for meeting the future water demand for Nairobi city. Scenario 2, the second ranked option has an EIRR of 6.5% and much higher future

operating costs for pumping, as reflected in the comparatively higher PV of operating costs. Table 8-64 below shows a comparison of the two Scenarios.

Table 8-64: Comparison of Scenarios 3A and 2 Economic Analysis

Item	Unit	Scenario 2	Scenario 3A
Capital costs (2012 – 2035)	US$ m	1,075.58	1,058.27
AIEC	US$/m^3 @ 5%	0.74	0.63
EIRR		6.5%	7.3%
PV all costs	US$ m @ 5%	$831.51	$669.45
PV CAPEX	"	$509.36	$471.50
PV OPEX (fixed)	"	$91.17	$82.95
PV OPEX (variable)	"	$216.58	$115.01

Note: *Capital costs are in constant 2012 prices and include costs of rehabilitation and expansion of the distribution network.*
Present Values calculated at a discount rate of 5%.
AIEC = Average Incremental Economic cost = discounted cost/ discounted cost of water

The reality of not investing sufficient capital to meet the projected demand may be underestimated in the analysis as it assumes that most of the water balance deficit and unsatisfied demand in the future-without project situation will be met by an expansion of groundwater production. Groundwater exploitation would have to rise to over 400,000m^3/d, almost five times the estimated current rate of abstraction. It is unlikely that the groundwater aquifer in the Nairobi area would be able to support this rate of pumping and in reality water would have to be sourced from further afield, meaning that the long term opportunity cost of alternative sources of water would be higher than the values used for the economic analysis.

a) Other Non-Quantified Positive Benefits

The development of the water supply and delivery infrastructure is also likely to produce several other positive impacts that are not fully reflected in the economic analysis.

Maragua 4 Dam. Construction of the new dam would allow minimum flows in the Maragua River downstream of the dam to be maintained at an appropriate level safeguarding other water abstraction infrastructure and supporting aquatic life. Currently the river experiences low flows in time of drought which has a negative impact on the environment. Water stored in the dam could be released during dry periods to maintain an appropriate minimum flow in the river with a positive environmental outcome. However this will require an appropriate management plan for the dam supported by monitoring and recording

Water delivery to higher levels. The construction of the high level Ngorongo WTW will allow more water to be delivered by gravity to higher elevation in some parts of Nairobi city which currently have a restricted water supply requiring pumping and supplemental tanker deliveries. Meeting the demand by a gravity system will reduce pumping costs, ensure the supply is more reliable and facilitate the efficient operation of the sewage system which is currently constrained by the lack of water.

Associated Economic Activity. Support for the sufficient and reliable supply of economical water delivered through the mains network will promote confidence in the economic development of the city with higher growth of commercial and industrial activity, generating more jobs, increased wages etc for the large workforce, many of whom are currently unemployed or underemployed.

Prevention of Epidemics. Providing improved water supply and sanitation to Nairobi city and especially to the informal settlements where half the people reside will lessen the likelihood of a major disease outbreak or an epidemic of cholera or typhoid which could have disastrous consequences resulting in more deaths, especially among the very young and the vulnerable. Poor water supply and sanitation is closely linked to the risk of fatal epidemics and this potential downside of not meeting the future water demand has not been fully reflected in the economic analysis.

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Chapter 9 - Development Strategy for Water Supply to Satellite Towns

1 Introduction

This Chapter outlines the different Options investigated for development of new water sources to meet the short term and long term water needs for Nairobi and Satellite Towns up to Year 2035. All the Options investigated for water supply to Satellite Towns include implementation of Option 3A – Water Supply to Nairobi City which is detailed in Chapter 7.

The development strategies discussed in this Chapter form an integrated solution for development of new water sources in the region for the benefit of all users within the wider Study Area. The wider Study Area in this case comprises of Nairobi City and 13 Satellite Towns as defined in the Terms of Reference.

The Satellite Towns fall within a radius of 70km from Nairobi City and consist of; Kikuyu, Ruiru-Juja, Kiambu, Karuri, Githunguri, Mavoko Municipality, Ngong Township, Ongata Rongai, Thika, Gatundu, Limuru, Tala-Kangundo Towns.

Some of the Satellite Towns are located within the vicinity of Nairobi City Boundary and are considered as part of the Greater Nairobi, and thus within the “Effective Envelop of the Nairobi Water Demand”. The Satellite Towns forming the Effective Envelop of Nairobi City Water Demand are: Kikuyu, Ruiru-Juja, Karuri, Mavoko Municipality, Ngong Township and Ongata Rongai.

2 Development Criteria

The study area has been divided into 12 demand centres which are defined by the present licensed water service providers mandated area of service. The 12 demand centres are:

1. Nairobi City

Area within Nairobi City Boundary - Served by Nairobi City Water & Sewerage Co. (NCWSC)

- Low Level Supply Zones
- Middle Level Supply Zones
- Upper Level Supply Zones

2. Satellite Towns within Nairobi Effective Water Demand Envelop

1. Kikuyu - Area served by Kikuyu Water & Sewerage Company
2. Kiambu - Area served by Kiambu Water & Sewerage Company
3. Karuri - Area served by Karuri Water & Sewerage Company
4. Ruiru-Juja - Area served by Ruiru-Juja Water & Sewerage Company
5. Mavoko Municipality - Area served by Mavoko-EPZA Water & Sewerage Co.

6. Ngong, Ongata Rongai & Kiserian - Area served by Oloolaiser Water & Sewerage Co.

3. Other Satellite Towns outside Nairobi Effective Water Demand Envelop

1. Limuru Town - Served by Limuru Water & Sewerage Company
2. Githunguri Town - Served by Githunguri Water & Sanitation Company
3. Gatundu Town - Served by Gatundu South Water & Sewerage Company
4. Thika Town - Served by Thika Water & Sewerage Company
5. Tala-Kangundo Towns - Served by Matungulu-Kangundo Water & Sewerage Co.

The basic philosophy used in the development of strategies for Satellite Towns is similar to the one adopted for Nairobi City and is outlined as follows:

- All demands should be fully met from year 2017 (short term) up to year 2035 (long term and ultimate planning horizon),
- All supplies assumed to be treated to a common acceptable standard for potable water supply,
- The basic costs for the required physical components are derived consistently,
- All Options assume the construction of the sources proposed under **Scenario 3A** for Nairobi City.

To assign the water sources to the defined demand centres, the following general considerations have been used in the development of strategies:

- Availability of local sources to supply the demand centres,
- Increase of surface water storage sources,
- Diversification of water sources (surface water, groundwater, rainfall harvesting) where appropriate,
- Optimal use of the existing facilities,
- Gravity supply where possible to reduce operating costs and minimise problems associated with the operation and maintenance of a pumping plant,
- Feasible transmission routes from sources to demand centres.

3 Potential Water Sources for Supply to Satellite Towns

3.1 Surface Water Sources

Preliminary assessment based on the daily flow rate which is exceeded with a probability of 95% show that run of river abstractions from rivers close to Satellite Towns have relative low safe yields and cannot meet the forecast water demands. In order to meet the present and future water demands impoundments on potential rivers close to the study area will be necessary.

Preliminary yield assessment of potential reservoirs to serve the Satellite Towns has been carried out as discussed in Chapter 5. Table 9-1 gives a list of proposed dams considered in the strategy development for water supply to Satellite Towns and the net yield estimates from the proposed sources.

Table 9-1: List of Proposed Dams for Satellite Towns Water Supply

Proposed Dam Site	Dam Height, m	Storage Capacity, Mm^3	Yield		Estimated Construction Cost (US$ M)*
			m^3/s	m^3/d	
Kamiti 1	50	16.4	0.19	16,416	45.82
Kamiti 2	25	1.72	0.06	5,184	8.19
Kamiti 3	30	3.75	0.10	8,640	18.27
Ndarugu 3	50	11.2	0.24	20,736	90.05
Riara	30	7.3	0.14	12,096	18.46
Komothai 1	35	3.47	0.13	11,232	19.86
Komothai 2	30	4.9	0.18	15,552	13.43
Ruiru 2	50	13.2	0.46	39,744	52.36
Ruiruaka 1	20	2.89	0.10	8,640	8.28
Ruiruaka 2	20	2.13	0.07	6,048	7.49
Karimenu 2	40	14.2	0.54	46,656	34.54
Gatamayu 1	30	3.17	0.15	12,960	14.69
Gatamayu 2	50	7.1	0.38	32,832	50.45
Thiririka	50	14.7	0.39	33,869	66.05
Stony Athi	25	23.1	0.70	60,480	40.86
Mbagathi	35	53.4	0.64	55,123	67.52
Ruabura	65	26.5	0.44	38,016	120.88
Thika 3A	40	13.0	0.46	40,000	36.30
		Total Yield	**4.76**	**411,520**	

** The Costs exclude Preliminaries and General Costs, Contingencies and Engineering Design and Supervision Costs.*

Figure 9-1 shows the location of Satellite Towns and potential dam sites considered for water supply to Satellite Towns.

3.2 Groundwater Sources

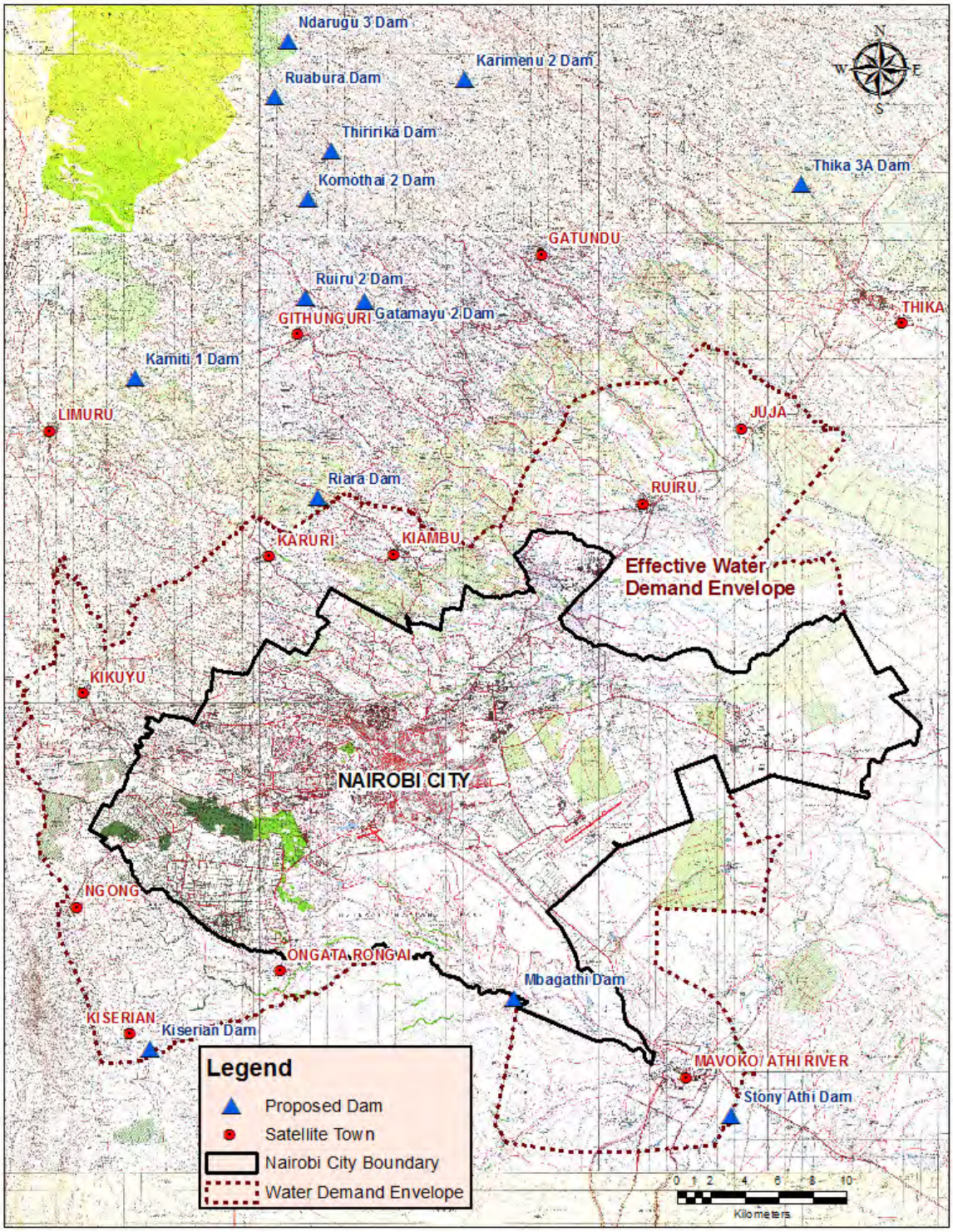
Groundwater development has also been considered within the planning period to supply the high altitude and remote demand centres where no alternative surface water sources are available.

The exploration of groundwater sources is not limited for development within the demand centres, instead, in some cases it might need to be sourced from outside the area of supply. Table 9-2 shows the groundwater production capacities considered for specific Satellite Towns. The capacities are based on groundwater assessment study carried out in specific Satellite Towns as discussed in Chapter 6 of this report.

Table 9-2: Maximum Groundwater Allocation to Satellite Towns

Satellite Town	Production Capacity	
	m^3/s	m^3/d
Kikuyu	0.21	18,000
Ngong & Ongata Rongai	0.03	2,500
Limuru	0.09	8,000
Githunguri	0.05	4,000
Gatundu	0.01	740
Tala-Kangundo	0.04	3,600
Total	**0.43**	**36,840**

Figure 9-1: Location Map of Satellite Towns and Potential Dams Considered for Water Supply



4 Proposed Development Strategies

The proposed development strategies for water supply to Nairobi and Satellite Towns have been classified to consider Nairobi plus the envelop area and the Satellite Towns outside water demand envelop separately.

The development strategies proposed define the utilization plan of major water sources within the region to the benefit of Nairobi and the surrounding areas defined by the water demand envelop.

To meet the demands for Nairobi City and Satellite Towns, three water supply strategies to demand centres have been developed. The three Options are:

- **Independent Water Supply Option** – Demands met by Independent Water Sources. Water supply systems to be managed by the existing Independent Water Service Providers
- **Strategic Water Supply Option** – Demands met by a limited number of major resource developments (strategic sources). All Strategic Sources supply Nairobi City with en route off-takes and bulk transfers to Satellite Towns.
- **Mixed Water Supply Option** – Demands met by a combination of Independent and Strategic Sources on the basis of Technical and Economic viability.

The Strategic and Mixed Water Supply Options comprise of an Integrated Water Sources Utilisation Plan in which sources are shared between Nairobi and the Satellite Towns.

The Strategic Water Sources are the major resource developments which can economically provide bulk supply to demand centres compared to localised sources. They have a high capital investment but offer a good return of capital.

The proposal is that the Strategic Sources be developed and operated by Nairobi City Water and Sewerage Company or alternatively by a Bulk Water Supplier which will then provide bulk sales of water to the water service providers in the Satellite Towns.

The Proposed Developments for the Satellite Towns will involve the conjunctive use of surface and ground water sources where possible. Limuru, Githunguri, Gatundu, Tala and Kangundo Towns fall outside the Nairobi City Water Supply Envelope and have relatively low water demands. This makes their water supply from Nairobi difficult in both technical and economic terms. It is therefore proposed to have independent water supply schemes for each of these Towns except for Tala and Kangundo which are in close proximity to each other hence are clustered together. Preference is given to groundwater sources for their water supply wherever feasible. Thika Town, due to its location relative to Nairobi and the other Satellite Towns will also have independent interventions. Thika Town is already supplied by an independent existing water infrastructure.

5 Design Criteria for Development of Options

5.1 Introduction

Conceptual Engineering Designs for the different components required to satisfy demands under each Option have been carried. Unit costs have then been applied to the elements sized to obtain the capital costs required for the implementation of the various schemes.

The design criteria and assumptions used to size the various components are discussed below while the costing criteria is discussed in Section 10 of this Chapter.

5.2 Earthfill and Rockfill Dams

Potential Dam Sites were identified using the 1:50,000 topographical maps published by Survey of Kenya and used to determine the site cross sections. Dam Height / Storage Volume relationships were derived for each site and used to obtain the Yield / Storage / Height relationships as outlined in Chapter 5.

For the purposes of sizing and costing, all Dams have been assumed to be Earthfill Embankments with the exception of Ndarugu 1 and Mbagathi Dam which have been assumed to be Rockfill Dams.

The following criteria has been used to estimate the Embankments Volumes for Earthfill Dams:

- Dam crest width of 10 metres.
- Upstream enbankment slope of 1:3.0 (V:H)
- Downstream enbankment slope of 1:2.5 (V:H)
- Freeboard of 4m

For Rockfill Embankment Dams, the following criteria has been used to estimate the embankments volumes:

- Dam crest width of 10 metres.
- Upstream enbankment slope of 1:2.25 (V:H)
- Downstream enbankment slope of 1:2.0 (V:H)
- Freeboard of 4m

The spillway and draw-off works have been sized and costed separately for each dam site on the basis of catchment area and dam height respectively.

5.3 Transmission Tunnels

Transmission Tunnels have been dimensioned to give a minimum opening of 3.2m diameter for the following reasons:

- A working height sufficient to accommodate labour and plant
- Requirement for ventilation, using either a venting in or out system with a minimum pipe diameter of 500mm
- A working width sufficient to accommodate access for vehicles for mucking out.
- A diameter sufficient to allow rock support to be implemented i.e. rock bolts or sprayed shotcrete. The latter requires an operator standing at least two metres from the rock face. Similarly the drilling of holes and the installation of rock bolts would require sufficient space to carry out the operation.

The tunnel hydraulic design parameters used are given below:

- The maximum velocity is limited to 3 m/s in order to reduce the erosion on the shotcrete lining of the tunnel and the lining, while being high enough to scour the tunnel clear of minor debris on the invert during periods of high flow.
- The normal flow depth does not exceed 67% of the tunnel height and the maximum flow depth under maximum flow conditions is limited to 75% of this. The maximum flow is defined as that with a statistical return period of 100 years. The intent is to prevent the

inadvertent and intermittent filling of the tunnel. Not only does this cause irregularity in the flow, it also risks trapping air within the flow which can be released explosively, with the risk of damage to the tunnel.

- The maximum Froude number of the flow at a depth of 67% of the tunnel height is limited to 0.60. The purpose of this is to minimize the likelihood and amplitude of waves on the surface of the water. This will also help to avoid trapping air in large quantities within the flow.

5.4 Transmission Pipelines

The Bulk Transmission Pipelines were routed using the 1:50,000 topographical maps published by the Survey of Kenya. Feasible pipeline routes were identified and wherever possible, the alignment followed existing roads. The following criteria were adopted:

- Hydraulic design of the pipes was carried out using the Colebrook White Equation using the start and end point elevations. A coefficient of roughness (K_s) of 1.0mm was used in the design.
- All pipes to be ferrous with protective internal lining.
- Velocities limited to maximum of 1.5m/s

5.5 Treatment Works and Source Reservoirs

The Treatment Works capacities are equivalent to the Ultimate Yields of the Proposed Dams. Phasing of the construction of the Treatment Works has been considered wherever necessary.

Where possible, source reservoirs have been located at high elevation points to supply water by gravity to demand centres. Storage capacities equivalent to half the daily water demand have been provided. The storage tanks have also been phased when necessary.

5.6 Pumping Stations

The number of Pumps and capacity to be installed has been sized depending on the projected daily maximum volume.

The sizing allows for necessary Standby Pumps on the basis of One Stand-By Pump for every Two Duty Pumps (50% stand-by capacity).

For costing purposes, the Pump Costs have been calculated to include the cost of pump house, pipework and necessary electricity supply.

5.7 Groundwater Development

Groundwater development has been proposed for Satellite Towns where either surface water sources are either scarce or not economical to develop. The total yield, expected discharge per borehole, depth of boreholes, depth to water level and pumping head to collector tank has been assumed based on preliminary hydrogeological studies carried out as part of this study and as reported in Chapter 6 of this report.

The borehole parameters for the various proposed groundwater developments used in sizing and costing are given in **Appendix 9**.

6 Independent Water Supply Option

6.1 General

In this water supply development Option, all demand centres as defined by the licensed water service providers mandated area of service will have individual water source or sources. This development option is partly what AWSB has been trying to achieve over the last few years in identifying individual sources for the various water service providers within AWSB mandated Area of Service.

The general criteria and assumptions used in developing this water supply strategy are listed below:

- Supply to Nairobi City remains the same as outlined in Scenario 3A
- No sharing of resource developments between demand centres
- All existing connections from Nairobi Transmission Pipelines to Satellite Towns to be disconnected
- Independent Sources to be developed for each of the demand centres
- Groundwater development considered where no local surface water sources are available

A Layout Plan showing the Long Term Development Strategy under this Option is given in **Figure 9-2** while the Implementation Schedule is shown in **Figure 9-3**. Individual Water Sources required for each Satellite Town are described in the following sections.

Figure 9-2: **Long Term Development Strategy – Independent Water Supply Option**

Figure 9-3: Implementation Schedule for the Independent Option

6.2 Nairobi City

The proposed new water sources for Nairobi City Water Supply as outlined in Scenario 3A and as discussed in Chapter 7 are listed below. The resource developments proposed are to satisfy the demands within Nairobi City Boundary (Nairobi County) which is the present mandated area of service for Nairobi City Water and Sewerage Company (NCWSC).

1. Wellfields in Kiunyu and Ruiru
2. Northern Collector Tunnel Phase I to Thika Dam
3. S. Mathioya Transfer to Thika Dam + Maragua 4 Dam (30Mm^3)
4. Northern Collector Tunnel Phase II to Thika Dam
5. Ndarugu 1 Dam (300Mm^3) with Natural Inflow

The water demand forecast for Nairobi City and the Implementation Plan for proposed future sources is shown in Figure 9-4. Details of proposed water supply facilities including their initial years of operation are given in Table 9-3.

Figure 9-4: Implementation Schedule for New Water Sources – Nairobi City

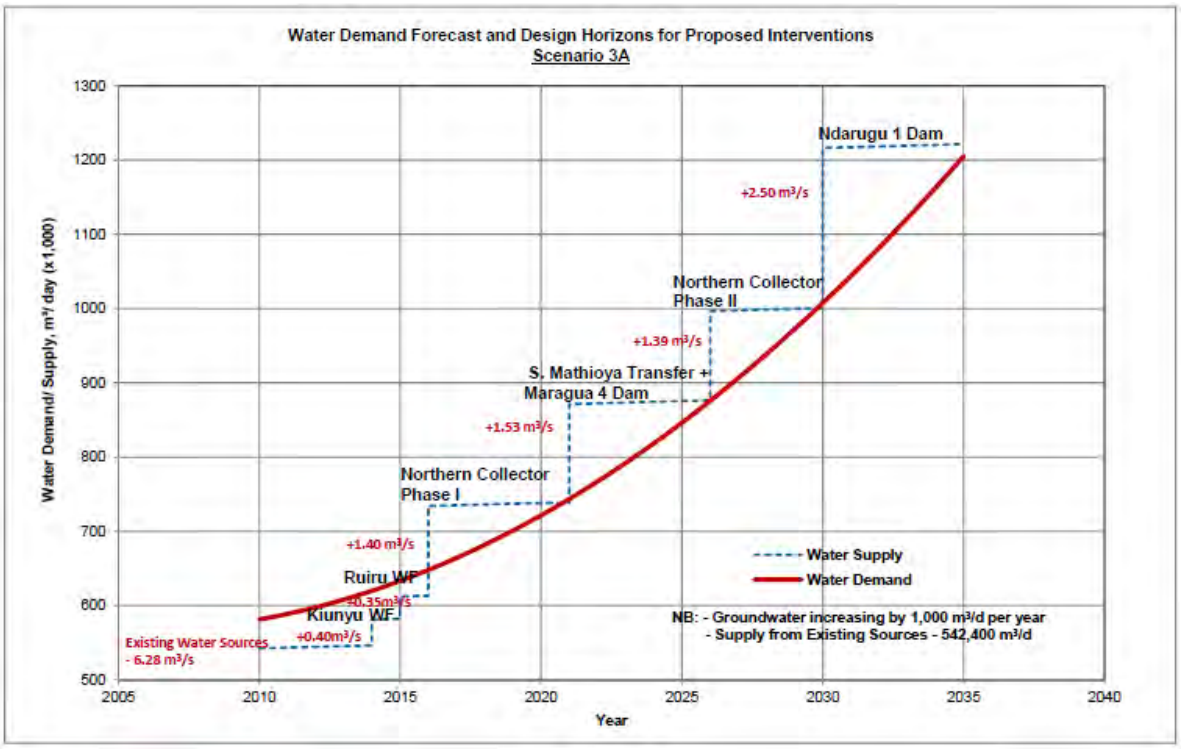


Table 9-3: Water Supply Infrastructure Required – Nairobi City

Phase	Infrastructure Required	Year of Operation
I.	**A.** Wellfield in Kiunyu (Yield, 34,560m^3/d) • 25Nr. Boreholes, Manifold System, Collector Tank, Chlorination Facility, Pumping Station & 45km long, 700mm dia. Pumping Main to Gigiri Reservoirs	2014
	B. Wellfield in Ruiru (Yield, 30,240m^3/d) • 15Nr. Boreholes, Manifold Sys`tem, Collector Tank, Chlorination Facility, Pumping Station & 15km long, 600mm dia. Pumping Main to Gigiri Reservoirs	2015
II.	Northern Collector Tunnel Phase I to Thika Dam (Total Yield, 120,960m^3/d) • 11.78 km long, 3.2m dia. Shortcrete lined Tunnel, • 44km long Raw Water Gravity Main, 1300mm dia., • Ngorongo Treatment Works of Capacity 120,960m^3/d, • 17.6km long, 1000mm dia. Treated Water Gravity Main to Kabete Reservoirs.	2016
III.	S. Mathioya Transfer to Thika Dam plus Maragua 4 Dam (Total Yield, 132,192m^3/d) • Maragua 4 Dam, 75m High & Storage 30Mm^3, • 3.36km long, 3.2m dia. Shortcrete lined Tunnel, • 24km long, 1000mm dia. Raw Water Gravity Main from Maragua 4 Dam to Ndunyu Chege Treatment Works, • 13km long, 600mm dia. Raw Water Gravity Main from Thika Dam to Ndunyu Chege Treatment Works • Ndunyu Chege Treatment Works of Capacity 132,192m^3/d, • 41km long, 1100mm dia. Treated Water Gravity Main to Gigiri Reservoirs.	2021
IV.	Northern Collector Tunnel Phase II to Thika Dam (Total Yield, 120,096m^3/d) • 7.9 km long, 3.2m dia. Shortcrete lined Tunnel, • 44km long, 1200mm dia. Raw Water Gravity Main, • Ngorongo Treatment Works, • 17.6km long, 1000mm dia. Treated Water Gravity Main to Kabete Reservoirs.	2026
V.	Ndarugu 1 Dam with Natural Inflow (Total Yield, 216,000m^3/d) • Ndarugu 1 Dam, 30m high & 300Mm^3, • Raw Water Pumping Station of Capacity 216,000m^3/d, • 7km long, 1200mm dia. Raw Water Pumping Main, • Ndarugu Treatment Works of Capacity 216,000m^3/d, • Treated Water Pumping Station of Capacity 216,000m^3/d, • 30km long, 1200mm dia. Treated Water Pumping Main to Kasarani, • Kasarani Booster Pumping Station of Capacity 164,160m^3/d • 12km long, 1100mm dia. Treated Water Pumping Main to Gigiri Reservoirs	2030

6.3 Satellite Towns Within Nairobi Water Demand Envelop

6.3.1 Kikuyu Town

The year 2035 water demand for Kikuyu area is 55,526m^3/d. The total production capacity of the present sources is 4,202m^3/d. The proposed future sources to augment the present sources and meet the ultimate water demand for Kikuyu area are:

1. Additional Groundwater Sources – Stage I - 9,000m^3/d
2. Kamiti 1 Dam (16.4Mm^3) - 16,416m^3/d
3. Additional Groundwater Sources – Stage II - 9,000m^3/d
4. Ndarugu 3 Dam - 20,736m^3/d

Groundwater is locally available and the first stage can be implemented before year 2015 to meet the present water supply deficit and the fast increasing water demand for Kikuyu Area.

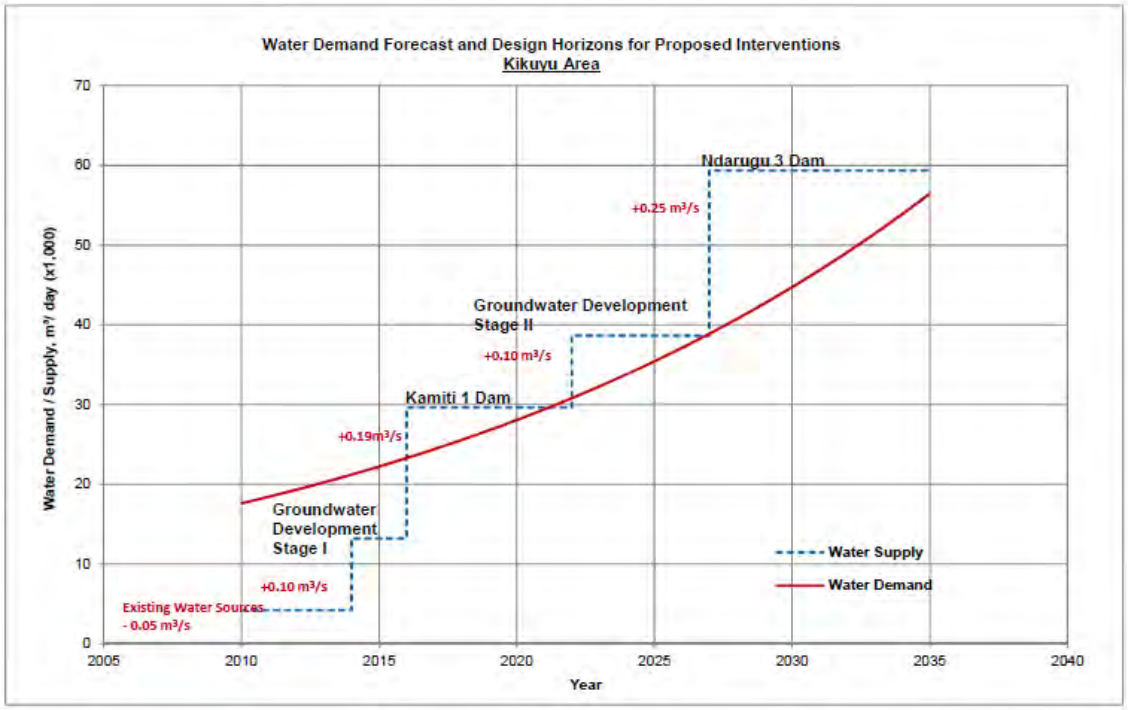
Kamiti 1 Dam has been selected for the reason that it is the only feasible potential surface water source which can supply the demand centre by gravity and can meet the water demand deficit within the planning period.

The water demand forecast for Kikuyu Area and the Implementation Schedule for proposed future sources is shown in Figure 9-5. Details of proposed water supply facilities including their initial years of operation are given in Table 9-4.

Table 9-4: Water Supply Infrastructure Required - Kikuyu

Phase	Infrastructure Required	Year of Operation
I.	Wellfield in Kikuyu with a total yield of 9,000m^3/day	2014
II.	Kamiti 1 Dam, Height 50m, Net Yield of 16,416m^3/day with • Treatment Works of capacity 16,416m^3/day • Ferrous Gravity Bulk Water Transmission, Diameter 450mm, Length 27km • System Storage of 8,000m^3	2016
III.	Additional Wellfield with a total yield of 9,000m^3/day	2022
IV.	Ndarugu 3 Dam, Height 50m, Net Yield of 20,736m^3/day with • Treatment Works of capacity 16,900m^3/day • Ferrous Gravity Bulk Water Transmission from Ndarugu 3 Dam to System Storage, Diameter 600mm, Length 43km • System Storage of 8,000m^3 • Pumping Station and Ferrous Bulk Water Rising Main from System Storage to Kikuyu Town, Diameter 600mm, Length 7km	2027

Figure 9-5: Implementation Schedule for New Water Sources – Kikuyu



6.3.2 Kiambu Town

The year 2035 water demand for Kiambu Area is 20,730m³/d. The present water supply is 3,060m³/d from groundwater sources and 230m³/d from NCWSC from Ngethu pipeline. The proposed future sources to augment the present sources and meet the ultimate water demand for Kiambu Area are:

1. Riara Dam (7Mm³) - 12,096m³/d
2. Komothai 2 Dam (4.9Mm³) - 15,552m³/d

The selection of Riara Dam is on the basis that it's close to the demand area and can supply Kiambu Town by gravity. Komothai 2 Dam has been selected to supplement Riara Dam and meet the forecast Year 2035 water demand for Kiambu Town. The dam will supply Kiambu Town and the surrounding areas by gravity.

The water demand forecast for Kiambu Area and the Implementation Schedule for proposed future sources is shown in Figure 9-6. Details of proposed water supply facilities including their initial years of operation are given in Table 9-5.

Figure 9-6: Implementation Schedule for New Water Sources - Kiambu

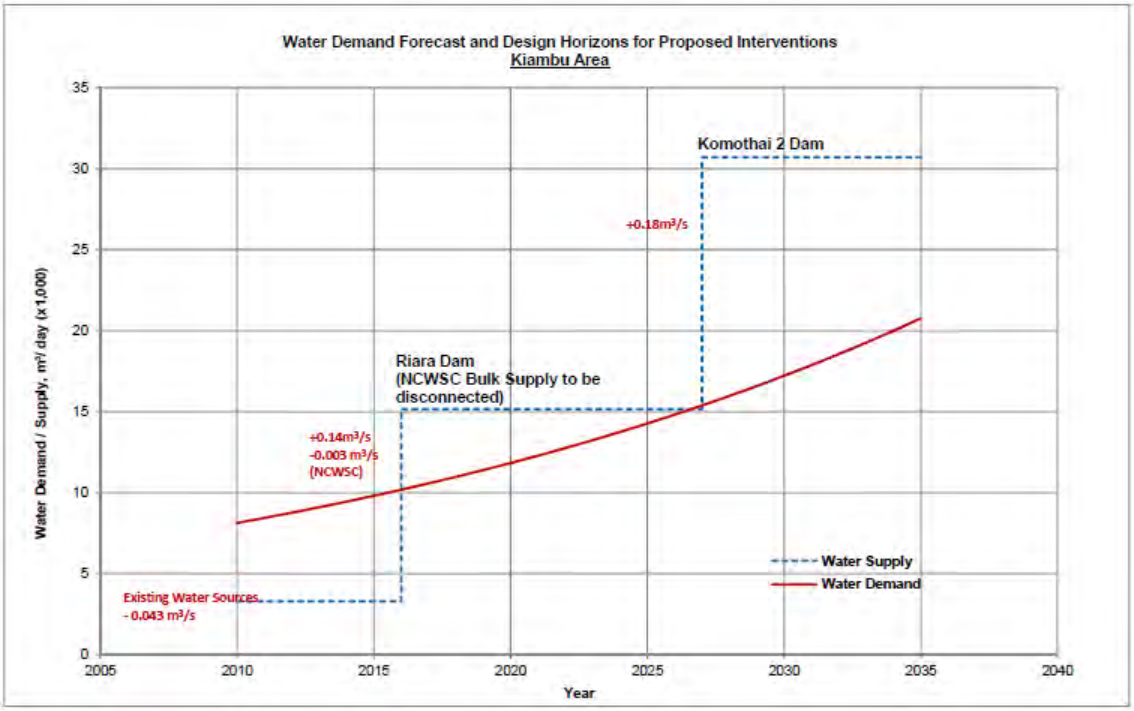


Table 9-5: Water Supply Infrastructure Required - Kiambu

Phase	Infrastructure Required	Year of Operation
I.	Riara Dam, Height 30m, Net Yield of 12,100m³/day with • Treatment Works of capacity 12,100m³/day • Ferrous Gravity Bulk Water Transmission, from Dam to System Storage, Diameter 350mm, Length 5km • System Storage of 6,000m³ • Ferrous Gravity Bulk Water Transmission from System Storage to Kiambu Town, Diameter 500mm, Length 4km	2016
II.	Komothai 2 Dam, Height 30m, Net Yield of 15,550m³/day with • Treatment Works of capacity 6,000m³/day • Ferrous Gravity Bulk Water Transmission, Diameter 300mm, Length 20km from Komothai 2 Dam to Kiambu Storage • Ferrous Gravity Bulk Water Transmission, Diameter 500mm, Length 4km from Kiambu Storage to Town • System Storage of 2,500m³	2027

6.3.3 Karuri Town

The year 2035 water demand for Karuri Area is 28,566m³/d. The present water supply is 1,667m³/d from groundwater sources and 1,100m³/d from NCWSC from Sasumua pipeline. The proposed future source to augment the present sources and meet the ultimate water demand for Karuri Area is Ruiru 2 Dam of capacity 13.2Mm³ to supply 39,744m³/d.

The selection of Ruiru 2 Dam is on the basis that its close to the demand area and can supply Karuri with minimal pumping costs. It is proposed that under the Independent Water Supply Option the NCWSC bulk supply be disconnected after the construction of Ruiru 2 Dam.

The water demand forecast for Kiambu Area and the Implementation Schedule for proposed future sources is shown in Figure 9-7. Details of proposed water supply facilities including their initial years of operation are given in Table 9-6.

Figure 9-7: Implementation Schedule for New Water Sources - Karuri

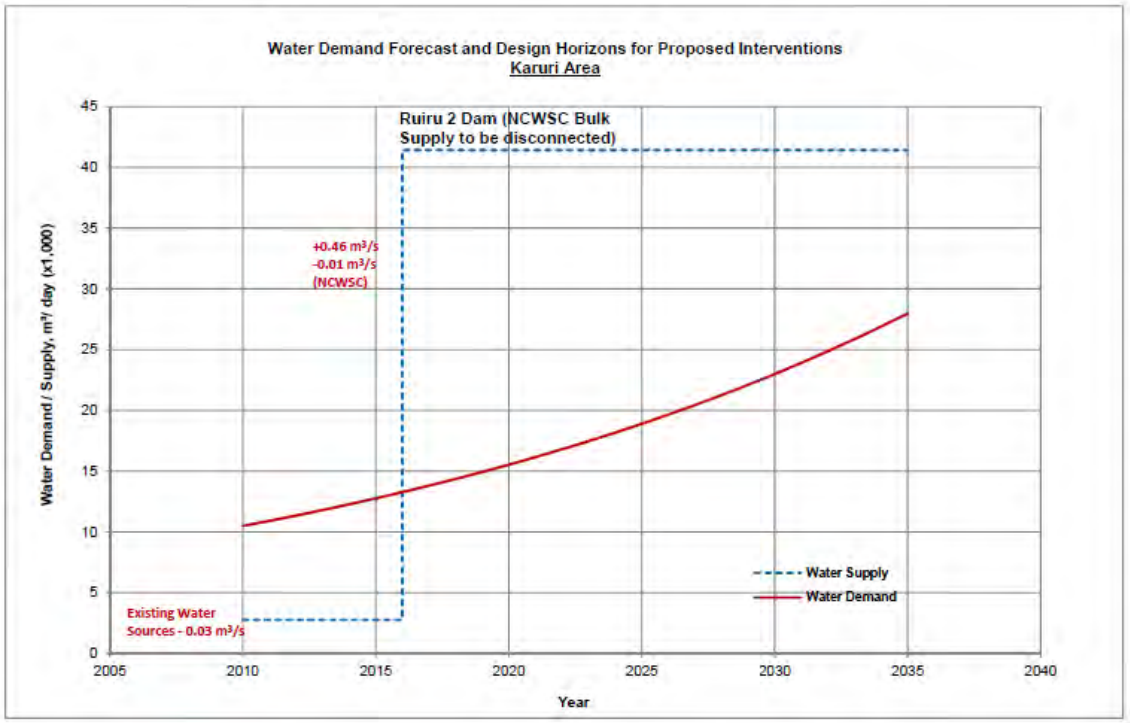


Table 9-6: Water Supply Infrastructure Required - Karuri

Phase	Infrastructure Required	Year of Operation
I.	Ruiru 2 Dam, Height 50m, Net Yield of 39,750m^3/day with • Treatment Works of capacity 17,500m^3/day • Ferrous Bulk Water Rising Main, from Dam to System Storage, Diameter 700mm, Length 17km • System Storage of 8,500m^3 • Ferrous Bulk Water Gravity Main from System Storage to Karuri Town, Diameter 700mm, Length 4km	2016
II.	Augmentation of aforementioned infrastructure • Treatment Works augmented to total capacity of 28,700m^3/day • System Storage augmented to total capacity of 13,000m^3	2030

6.3.4 Ruiru-Juja Towns

The year 2035 water demand for Ruiru-Juja Area is 131,978m³/d. The present total water supply to these towns is 6,480m³/d from Ruiru River, Ndarugu river, groundwater sources and 480m³/d from NCWSC through Ngethu pipeline. The proposed future sources to augment the present sources and meet the ultimate water demand for Ruiru-Juja area are:

1. New Ruiru Water Supply - 13,000m³/d (Under Construction – commissioning, end of 2012)
2. Augmentation of Juja Water Supply - 4,000m³/d (Under Construction – commissioning, end of 2012)
3. Karimenu 2 Dam (14.2Mm³) - 46,656m³/d
4. Gatamayu 2 Dam (7.1Mm³) - 32,832m³/d
5. Thiririka Dam (14.7Mm³) - 33,869m³/d

The selection of the three dam sites is on the basis that they are close to the demand areas and can supply water by gravity. It is proposed that under the Independent Water Supply Option the NCWSC bulk supply be disconnected after the construction of Karimenu 2 Dam.

The water demand forecast for Ruiru-Juja Area and the Implementation Schedule for proposed future sources is shown in Figure 9-8. Details of proposed water supply facilities including their initial years of operation are given in Table 9-7.

Figure 9-8: Implementation Schedule for New Water Sources – Ruiru-Juja

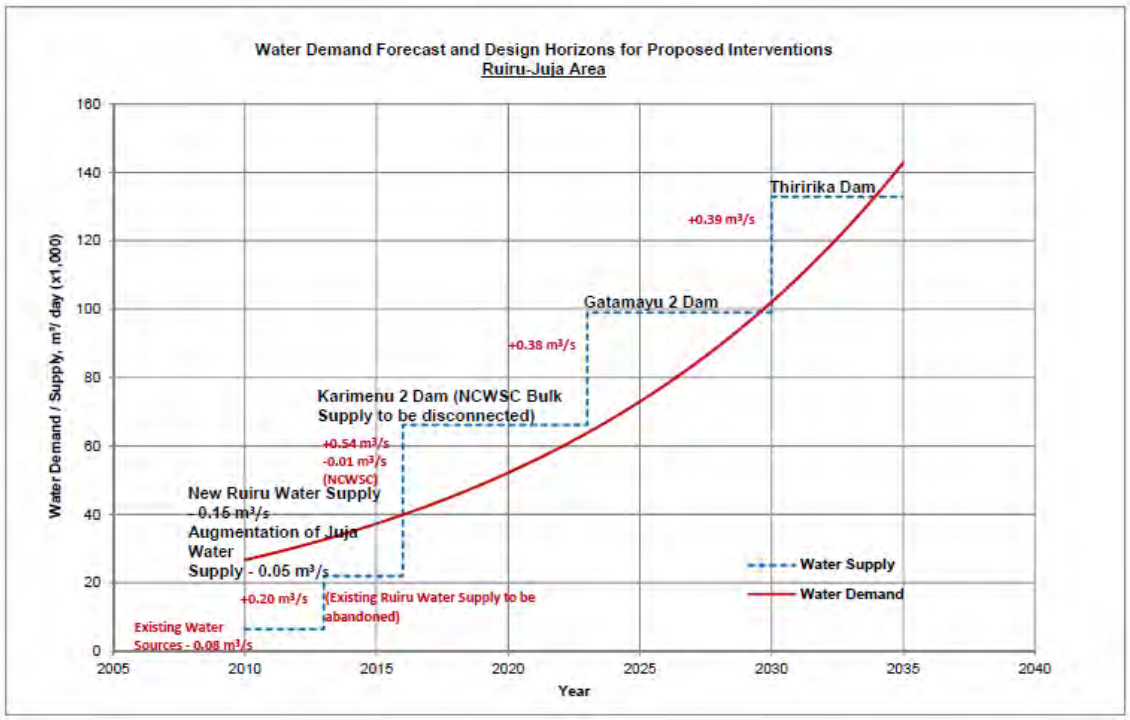


Table 9-7: Water Supply Infrastructure Required - Ruiru-Juja

Phase	Infrastructure Required	Year of Operation
I.	Karimenu 2 Dam, Height 40m, Net Yield of 46,650m^3/day with • Treatment Works of capacity 46,650m^3/day • Ferrous Bulk Water Gravity Main, from Dam to System Storage, Diameter 700mm, Length 18km • System Storage of 23,000m^3 • Ferrous Bulk Water Gravity Main from System Storage to Ruiru and Juja Town, Diameter 800mm, Length 25km	2016
II.	Gatamayu 2 Dam, Height 50m, Net Yield of 32,800m^3/day with • Treatment Works of capacity 32,000m^3/day • Ferrous Bulk Gravity Main from Dam to Storage, Diameter 500mm, Length 20km • System storage of 16,000m^3 • Ferrous Bulk Water Gravity Main from System Storage to Ruiru and Juja Town, Diameter 700mm, Length 19km	2023
III.	Thiririka Dam, Height 50m, Net Yield of 33,900m^3/day with • Treatment Works of capacity 33,000m^3/day • Ferrous Bulk Gravity Transmission of diameter 500mm and total length 27km from Dam to Storage • System storage of 16,000m^3	2030

6.3.5 Mavoko Municipality

The year 2035 water demand for Mavoko Municipality Area is 80,222m^3/d. The present total water supply to Mavoko is 9,170m^3/d from Nol Turesh Water Supply system, Groundwater sources and 7,500m^3/d from NCWSC Bulk Supply. The proposed future sources to augment the present sources and meet the ultimate water demand for Mavoko Municipality area are:

1. Stony Athi Dam (21Mm^3) - 60,480m^3/d
2. Mbagathi Dam (45Mm^3) - 55,123m^3/d

The selection of the two dam sites is on the basis that they are close to the demand area and no feasible alternative surface water sources exist within and in the vicinity of Mavoko Municipality. It is proposed that under the Independent Water Supply Option that the NCWSC bulk supply be disconnected after the construction of Stony Athi Dam. Water supply from the two sources will be through pumping.

The water demand forecast for Mavoko Municipality Area and the Implementation Schedule for proposed future sources is shown in Figure 9-9. Details of proposed water supply facilities including their initials year of operation are given in Table 9-8.

Figure 9-9: Implementation Schedule for New Water Sources - Mavoko

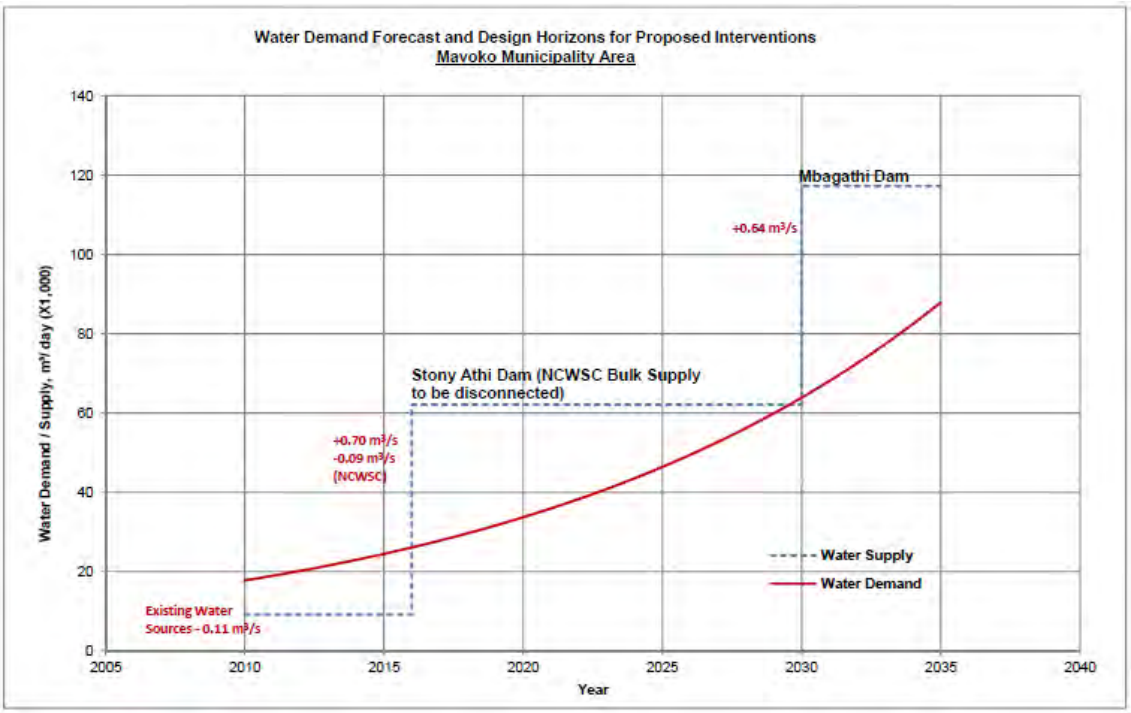


Table 9-8: Water Supply Infrastructure Required - Mavoko

Phase	Infrastructure Required	Year of Operation
I.	Stony Athi Dam, Height 25m, Net Yield of 60,500m³/day with • Treatment Works of capacity 60,500m³/day • Pumping station from Treatment Works to Storage • Ferrous Bulk Gravity Main from Treatment Works to Storage, Diameter 800mm, Length 5km • System storage of 30,000m³ • Ferrous Bulk Gravity Main from Storage to Mavoko, Diameter 800mm, Length 4km	2016
II.	Mbagathi Dam, Height 35m, Net Yield of 55,100m³/day with • Treatment Works of capacity 18,000m³/day • Ferrous Bulk Gravity Main, Diameter 500mm, Length 14km • System storage of 9,000m³ • Pumping station from Treatment Works to Storage	2030

6.3.6 Ngong, Ongata Rongai and Kiserian

The year 2035 water demand for Ngong, Ongata Rongai and Kiserian Areas is 54,246m³/d. The present total water supply to these Towns is 4,246m³/d from Boreholes, Springs and Mbagathi River Intake. The proposed future sources to augment the present sources and meet the ultimate water demand for Ngong, Ongata Rongai and Kiserian are:

1. Kiserian Dam (1.2Mm³) - 15,000m³/d (Under Construction)

2. Ruabura Dam (19Mm^3) - 38,016m^3/d

Ruabura Dam is about 50km outside the demand areas and the transmission pipelines will traverse through Nairobi. There are no other potential dam sites within the vicinity of the demand area. The dam will provide additional water supply to meet the ultimate water demand of Ngong, Ongata Rongai and Kiserian Areas.

Supply from Kiserian Dam will be through pumping while Ruabura Dam will supply Ongata Rongai and Kiserian Towns by gravity. Pumping will however be required to supply Ngong Town and the surrounding high altitude areas.

The water demand forecast for Ngong, Ongata Rongai and Kiserian Areas and the Implementation Schedule for proposed future sources is shown in Figure 9-10. Details of proposed water supply facilities including their initial years of operation are given in Table 9-9.

Figure 9-10: Implementation Schedule for New Water Sources - Ngong, Ongata Rongai & Kiserian

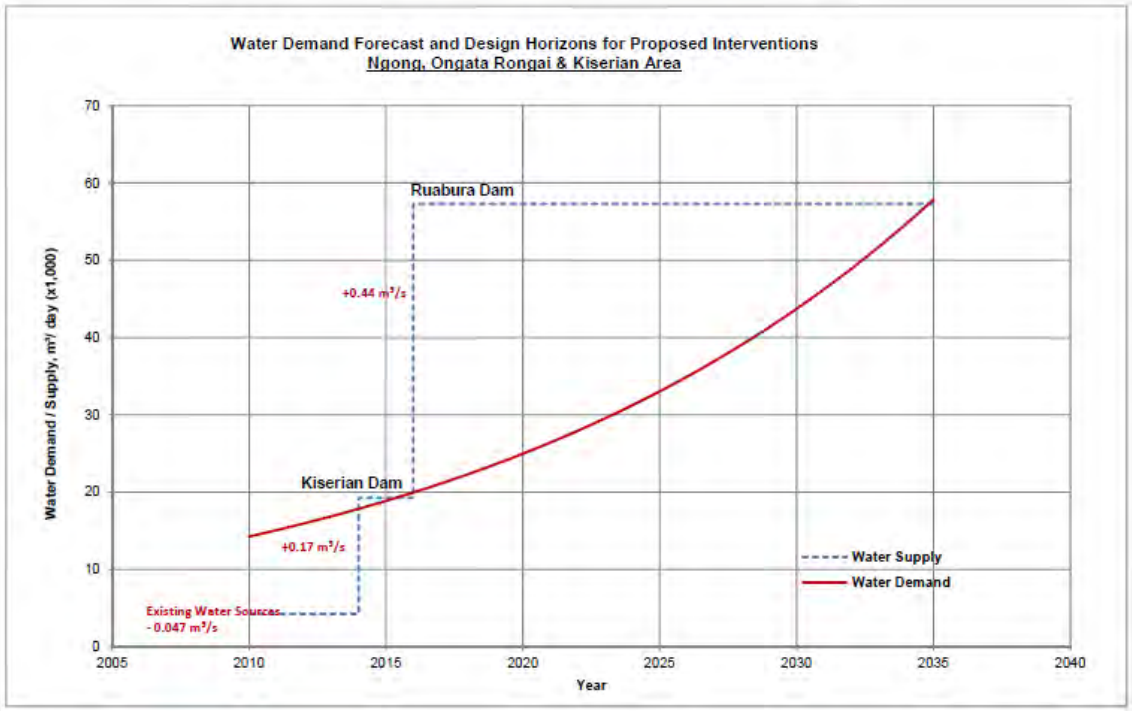


Table 9-9: Water Supply Infrastructure Required - Ngong, Ongata Rongai & Kiserian

Infrastructure Required	Year of Operation
Ruabura Dam, Height 65m, Net Yield of 38,000m^3/day with • Treatment Works of capacity 35,000m^3/day • Ferrous Bulk Gravity Transmission from Dam to Storage, diameter 700mm and total length 56km • System Storage of 18,000m^3 • Pumping station for water supply from Storage to Ngong Town • Ferrous Bulk Rising Main from Storage to Ngong Town, diameter 700mm and length 4km.	2016

7 Strategic Water Supply Option

7.1 General

The Strategic Water Supply Option comprises of water supply to Nairobi and Satellite Towns through a limited number of Strategic Sources. The proposal is to have an Integrated Water Sources Utilization Plan in which Sources are shared between Nairobi and the Satellite Towns.

The Strategic Water Sources are the major resource developments which can provide Bulk Supply to demand centres economically compared to alternative localised sources. They have a high capital investment but will offer a relative good return of capital.

The Strategic Sources are to be developed and operated under NCWSC or an Alternative Bulk Water Supplier. Under this proposal, NCWSC can provide Bulk Water Supplies to the mandated Water Service Providers within the Envelop Areas or the companies can merge into NCWSC to have a single water company which will operate within Nairobi Water Demand Envelop areas.

The existing local water sources for the Satellite Towns which fall within the Nairobi Water Demand Envelop will remain with the future supplies being from the proposed Strategic Sources. The sources which are presently under development have also been retained.

The general criteria and assumptions used in developing this water supply strategy are listed below:

- Existing local water supply schemes maintained but unreliable and uneconomical schemes with comparison to supply from Strategic Sources to be abandoned
- Future supplies limited to Strategic Sources
- Groundwater development considered in areas where supply from strategic sources (high altitude or remote demand areas) will be uneconomical.

A Layout Plan showing the Long Term Development Strategy under this Option is given in **Figure 9-11** and the Implementation Schedule is shown in **Figure 9-12**.

Figure 9-11: Long Term Development Strategy – Strategic Water Supply Option

Figure 9-12: Implementation Schedule for the Strategic Option

7.2 Nairobi Water Demand Envelop

The combined year 2035 water demand for Nairobi and Satellite Towns under the Nairobi Water Demand Envelop is 1,576,589m^3/d. The present total water supply to the demand areas is 561,225m^3/d with 542,400m^3/d being supplying Nairobi City alone. This shows that presently there is a huge water supply deficit in the Satellite Towns within the Nairobi Water Demand Envelop.

The proposed water sources which have been classified as Strategic Sources and which have to be developed to supply Nairobi and the Satellite Towns within the Nairobi Water Demand Envelop are:

1. Wellfields in Kiunyu and Ruiru
2. Northern Collector Tunnel Phase I to Thika Dam
3. Ruiru 2 Dam (36Mm^3) with Ndurire Transfer
4. Karimenu 2 Dam (14.2Mm^3)
5. Thiririka Dam (14.7Mm^3)
6. Ruabura Dam (19Mm^3)
7. S. Mathioya Transfer to Thika Dam + Maragua 4 Dam (30Mm^3)
8. Northern Collector Tunnel Phase II to Thika Dam
9. Ndarugu 1 Dam (300Mm^3) with Natural Inflow
10. Chania-Komu Transfer to Ndarugu 1 Dam

The combined water demand forecast for Nairobi and the Satellite Towns within the Nairobi Water Demand Envelop together with the Implementation Schedule for proposed future sources is shown in Figure 9-13. Table 9-10 shows the bulk supply infrastructure required for this Option.

As part of the bulk water supply infrastructure, transfers between Nairobi City main service reservoirs have also been considered. This is to ensure that a balance is maintained so as to sustain the bulk transfers to Satellite Towns.

It is also proposed that the storage capacity of Service Reservoirs within Nairobi City be increased as follows:

- Year 2016 - 201,000m^3
- Year 2026 - 176,000m^3
- Year 2035 - 162,000m^3

Figure 9-13: Implementation Schedule for New Water Sources - Nairobi Water Demand Envelop Areas

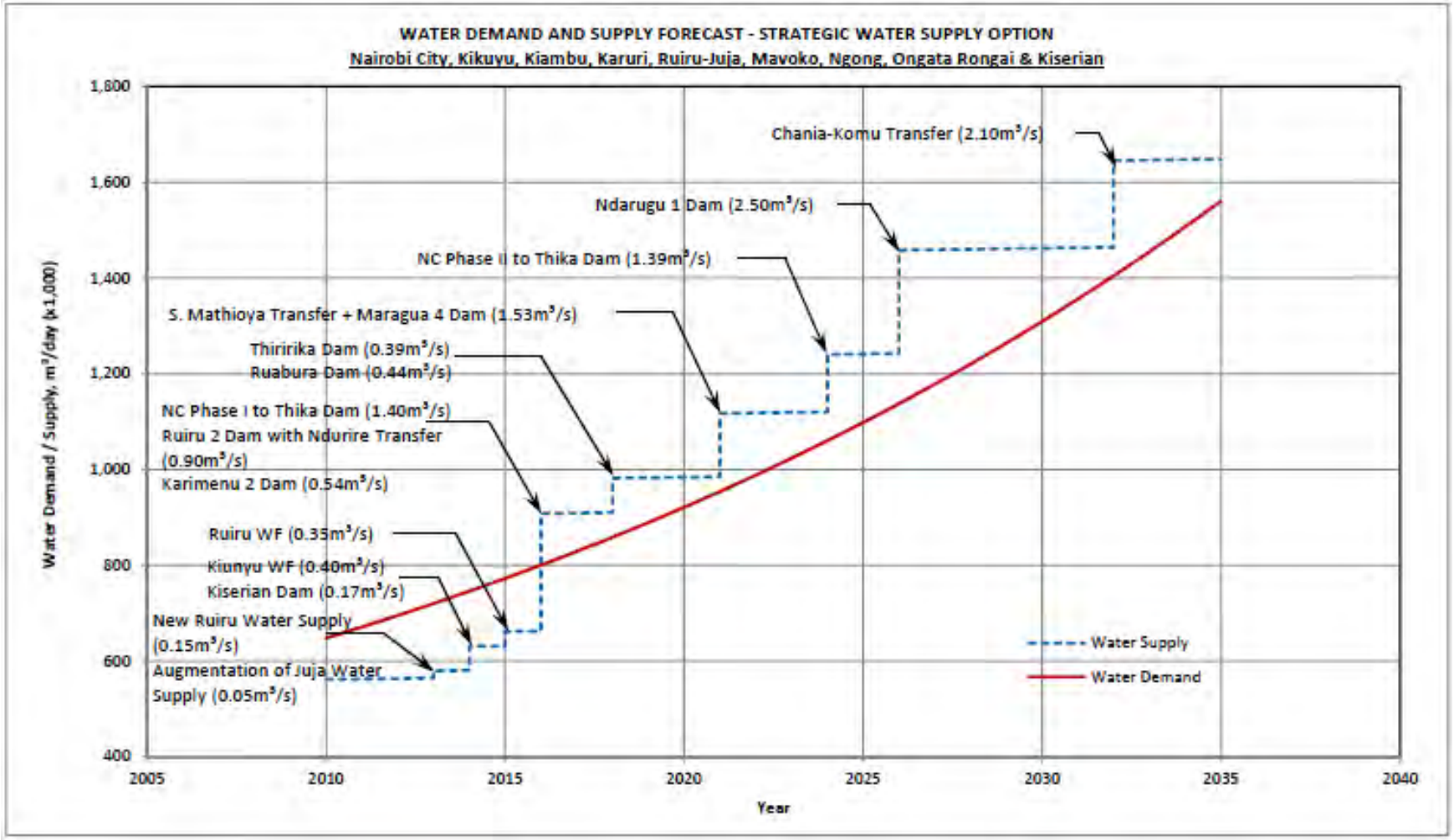


Table 9-10: Proposed Bulk Water Supply Infrastructure Required for Nairobi Water Demand Envelop Areas

Phase	Infrastructure Required	Year of Operation
I.	**A.** Wellfield in Kiunyu (Yield, 34,560m^3/d) • 25Nr. Boreholes, Manifold System, Collector Tank, Chlorination Facility, Pumping Station & 45km long, 700mm dia. Pumping Main to Gigiri Reservoirs	2014
	B. Wellfield in Ruiru (Yield, 30,240m^3/d) • 15Nr. Boreholes, Manifold System, Collector Tank, Chlorination Facility, Pumping Station & 15km long, 600mm dia. Pumping Main to Gigiri Reservoirs	2015
II.	Northern Collector Tunnel Phase I to Thika Dam (Total Yield, 120,960m^3/d) • 11.78 km long, 3.2m dia. Shortcrete lined Tunnel, • 44km long Raw Water Gravity Main, 1300mm dia., • Ngorongo Treatment Works of Capacity 120,960m^3/d, • 17.6km long, 1000mm dia. Treated Water Gravity Main to Kabete Reservoirs.	2016
III.	Ruiru 2 Dam, Height 70m, Net Yield of 77,760m^3/day with • Treatment Works of capacity 77,760m^3/day • Ferrous Gravity Bulk Water Transmission from Ruiru 2 Dam to Bulk Main from Karimenu Dam, Diameter 900mm, Length 13km	2016
IV.	Karimenu 2 Dam, Height 40m, Net Yield of 46,650m^3/day with • Treatment Works of capacity 46,650m^3/day • Ferrous Gravity Bulk Water Transmission from Karimenu Dam, Diameter 700mm, Length 30km • Ferrous Gravity Bulk Water Transmission from Karimenu Dam, Diameter 1200mm, Length 12km	2016
V.	Thiririka Dam, Height 50m, Net Yield of 33,900m^3/day with • Treatment Works of capacity 33,900m^3/day • Ferrous Gravity Bulk Water Transmission from Thiririka Dam to Bulk Main from Ruabura Dam, Diameter 700mm, Length 19km	2018
VI.	Ruabura Dam, Height 65m, Net Yield of 38,000m^3/day with • Treatment Works of capacity 38,000m^3/day • Ferrous Gravity Bulk Water Transmission from Ruabura Dam to Uthiru and Dagoretti Reservoirs with the following characteristics: • Diameter 600mm, Length 28km • Diameter 1000mm, Length 19km	2018
VII.	S. Mathioya Transfer to Thika Dam plus Maragua 4 Dam (Total Yield, 132,192m^3/d) • Maragua 4 Dam (30Mm^3), • 3.36km long, 3.2m dia. Shortcrete lined Tunnel, • 24km long, 1000mm dia. Raw Water Gravity Main from Maragua 4 Dam to Ndunyu Chege Treatment Works, • 13km long, 600mm dia. Raw Water Gravity Main from Thika Dam to Ndunyu Chege Treatment Works • Ndunyu Chege Treatment Works of Capacity 132,192m^3/d, • 41km long, 1100mm dia. Treated Water Gravity Main to Gigiri	2021

Phase	Infrastructure Required	Year of Operation
	Reservoirs.	
VIII.	Northern Collector Tunnel Phase II to Thika Dam (Total Yield, 120,096m^3/d) • 7.9 km long, 3.2m dia. Shortcrete lined Tunnel, • 44km long, 1200mm dia. Raw Water Gravity Main, • Ngorongo Treatment Works, • 17.6km long, 1000mm dia. Treated Water Gravity Main to Kabete Reservoirs.	2024
IX.	Ndarugu 1 Dam with Natural Inflow (Total Yield, 216,000m^3/d) • Ndarugu 1 Dam (300Mm^3), • Raw Water Pumping Station of Capacity 216,000m^3/d, • 7km long, 1200mm dia. Raw Water Pumping Main, • Ndarugu Treatment Works of Capacity 216,000m^3/d, • Treated Water Pumping Station of Capacity 216,000m^3/d, • 30km long, 1200mm dia. Treated Water Pumping Main to Kasarani, • Kasarani Booster Pumping Station of Capacity 164,160m^3/d • 12km long, 1100mm dia. Treated Water Pumping Main to Gigiri Reservoirs	2026
X.	Chania to Komu River Transfer (Total Yield, 181,440m^3/d) • 2km long, 3.2m dia. Shortcrete lined Tunnel, • Raw Water Pumping Station of Capacity 181,440m^3/d, • 7km long, 1200mm dia. Raw Water Pumping Main, • Ndarugu Treatment Works of Capacity 181,440m^3/d, • Treated Water Pumping Station of Capacity 181,440m^3/d, • 30km long, 1200mm dia. Treated Water Pumping Main to Kasarani, • Kasarani Booster Pumping Station of Capacity 138,240m^3/d • 12km long, 1100mm dia. Treated Water Pumping Main to Gigiri Reservoirs	2032

The bulk infrastructure required for offtakes and transfers from the main transmission pipelines to serve the Satellite Towns is discussed in Section 7.3 below.

7.3 Satellite Towns Within Nairobi Water Demand Envelop

7.3.1 Kikuyu Town

The year 2035 water demand for Kikuyu Area is 55,526m^3/d. The total production capacity of the present sources is 4,202m^3/d. It is proposed that Kikuyu Area will be supplied through NCWSC via the Strategic Water Sources in two stages:

1. NCWSC Bulk Supply – Stage I - 32,000m^3/d
2. NCWSC Bulk Supply – Stage II - 20,000m^3/d

The bulk transfer from Nairobi City to Kikuyu Town will be through pumping from Dagoreti Reservoir.

The water demand forecast for Kikuyu Area and the Implementation Schedule for proposed future sources is shown in Figure 9-14. Details of proposed water supply facilities including their initial years of operation are given in Table 9-11.

Figure 9-14: Implementation Schedule for New Water Sources - Kikuyu

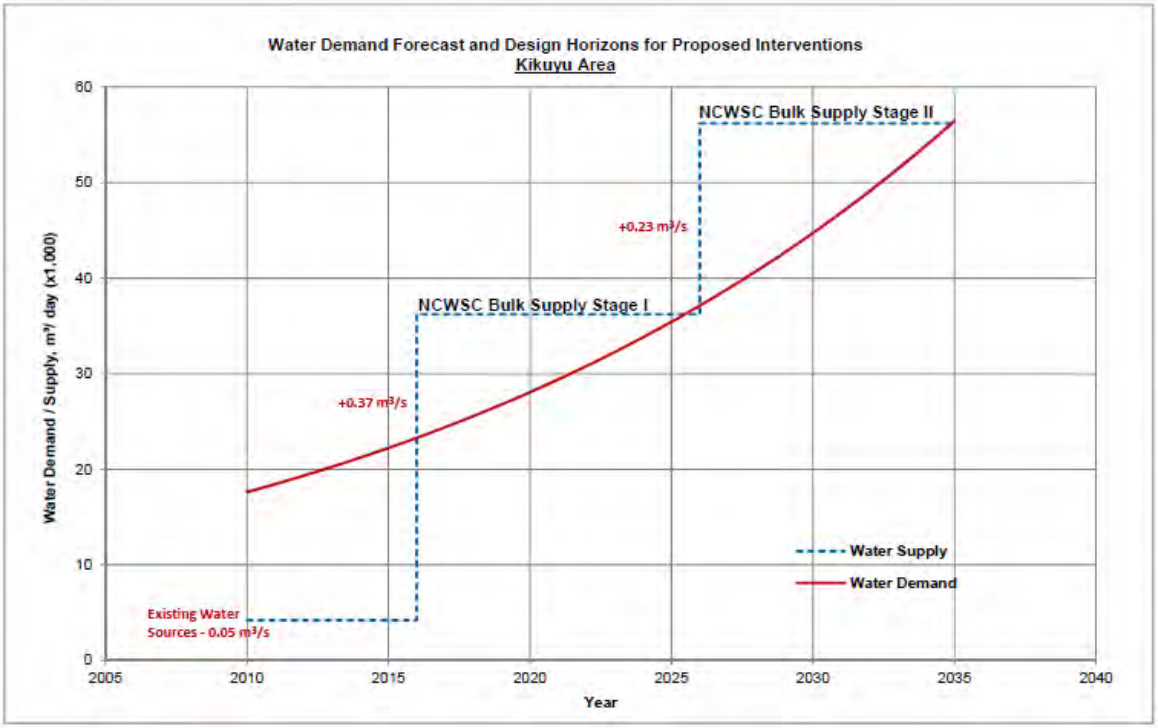


Table 9-11: Water Supply Infrastructure Required - Kikuyu

Phase	Infrastructure Required	Year of Operation
I.	Bulk Supply of 32,000m³/day from Nairobi City Water & Sewerage Company (NCWSC) Dagoretti Tank, Rising Main of diameter 800mm, Length 5km.	2016
II.	Additional Supply of 20,000m³/day from Nairobi City Water & Sewerage Company (NCWSC) using the existing Rising Main.	2026

7.3.2 Kiambu Town

The year 2035 water demand for Kiambu Area is 20,730m³/d. The present water supply is 3,060m³/d from groundwater sources and 230m³/d from NCWSC through Ngethu pipeline.

It is proposed that Kiambu Area will be supplied through additional NCWSC Bulk Supply using the Strategic Water Sources to be developed in two stages:

1. NCWSC Bulk Supply – Stage I - 9,000m³/d
2. NCWSC Bulk Supply – Stage II - 9,000m³/d

The bulk transfer to Kiambu Area will be via offtakes from the main transmission pipelines to Nairobi City which traverse the demand area.

The water demand forecast for Kiambu Area and the Implementation Schedule for proposed future sources is shown in Figure 9-15. Details of proposed water supply facilities including their initial year of operation are given in Table 9-12.

Figure 9-15: Implementation Schedule for New Water Sources - Kiambu

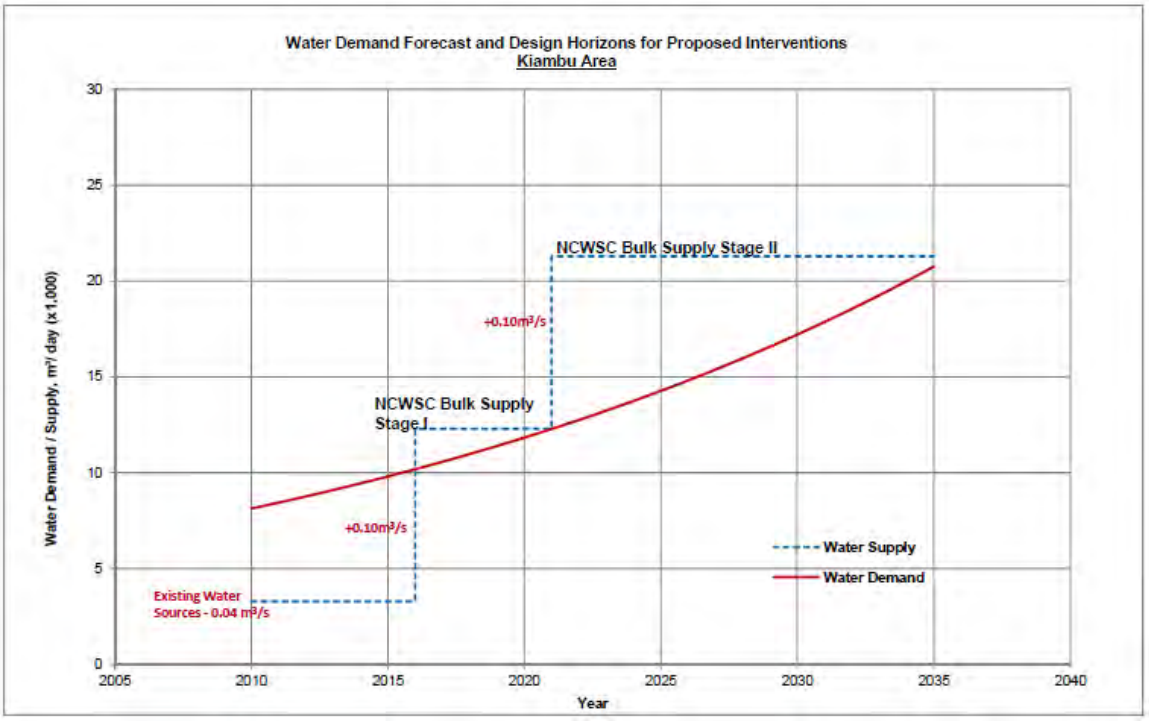


Table 9-12: Water Supply Infrastructure Required - Kiambu

Phase	Infrastructure Required	Year of Operation
I.	Bulk Supply of 9,000m³/day from Nairobi City Water & Sewerage Company (NCWSC), Diameter 500mm, Length 6km	2016
II.	Additional Supply of 9,000m³/day from Nairobi City Water &Sewerage Company (NCWSC)	2021

7.3.3 Karuri Town

The year 2035 water demand for Karuri Area is 28,566m³/d. The present water supply is 1,667m³/d from groundwater sources and 1,100m³/d from NCWSC through Sasumua pipeline.

It is proposed that Karuri Area will be supplied through additional NCWSC Bulk Supply using the Strategic Water Sources to be developed in two stages:

1. NCWSC Bulk Supply – Stage I - 13,000m³/d
2. NCWSC Bulk Supply – Stage II - 13,000m³/d

The bulk transfer to Karuri Area will be via offtakes from the main transmission pipelines to Nairobi City which traverse the demand area.

The water demand forecast for Karuri Area and the Implementation Schedule for proposed future sources is shown in Figure 9-16. Details of proposed water supply facilities including their initial years of operation are given in Table 9-13.

Figure 9-16: Implementation Schedule for New Water Sources - Karuri

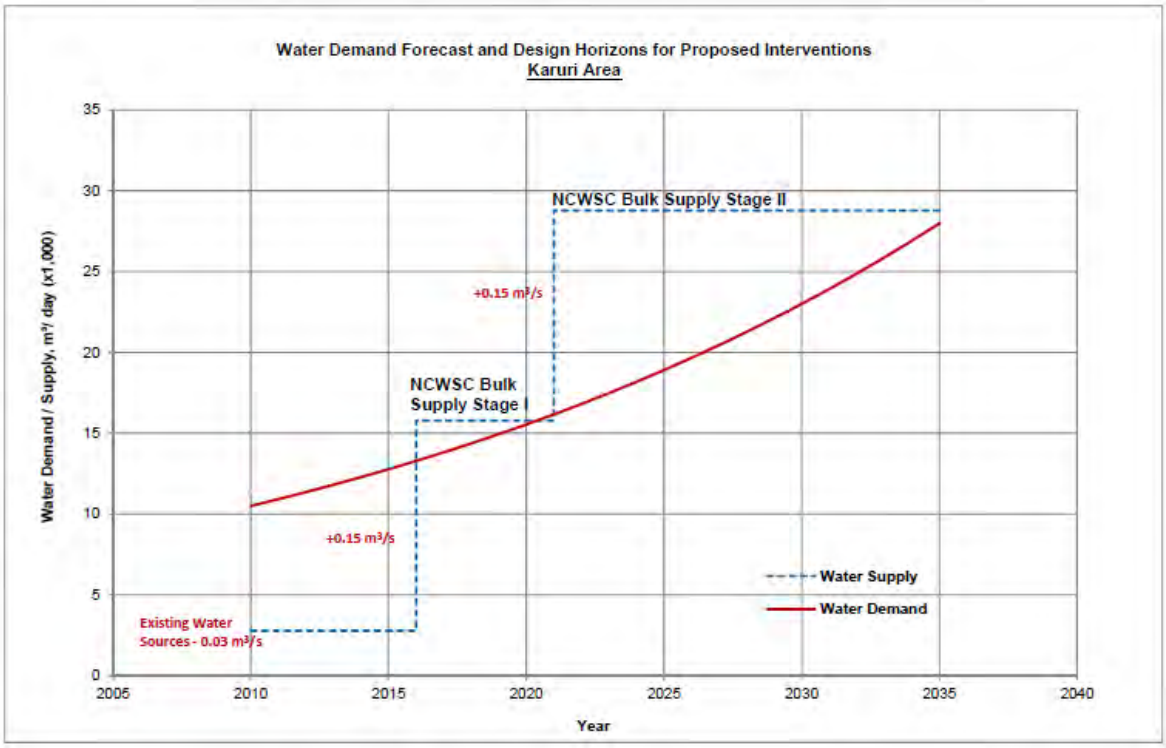


Table 9-13: Water Supply Infrastructure Required - Karuri

Phase	Infrastructure Required	Year of Operation
I.	Bulk Supply of 13,000m³/day from Nairobi City Water & Sewerage Company (NCWSC), Diameter 600mm, Length 21km	2016
II.	Additional Supply of 13,000m³/day from Nairobi City Water & Sewerage Company (NCWSC)	2021

7.3.4 Ruiru-Juja Towns

The year 2035 water demand for Ruiru-Juja Areas is 131,978m³/d. The present total water supply to these Towns is 6,480m³/d from Ruiru River, Ndarugu River, groundwater sources and 480m³/d from NCWSC through Ngethu pipeline.

It is proposed that Ruiru-Juja Areas will be supplied through additional NCWSC Bulk Supply using the Strategic Water Sources to be developed in two stages:

1. NCWSC Bulk Supply – Stage I - 13,000m³/d
2. NCWSC Bulk Supply – Stage II - 13,000m³/d

The bulk transfer in Ruiru-Juja Areas will be via offtakes from the main transmission pipeline which supply Nairobi City. In Stage II, the transfers will be from offtakes from the Ndarugu Scheme pumped transmission Pipeline.

The water demand forecast for Ruiru-Juja Areas and the Implementation Schedule for proposed future sources is shown in Figure 9-17. Details of proposed water supply facilities including their initial years of operation are given in Table 9-14.

Figure 9-17: Implementation Schedule for New Water Sources - Ruiru-Juja

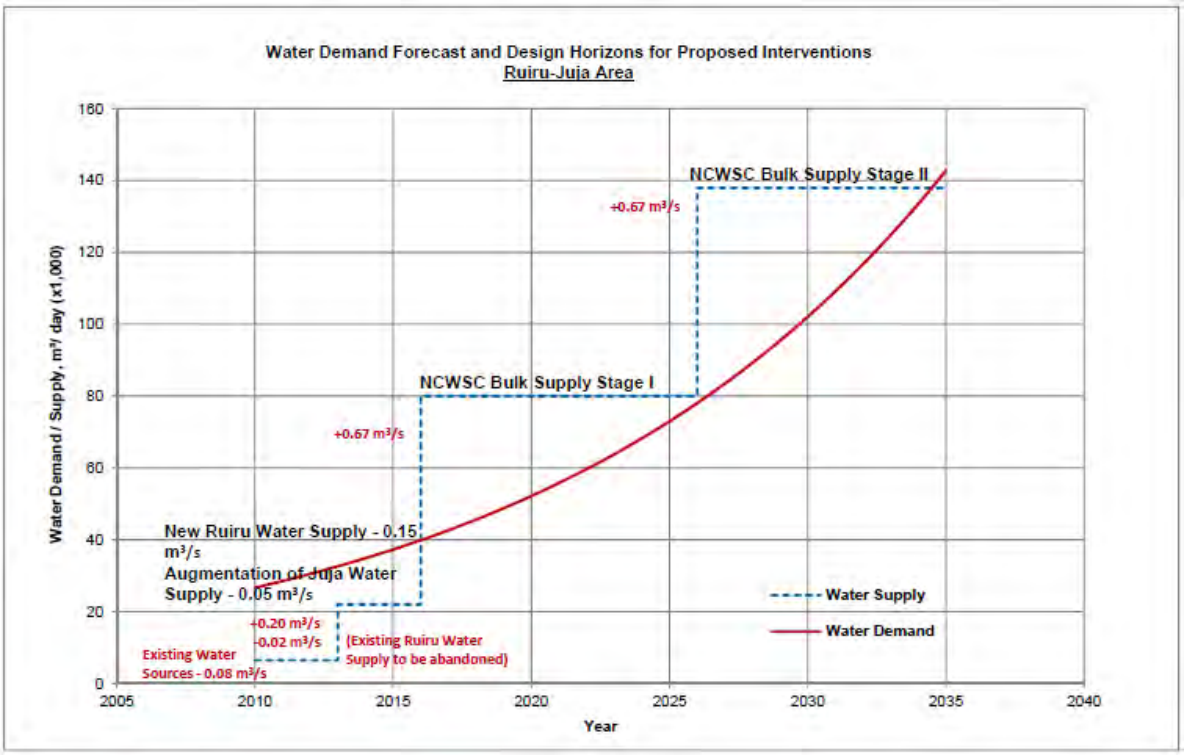


Table 9-14: Water Supply Infrastructure Required - Ruiru-Juja

Phase	Infrastructure Required	Year of Operation
I.	Bulk Supply of 58,000m³/day from Nairobi City Water & Sewerage Company (NCWSC), Diameter 800mm, Length 14km	2016
II.	Additional Supply of 58,000m³/day from Nairobi City Water & Sewerage Company (NCWSC), Diameter 800mm, Length 14km	2026

7.3.5 Mavoko Municipality

The year 2035 water demand for Mavoko Municipality Area is 80,222m³/d. The present total water supply to this Town is 9,170m³/d from Nol Turesh Water Supply system, Groundwater sources and 7,500m³/d from NCWSC bulk supply.

It is proposed that Mavoko Municipality will be supplied through additional NCWSC Bulk Supply using the Strategic Water Sources to be developed in two stages:

1. NCWSC Bulk Supply – Stage I - 36,000m³/d
2. NCWSC Bulk Supply – Stage II - 36,000m³/d

The bulk supply to Mavoko Municipality will be by gravity from Nairobi City main source reservoirs.

The water demand forecast for Mavoko Municipality Area and the Implementation Schedule for proposed future sources is shown in Figure 9-18. Details of proposed water supply facilities including their initial years of operation are given in Table 9-15.

Figure 9-18: Implementation Schedule for New Water Sources - Mavoko

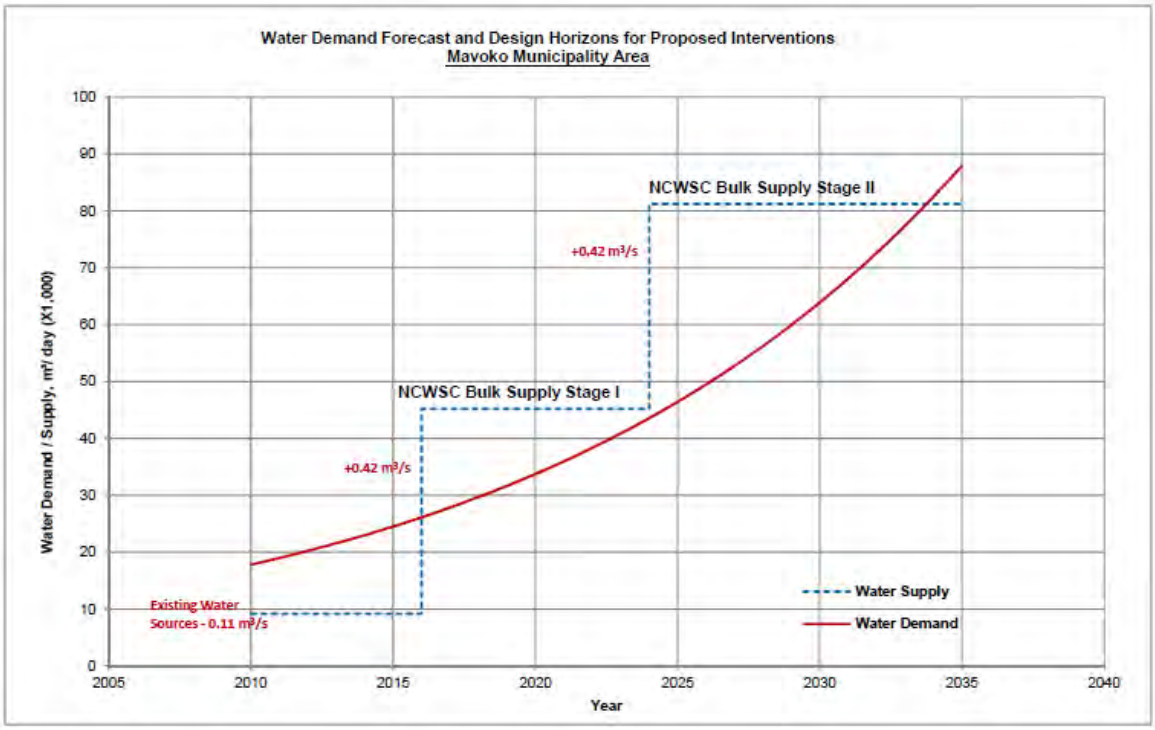


Table 9-15: Water Supply Infrastructure Required - Mavoko

Phase	Infrastructure Required	Year of Operation
I.	Bulk Supply of 22,000m³/day from Nairobi City Water & Sewerage Company (NCWSC) using the existing Pipeline capacity	2016
II.	Bulk Supply of 14,000m³/day from Nairobi City Water & Sewerage Company (NCWSC) using the new Pipeline, Dia. 500mm, Length 24km	2016
III.	Additional Supply of 36,000m³/day from Nairobi City Water & Sewerage Company (NCWSC), Diameter 700mm, Length 24km	2024

7.3.6 Ngong, Ongata Rongai and Kiserian

The year 2035 water demand for Ngong, Ongata Rongai and Kiserian Areas is 54,246m³/d. The present total water supply to these Towns is 4,246m³/d from Boreholes, Springs and Mbagathi River Intake.

It is proposed that Ngong, Ongata Rongai and Kiserian will be supplied through additional NCWSC Bulk Supply using the Strategic Water Sources to be developed in two stages:

1. NCWSC Bulk Supply – Stage I - 18,000m³/d
2. NCWSC Bulk Supply – Stage II - 18,000m³/d

The bulk water supply to the demand areas will be by gravity from Nairobi City main source reservoirs except for Ngong Town and the surrounding high altitude areas where pumping from Dagoreti Reservoir will have to be carried out.

The water demand forecast for Ngong, Ongata Rongai and Kiserian area and the Implementation Schedule for proposed future sources is shown in Figure 9-19. Details of proposed water supply facilities including their initial years of operation are given in Table 9-16.

Figure 9-19: Implementation Schedule for New Water Sources - Ngong, Ongata Rongai & Kiserian

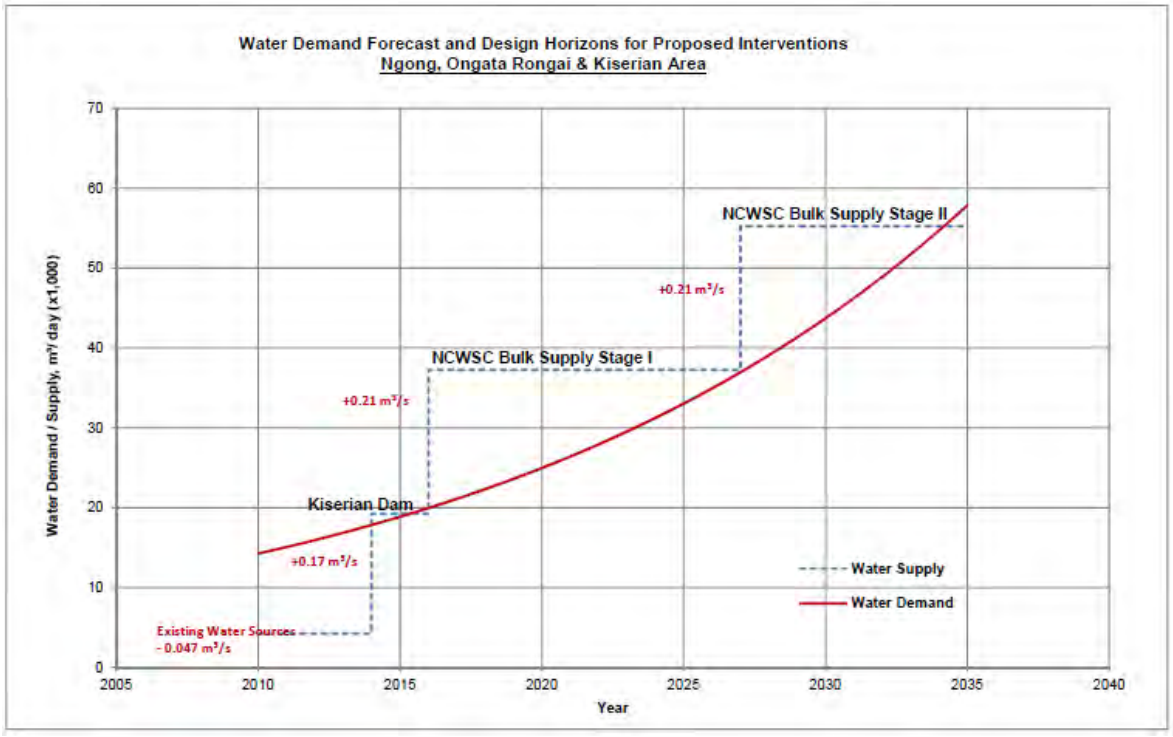


Table 9-16: Water Supply Infrastructure Required - Ngong, Ongata Rongai & Kiserian

Phase	Infrastructure Required	Year of Operation
I.	Bulk Supply of 18,000m^3/day from Nairobi City Water & Sewerage Company (NCWSC) Kabete Tank to Ongata Rongai using a new Gravity Main, Diameter 500mm, Length 17km	2016
II.	Additional Supply of 18,000m^3/day from Dagoretti Tank to Ngong, Rising Main, Diameter 700mm, Length 13km including augmentation of Pumping Facilities.	2027

8 Mixed Water Supply Option

8.1 General

In the Mixed Water Supply Option, preference in Development of Localised Water Sources to supply the Satellite Towns has been considered.

In this Option, the existing local water sources will remain and will be supplemented by additional Localised Water Sources. In the cases where there are inadequate local sources to supply the Satellite Towns, then supply using the Strategic Sources which supply Nairobi City will have to be used. Sharing of sources between Satellite Towns will also be carried out. This concept therefore forms an Integrated Utilization Plan in which Sources are shared between Nairobi and the Satellite Towns.

This development Option is similar in some ways to the recommendations made under the Long Term Development Plan by Howard Humphreys (1986) for regional water supply. The existing NCWSC bulk supplies to the Satellite Towns have been retained under this option.

The general criteria and assumptions used in developing this water supply strategy are listed below:

- Supply from Local Sources to be considered as a priority
- Storage to augment existing local run of river schemes
- Groundwater Development considered where no local surface water sources are available
- Supply from Strategic Sources to supplement the Local Sources

A Layout Plan showing the Long Term Development Strategy under this Option is given in **Figure 9-20**, while the Implementation Schedule is shown in **Figure 9-21**.

Figure 9-20: Long Term Development Strategy – Mixed Water Supply Option

Figure 9-21: Implementation Schedule for the Mixed Option

8.2 Nairobi Water Demand Envelop

The combined year 2035 water demand for Nairobi plus the Satellite Towns under the water demand envelop is 1,576,589m^3/d. The present total water supply to the demand areas is 561,225m^3/d with 542,400m^3/d being supplied to Nairobi City alone. This shows that presently there is a huge water supply deficit in the Satellite Towns within the Nairobi Water Demand Envelop.

The proposed water sources which have been classified as Strategic Sources and which are made to supply Nairobi and the Satellite Towns under the Nairobi Water Demand Envelop are:

1. Wellfield in Kiunyu and Ruiru
2. Northern Collector Tunnel Phase I to Thika Dam
3. S. Mathioya Transfer to Thika Dam + Maragua 4 Dam (30Mm^3)
4. Northern Collector Tunnel Phase II to Thika Dam
5. Ndarugu 1 Dam (300Mm^3) with Natural Inflow
6. Chania-Komu Transfer to Ndarugu 1 Dam

The combined water demand forecast for Nairobi and the Satellite Towns under the Nairobi Water Demand Envelop together with the Implementation Schedule for proposed future sources is shown in Figure 9-22. Table 9-17 shows the bulk supply infrastructure required for this option.

Table 9-17: Proposed Bulk Water Supply Infrastructure Required for Nairobi Water Demand Envelop Areas

Phase	Infrastructure Required	Year of Operation
I.	**A.** Wellfield in Kiunyu (Yield, 34,560m^3/d) • 25Nr. Boreholes, Manifold System, Collector Tank, Chlorination Facility, Pumping Station & 45km long, 700mm dia. Pumping Main to Gigiri Reservoirs	2014
	B. Wellfield in Ruiru (Yield, 30,240m^3/d) • 15Nr. Boreholes, Manifold System, Collector Tank, Chlorination Facility, Pumping Station & 15km long, 600mm dia. Pumping Main to Gigiri Reservoirs	2015
II.	Northern Collector Tunnel Phase I to Thika Dam (Total Yield, 120,960m^3/d) • 11.78 km long, 3.2m dia. Shortcrete lined Tunnel, • 44km long Raw Water Gravity Main, 1300mm dia., • Ngorongo Treatment Works of Capacity 120,960m^3/d, • 17.6km long, 1000mm dia. Treated Water Gravity Main to Kabete Reservoirs.	2016
III.	S. Mathioya Transfer to Thika Dam plus Maragua 4 Dam (Total Yield, 132,192m^3/d) • Maragua 4 Dam (30Mm^3), • 3.36km long, 3.2m dia. Shortcrete lined Tunnel, • 24km long, 1000mm dia. Raw Water Gravity Main from Maragua 4 Dam to Ndunyu Chege Treatment Works,	2019

Phase	Infrastructure Required	Year of Operation
	• 13km long, 600mm dia. Raw Water Gravity Main from Thika Dam to Ndunyu Chege Treatment Works • Ndunyu Chege Treatment Works of Capacity 132,192m^3/d, • 41km long, 1100mm dia. Treated Water Gravity Main to Gigiri Reservoirs.	
IV.	Northern Collector Tunnel Phase II to Thika Dam (Total Yield, 120,096m^3/d) • 7.9 km long, 3.2m dia. Shortcrete lined Tunnel, • 44km long, 1200mm dia. Raw Water Gravity Main, • Ngorongo Treatment Works, • 17.6km long, 1000mm dia. Treated Water Gravity Main to Kabete Reservoirs.	2024
V.	Ndarugu 1 Dam with Natural Inflow (Total Yield, 216,000m^3/d) • Ndarugu 1 Dam (300Mm^3), • Raw Water Pumping Station of Capacity 216,000m^3/d, • 7km long, 1200mm dia. Raw Water Pumping Main, • Ndarugu Treatment Works of Capacity 216,000m^3/d, • Treated Water Pumping Station of Capacity 216,000m^3/d, • 30km long, 1200mm dia. Treated Water Pumping Main to Kasarani, • Kasarani Booster Pumping Station of Capacity 164,160m^3/d • 12km long, 1100mm dia. Treated Water Pumping Main to Gigiri Reservoirs	2028
VI.	Chania to Komu River Transfer (Total Yield, 181,440m^3/d) • 2km long, 3.2m dia. Shortcrete lined Tunnel, • Raw Water Pumping Station of Capacity 181,440m^3/d, • 7km long, 1200mm dia. Raw Water Pumping Main, • Ndarugu Treatment Works of Capacity 181,440m^3/d, • Treated Water Pumping Station of Capacity 181,440m^3/d, • 30km long, 1200mm dia. Treated Water Pumping Main to Kasarani, • Kasarani Booster Pumping Station of Capacity 138,240m^3/d • 12km long, 1100mm dia. Treated Water Pumping Main to Gigiri Reservoirs	2033

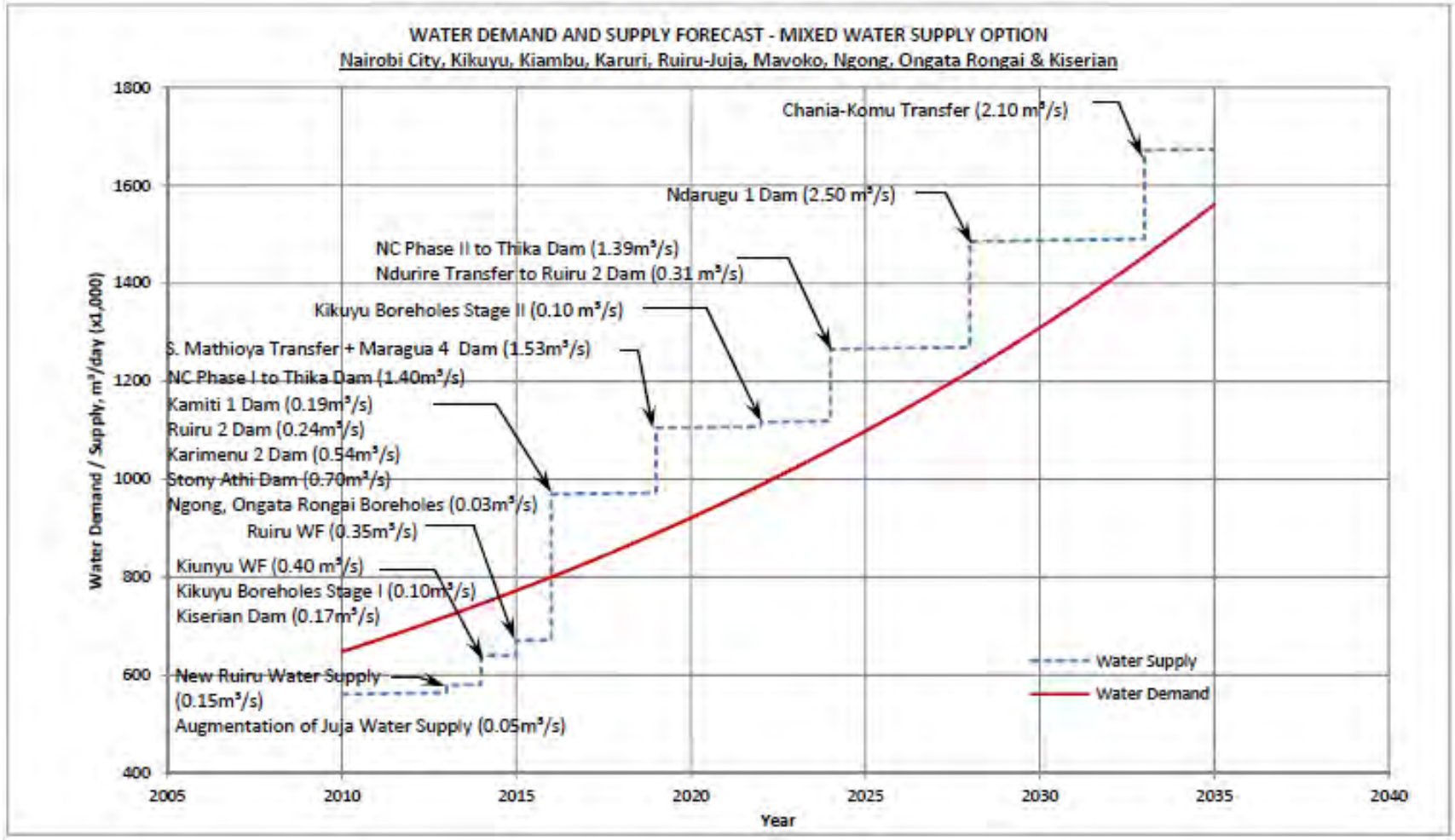
As part of the bulk water supply infrastructure, transfers between Nairobi City main Service Reservoirs have also been considered. This is to ensure that a balance is maintained to sustain the bulk transfers to Satellite Towns.

It is also proposed that the storage capacity of Service Reservoirs within Nairobi City be increased as follows:

- Year 2016 - 127,000m^3
- Year 2026 - 144,000m^3
- Year 2035 - 158,000m^3

The bulk infrastructure required for offtakes and transfers from the main transmission pipelines to serve the Satellite Towns is discussed in Section 8.3 below.

Figure 9-22: Implementation Schedule for New Water Sources - Nairobi Water Demand Envelop Areas



8.3 Satellite Towns within Nairobi Water Demand Envelop

8.3.1 Kikuyu Town

The year 2035 water demand for Kikuyu Area is 55,526m^3/d. The total production capacity of the present sources is 4,202m^3/d. The proposed future sources to augment the present sources and meet the ultimate water demand for Kikuyu Area are:

1. Additional Groundwater Sources – Stage I - 9,000m^3/d
2. Kamiti 1 Dam (16.4Mm^3) - 16,416m^3/d
3. Additional Groundwater Sources – Stage II - 9,000m^3/d
4. NCWSC Bulk Supply - 20,000m^3/d

The selection of groundwater sources in the first phase of development is on the basis that groundwater is locally available and the first stage can be implemented before year 2015 to meet the present water supply deficit and the fast increasing water demand for Kikuyu area.

Kamiti 1 dam has been selected for the reason that it is the only potential surface water source which can supply the demand centre by gravity and can reduce the water demand deficit within the planning period.

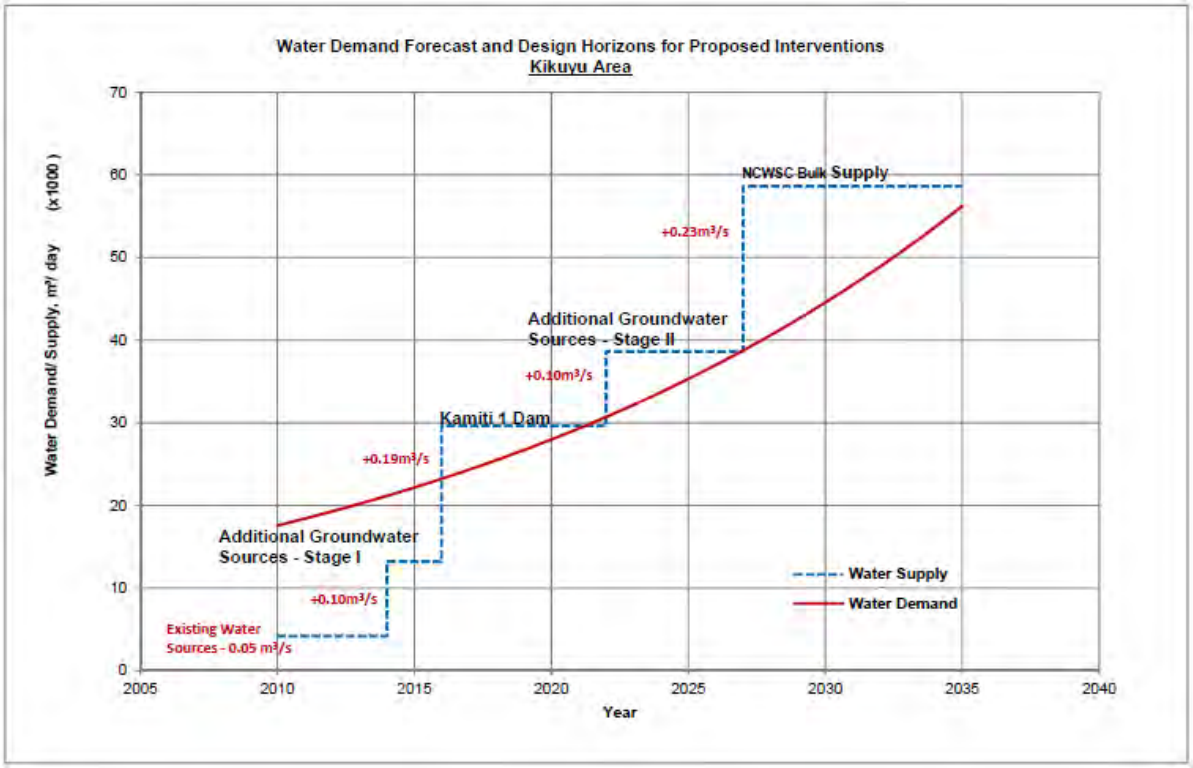
The water sources proposed under this Option specifically for Kikuyu Area do not meet the water demand, therefore, it will be necessary to augment supply from NCWSC Bulk Supply. The bulk supply will be through pumping from Dagoretti Reservoir which presently serves the upper zones of Nairobi.

The water demand forecast for Kikuyu Area and the Implementation Schedule for proposed future sources is shown in Figure 9-23. Details of proposed water supply facilities including their initial years of operation are given in Table 9-18.

Table 9-18: Water Supply Infrastructure Required - Kikuyu

Phase	Infrastructure Required	Year of Operation
I.	Wellfield in Kikuyu with a total yield of 9,000m^3/day	2014
II.	Kamiti 1 Dam, Height 50m, Net Yield of 16,416m^3/day with • Treatment Works of capacity 16,416m^3/day • Ferrous Gravity Bulk Water Transmission, Diameter 450mm, Length 27km • System Storage of 8,000m^3	2016
III.	Additional Wellfield with a total yield of 9,000m^3/day	2022
IV.	Bulk Supply of 20,000m^3/day from NCWSC using the new Bulk Water Rising Main from Dagoretti Tank to Kikuyu Town, Diameter 500mm and Length 5km	2027

Figure 9-23: Implementation Schedule for New Water Sources - Kikuyu



8.3.2 Kiambu Town

The year 2035 water demand for Kiambu Area is 20,730m^3/d. The present water supply is 3,060m^3/d from groundwater sources and 230m^3/d from NCWSC through Ngethu pipeline.

It is proposed that Ruiru 2 Dam (36Mm^3) be constructed to supply an additional 21,000m^3/d to Kiambu Area. The proposed scheme will also supply Karuri Area.

The selection of Ruiru 2 Dam is that it's close to the demand area and can supply Kiambu Town by gravity.

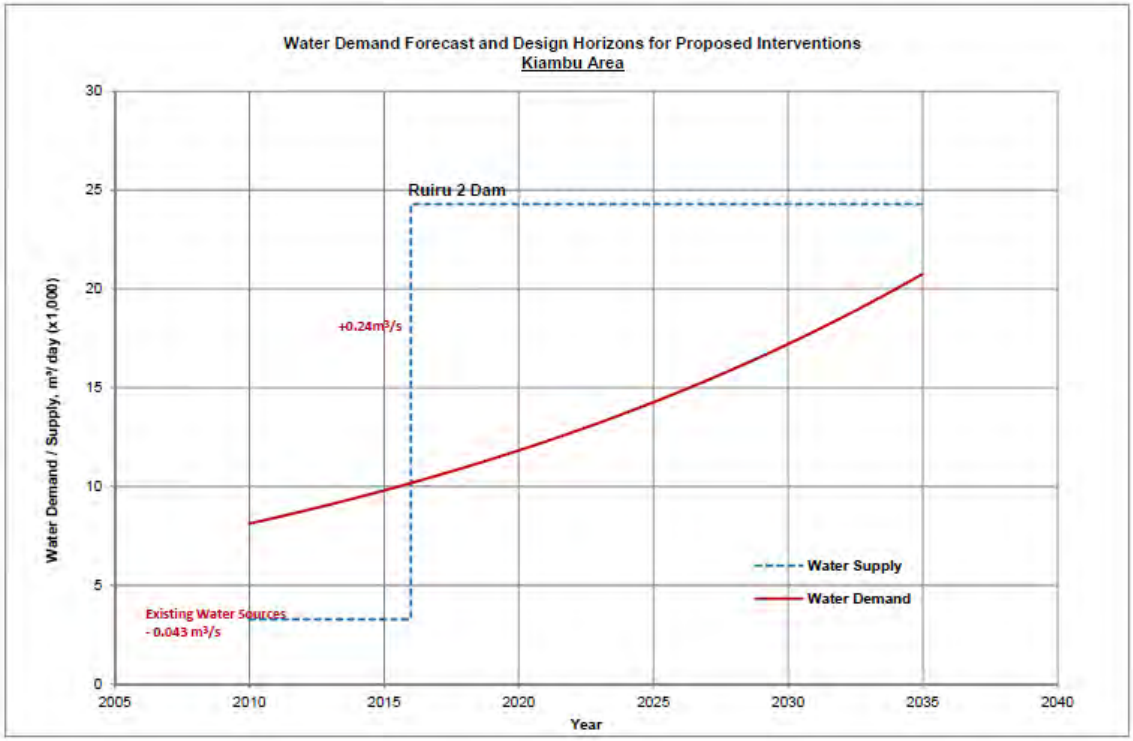
The water demand forecast for Kiambu Area and the Implementation Schedule for proposed future sources is shown in Figure 9-24. Details of proposed water supply facilities including their initial year of operation are given in Table 9-19.

Table 9-19: Water Supply Infrastructure Required - Kiambu

Phase	Infrastructure Required	Year of Operation
I.	Ferrous Gravity Main from System Storage to Kiambu Town of Capacity 21,000m^3/d, Diameter 400mm and Length 4km of Capacity 30,000m^3/d, Diameter 500mm and Length 10km	2016

NB: Main Infrastructure shown under Karuri Town

Figure 9-24: Implementation Schedule for New Water Sources – Kiambu



8.3.3 Karuri Town

The year 2035 water demand for Karuri Area is 28,566m^3/d. The present water supply is 1,667m^3/d from groundwater sources and 1,100m^3/d from NCWSC through Sasumua pipeline.

It is proposed that Ruiru 2 Dam (36Mm^3) be constructed to supply an additional 30,000m^3/d to Karuri Area. The proposed scheme will also supply Kiambu Area.

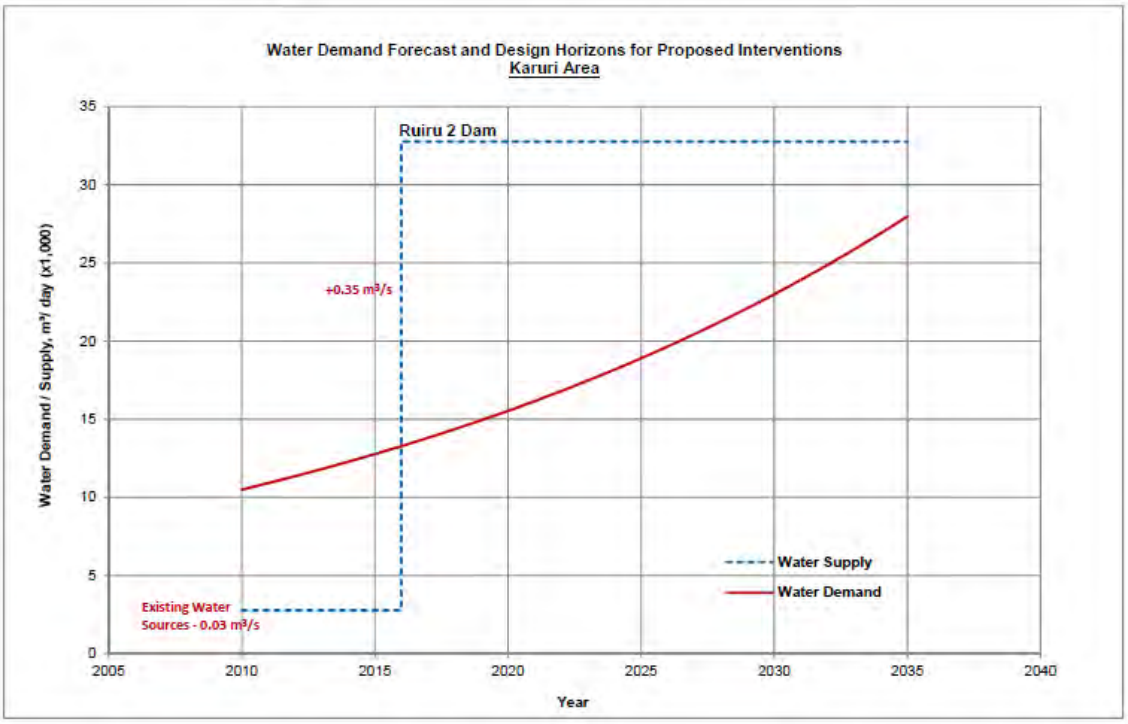
The selection of Ruiru 2 Dam is on the basis that it is close to the demand area and can supply Karuri Town with minimal pumping costs.

The water demand forecast for Karuri Area and the Implementation Schedule for proposed future sources is shown in Figure 9-25. Details of proposed water supply facilities including their initial years of operation are given in Table 9-20.

Table 9-20: Water Supply Infrastructure Required - Karuri

Phase	Infrastructure Required	Year of Operation
I.	Ruiru 2 Dam, Height 70m, Net Yield of 51,000m^3/day (shared with Kiambu) including: • Treatment Works of capacity 51,000m^3/day (shared with Kiambu) • Treated Water Gravity Main, from Ruiru 2 Dam to System Storage of Capacity 51,000m^3/d, Diameter 800mm, Length 15km (shared with Kiambu) • System Storage of Capacity 25,500m^3 (shared with Kiambu) • Treated Water Rising Main from System Storage to Karuri Town of Capacity 30,000m^3/d, Diameter 500mm and Length 10km	2016

Figure 9-25: Implementation Schedule for New Water Sources - Karuri



8.3.4 Ruiru-Juja Towns

The year 2035 water demand for Ruiru-Juja Area is 131,978m³/d. The present total water supply to these Towns is 6,480m³/d from Ruiru River, Ndarugu River, groundwater sources and 480m³/d from NCWSC through Ngethu pipeline. The proposed future sources to augment the present sources and meet the ultimate water demand for Ruiru-Juja Area are:

1. New Ruiru Water Supply - 13,000m³/d (Under Construction)
2. Augmentation of Juja Water Supply - 4,000m³/d (Under Construction)
3. Karimenu 2 Dam (14.2Mm³) - 46,656m³/d
4. Ndurire Transfer to Ruiru 2 Dam - 26,700m³/d
5. NCWSC Bulk Supply - 20,000m³/d

The water demand forecast for Ruiru-Juja Area and the Implementation Schedule for proposed future sources is shown in Figure 9-26. Details of proposed water supply facilities including their initial years of operation are given in Table 9-21.

Figure 9-26: Implementation Schedule for New Water Sources - Ruiru-Juja

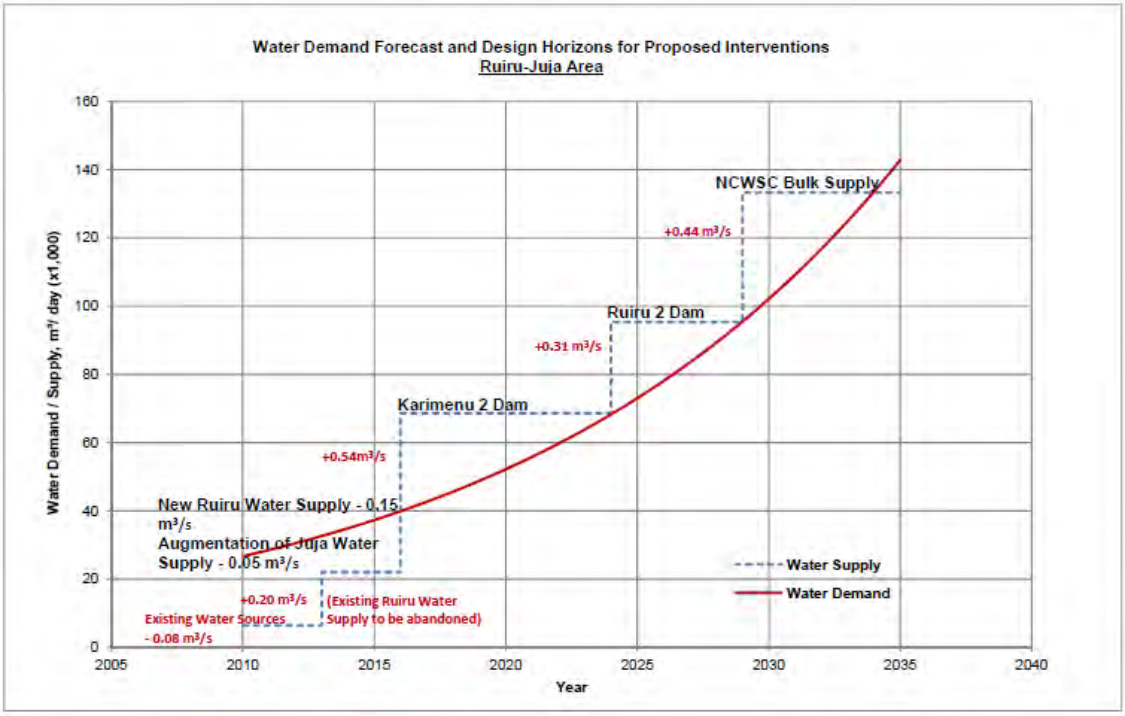


Table 9-21: Water Supply Infrastructure Required - Ruiru-Juja

Phase	Infrastructure Required	Year of Operation
I.	Karimenu 2 Dam, Height 40m, Net Yield of 46,650m³/d with • Treatment Works of capacity 46,650m³/day • Treated Water Gravity Main from Dam to System Storage of Capacity 46,650m³/d, Diameter 700mm, Length 18km • System Storage of Capacity 23,300m³ • Treated Water Gravity Main from System Storage to Ruiru-Juja Towns of Capacity 46,650m³/d, Diameter 700mm and Length 16km	2016
II.	Ndurire Transfer to Ruiru 2 Dam with an additional Yield of 26,700m³/d at Ruiru 2 Dam (Ruiru 2 Dam to serve Kiambu and Karuri Towns) • Transfer Tunnel from Ndurire River to Bathi River of Diameter 3.2m, Length 1.7km • Augmentation of Ruiru 2 Dam Treatment Works by 26,700m³/d • Augmentation Treated Water Gravity Main to System Storage by 26,700m³/d Capacity pipeline of Diameter 500mm and Length 15km • Ferrous Bulk Water Gravity Main from System Storage to Ruiru-Juja Towns of Capacity 26,700m³/d, Diameter 500mm and Length 20km	2024
III.	Bulk Supply of 38,000m³/day from NCWSC off Ndarugu-Kasarani Rising Mains • Rising Main off Ndarugu-Kasarani Rising Mains to High Level Storage of Capacity 38,000m³/d, Diameter 500mm and Length 2km • High Level Storage of Capacity 19,000m³	2029

8.3.5 Mavoko Municipality

The year 2035 water demand for Mavoko Municipality Area is 80,222m^3/d. The present total water supply to this Town is 9,170m^3/d from Nol Turesh Water Supply system, Groundwater sources and 7,500m^3/d from NCWSC bulk supply.

The proposed future sources to augment the present sources and meet the ultimate water demand for Mavoko Municipality Area are:

1. Stony Athi Dam (21Mm^3) - 60,480m^3/d
2. NCWSC Bulk Water Supply - 12,000m^3/d

The basis selection of Stony Athi Dam is that it is close to the demand area and remaining supply deficit can easily be met through additional NCWSC Bulk Supply.

The water demand forecast for Mavoko Municipality Area and the Implementation Schedule for proposed future sources is shown in Figure 9-27. Details of proposed water supply facilities including their initial years of operation are given in Table 9-22.

Figure 9-27: Implementation Schedule for New Water Sources - Mavoko

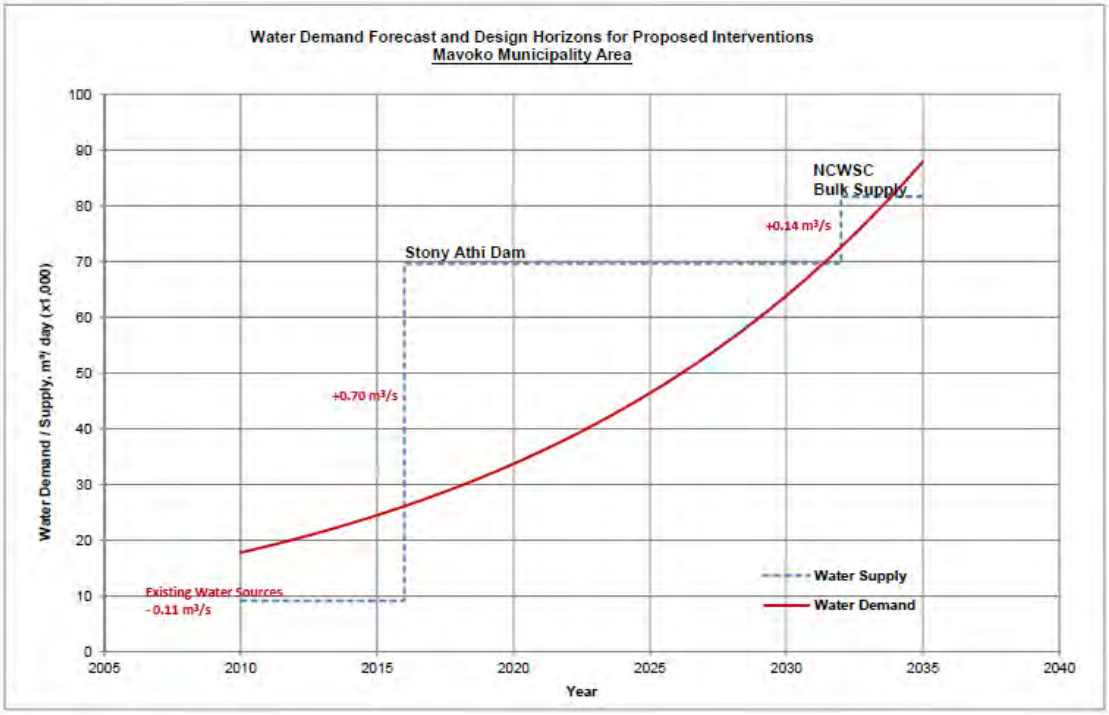


Table 9-22: Water Supply Infrastructure Required - Mavoko

Phase	Infrastructure Required	Year of Operation
I.	Stony Athi Dam, Height 25m, Net Yield of 60,500m^3/day with • Treatment Works of capacity 60,500m^3/day • Pumping station from Treatment Works to Storage • Ferrous Bulk Gravity Main from Treatment Works to Storage, Diameter 800mm, Length 5km • System storage of 30,000m^3 • Ferrous Bulk Gravity Main from Storage to Mavoko, Diameter	2016

Phase	Infrastructure Required	Year of Operation
	800mm, Length 4km	
II.	Bulk Supply of 12,000m³/day from NCWSC using the Existing 600mm dia. Pipeline from Nairobi presently serving Mavoko-EPZA	2032

8.3.6 Ngong, Ongata Rongai and Kiserian

The year 2035 water demand for Ngong, Ongata Rongai and Kiserian Areas is 54,246m³/d. The present total water supply to these Towns is 4,246m³/d from Boreholes, Springs and Mbagathi River Intake. The proposed future sources to augment the present sources and meet the ultimate water demand for Ngong, Ongata Rongai and Kiserian are:

1. Kiserian Dam (1.2Mm³) - 15,000m³/d (Under Construction)
2. Additional Groundwater Sources - 2,500m³/d
3. NCWSC Bulk Water Supply - 33,000m³/d

Based on preliminary hydrogeological studies carried out in the area, groundwater sources of the proposed capacity can meet the initial deficit in water demand. NCWSC bulk supply has been proposed thereafter and will be via pumping from Dagoretti Reservoir to serve Ngong Town and the surrounding high altitude areas and via Kabete Reservoirs to serve Ongata Rongai and Kiserian Areas.

The water demand forecast for Ngong, Ongata Rongai and Kiserian Areas and the Implementation Schedule for proposed future sources is shown in Figure 9-28. Details of proposed water supply facilities including their initial years of operation are given in Table 9-22.

Figure 9-28: Implementation Schedule for New Water Sources - Ngong, Ongata Rongai & Kiserian

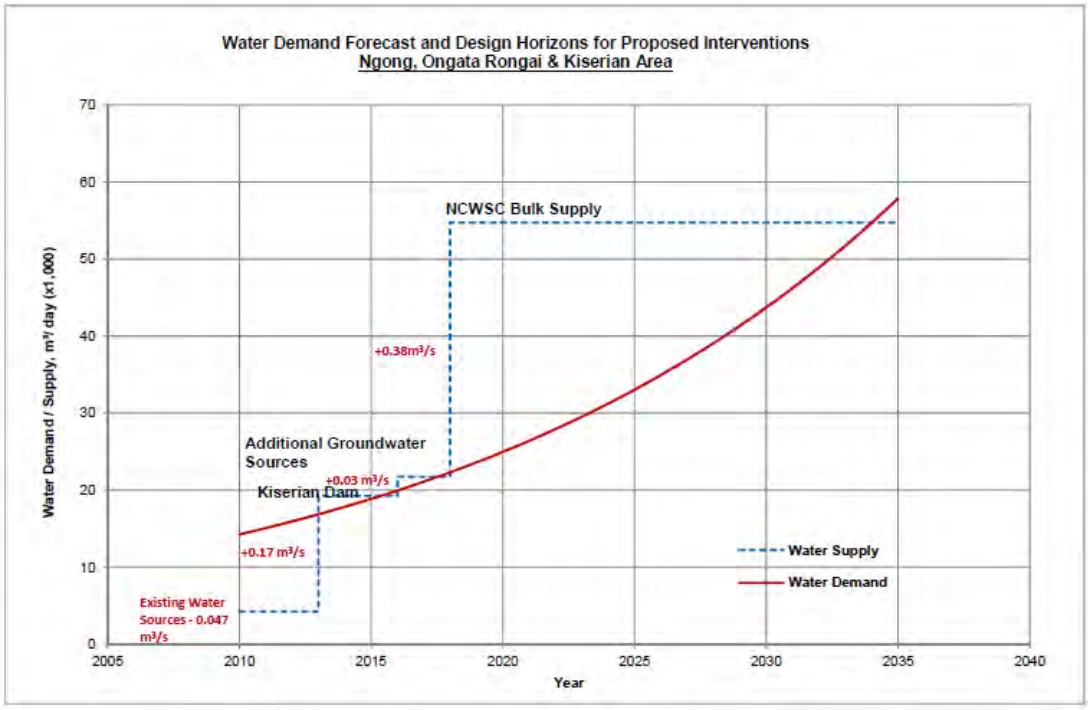


Table 9-23: Water Supply Infrastructure Required - Ngong, Ongata Rongai & Kiserian

Phase	Infrastructure Required	Year of Operation
I.	Groundwater sources with a total yield of 2,500m^3/day	2016
II.	Bulk Supply of 33,000m^3/day from NCWSC to Ngong and Ongata Rongai Towns • Rising Main from Dagoretti Reservoir to Ngong Town of Capacity 14,000m^3/d, Diameter 500mm and Length 10km • Gravity Main from Kabete Reservoirs to Ongata Rongai Town of Capacity 19,000m^3/d, Diameter 500mm and Length 17km	2018

9 Development Strategy for Satellite Towns outside Nairobi Water Demand Envelop

9.1 General

The water supply Options for Satellite Town located outside the Nairobi Water Demand Envelop are similar in three proposed Development Strategies. These are with exception to supply for Githunguri Town where disconnection of the existing NCWSC Bulk Supply under the Independent Water Supply Option has been considered.

9.2 Limuru Town

The year 2035 water demand for Limuru Town is 9,208m^3/d. The present water supply is 1,776m^3/d from Groundwater Sources. The proposed future sources to augment the present sources and meet the ultimate water demand for Limuru Town is additional Groundwater Development to be developed in two stages:

1. Groundwater Sources – Stage I - 4,000m^3/d
2. Groundwater Sources – Stage II - 4,000m^3/d

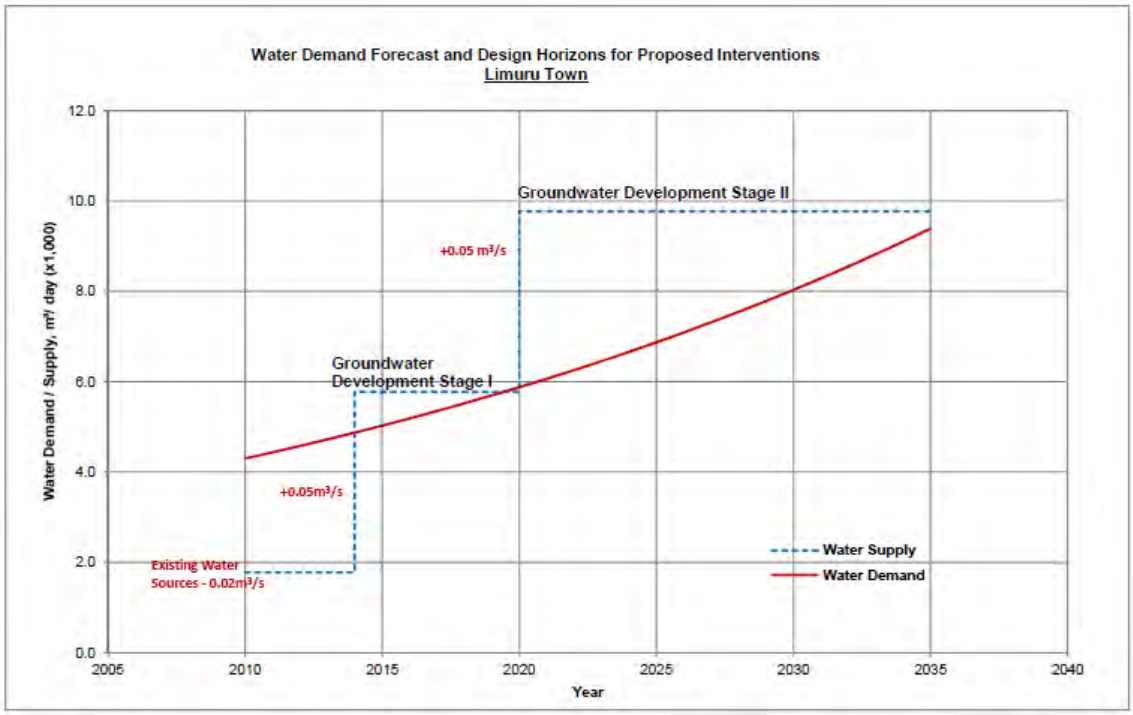
The altitude of Limuru Town is too high compared to the available surface water sources and therefore supply from Groundwater / Boreholes will be more economical. According to Hydrogeology studies carried out in the area, there is adequate groundwater potential within the Town and the surrounding areas to meet the forecast demand.

The water demand forecast for Limuru Town and the Implementation Schedule for proposed future sources is shown in Figure 9-29. Details of proposed water supply facilities including their initial years of operation are given in Table 9-24.

Table 9-24: Water Supply Infrastructure Required - Limuru

Phase	Infrastructure Required	Year of Operation
I.	• Wellfield with a total yield of 4,000m^3/day • System Storage of 2,000m^3	2014
II.	• Wellfield with a total yield of 4,000m^3/day • System Storage of 2,000m^3	2020

Figure 9-29: Implementation Schedule for New Water Sources - Limuru



9.3 Githunguri Town

The year 2035 water demand for Githunguri Town is 4,603m³/d. The present water supply is 1,336m³/d from Groundwater Sources with 400m³/d from NCWSC through Sasumua pipeline. The proposed future sources to augment present sources and meet the ultimate water demand for Limuru Town is additional Groundwater Development to be developed in two stages:

1. Groundwater Sources – Stage I - 2,000m³/d
2. Groundwater Sources – Stage II - 2,000m³/d

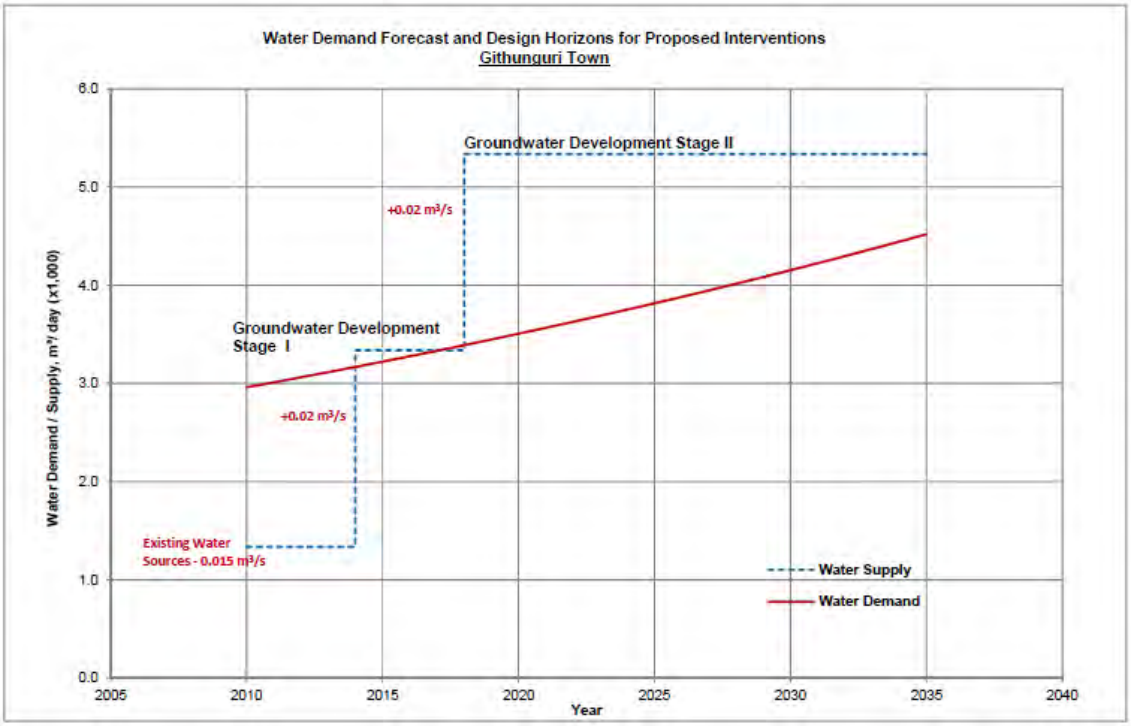
The altitude of Githunguri Town is high compared to the available surface water sources and therefore supply from Boreholes will be more economical. According to Hydrogeology studies carried out in the area, the groundwater potential in the area is adequate to meet the forecast demand.

The water demand forecast for Githunguri Town and the Implementation Schedule for proposed future sources is shown in Figure 9-30. Details of proposed water supply facilities including their initial years of operation are given in Table 9-25.

Table 9-25: Water Supply Infrastructure Required - Githunguri

Phase	Infrastructure Required	Year of Operation
I.	• Wellfield with a total yield of 2,000m³/day • System Storage of 1,000m³	2014
II.	• Wellfield with a total yield of 2,000m³/day • System Storage of 1,000m³	2018

Figure 9-30: Implementation Schedule for New Water Sources - Githunguri



9.4 Gatundu Town

The year 2035 water demand for Gatundu Town is 3,149m^3/d. The present water supply is 3,000m^3/d from Ndarugu River Intake close to the Aberdare Forest edge.

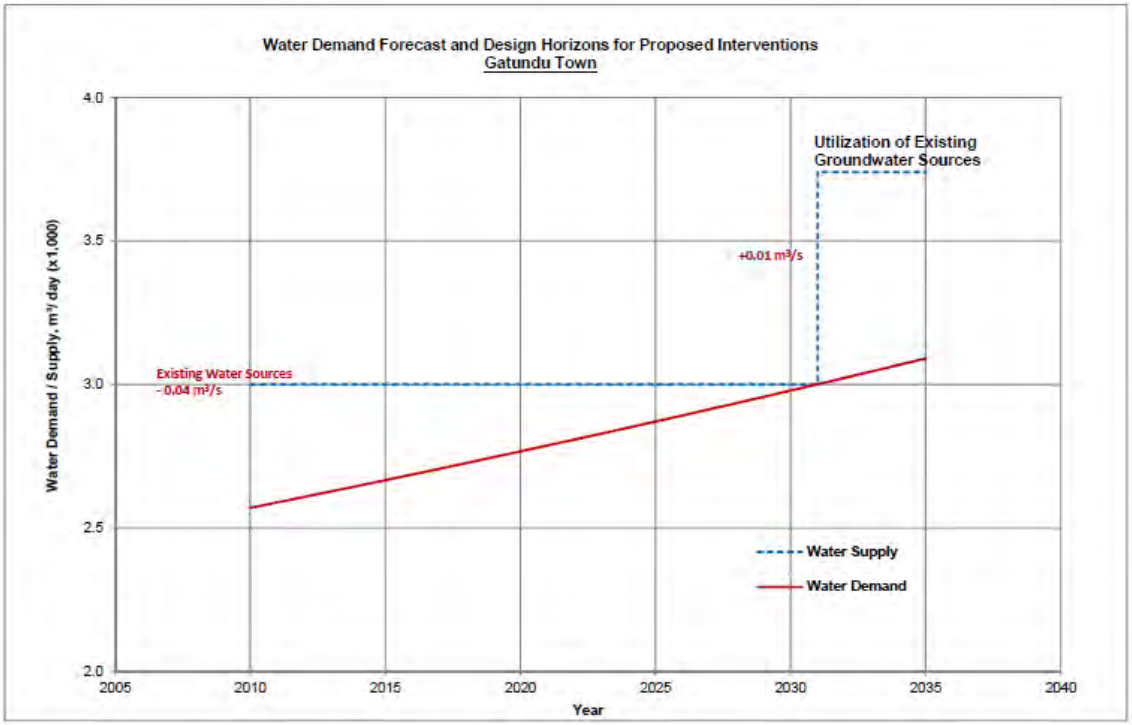
There are existing Boreholes within close proximity to the Town which are not presently fully utilised and can therefore be mobilised to meet the Town's ultimate water demand.

The water demand forecast for Gatundu Town and the Implementation Schedule for proposed future sources is shown in Figure 9-31. Details of proposed water supply facilities including their initial years of operation are given in Table 9-26.

Table 9-26: Water Supply Infrastructure Required - Gatundu

Infrastructure Required	Year of Operation
• Wellfield with a total yield of 740m^3/day • System Storage of 400m^3	2031

Figure 9-31: Implementation Schedule for New Water Sources - Gatundu



9.5 Thika Town

The year 2035 water demand for Thika Town is 59,545m^3/d. The present water supply is 26,000m^3/d from Chania River Intake located close to the Town.

There is an existing Intake on Thika River located close to the Town which is currently not being utilised. The capacity of the Intake is 10,368m^3/d. This source can be utilised to supplement the present water supply from Chania River.

The existing water supply infrastructure for Thika Water Supply was designed for a total operating capacity of 36,000m^3/d with the two pumping intakes at Chania and Thika River being fully utilised. This is according to the Final Design Report for Thika Augmentation Works Phase II proposed by Mangat, I. B. Patel & Partners Consulting Engineers (1984).

Due to treatment plant inefficiencies coupled with poor water quality in wet seasons, the plant cannot achieve its design capacity and presently only the Intake on Chania River is being utilised. The problem is further compounded as the old Phase of the Treatment Plant which is highly inefficient and in a dilapidated state.

It is recommended that rehabilitation works be carried out for the existing water supply system so as to ensure the full capacity of the system is achieved. This will ensure that the forecast water demand to year 2022 can be met.

To meet the ultimate year 2035 water demand for Thika Town, it is proposed that a dam on Thika River at the confluence with Kiama River (Thika 3A Dam) be constructed. The Dam is located approximately 5km upstream of the existing Thika River Intake and can provide an additional 40,000m^3/d.

This proposed dam site is downstream of existing Thika (Ndakaini) Dam and will trap spills from the dam and inflows from the intermediate catchment. The proposed dam is also set to benefit

from additional spills expected at Thika Dam with the construction of the Northern Collector Tunnel Project.

The water demand forecast for Thika Town and the Implementation Schedule for proposed future sources is shown in Figure 9-32. Details of proposed water supply facilities including their initial years of operation are given in Table 9-27.

Figure 9-32: Implementation for New Water Sources - Thika

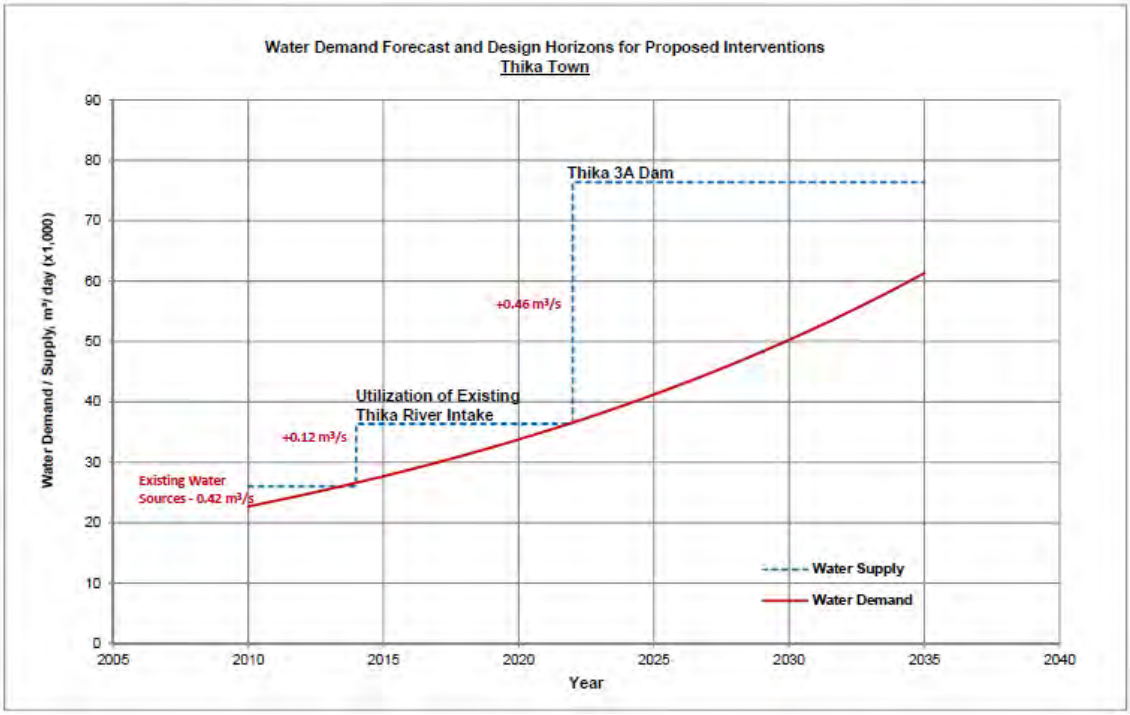


Table 9-27: Water Supply Infrastructure Required - Thika

Phase	Infrastructure Required	Year of Operation
I.	Augmentation of Existing Thika Water Supply by 10,400m^3/day	2014
II.	Thika 3A Dam, Height 40m, Net Yield of 40,000m^3/day with • Treatment Works of capacity 24,000m^3/day • Ferrous Bulk Rising Main from Treatment Works to System Storage, diameter 700mm and total length 0.5km • System Storage of 12,000m^3 • Ferrous Bulk Gravity Main from System Storage to Thika Town, diameter 700mm and length 6km.	2022

9.6 Tala-Kangundo Towns

The year 2035 water demand for Tala-Kangundo Towns is 3,432m^3/d. The present water supply is 250m^3/d from groundwater sources.

The proposed future sources to augment the present sources and meet the ultimate water demand for Tala-Kangundo Towns is additional Groundwater Development to be developed in two stages:

1. Groundwater Sources – Stage I - 1,800m^3/d
2. Groundwater Sources – Stage II - 1,800m^3/d

There are no available surface water sources within or in the vicinity of the two Towns which can be economically developed and therefore consideration of groundwater sources development has been made.

Although groundwater sources make up the present water supply to the two sources, the capacity is limited. However, preliminary hydrogeological studies have shown that the required demand can be met by development of additional boreholes in the area.

The water demand forecast for Tala-Kangundo Towns and the Implementation Schedule for proposed future sources is shown in Figure 9-33. Details of proposed water supply facilities including their initial years of operation are given in Table 9-28.

Figure 9-33: Implementation Schedule for New Water Sources - Tala-Kangundo

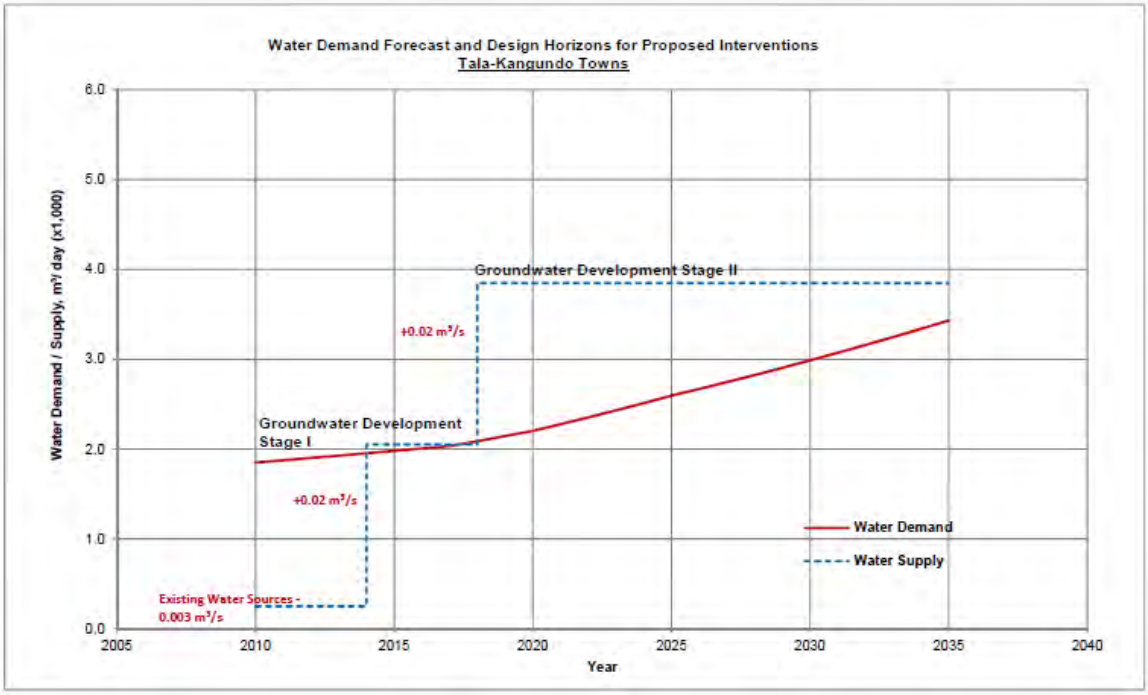


Table 9-28: Water Supply Infrastructure Required - Tala-Kangundo

Phase	Infrastructure Required	Year of Operation
I.	• Wellfield with a total yield of 1,800m^3/day • System Storage of 900m^3	2014
II.	• Wellfield with a total yield of 1,800m^3/day • System Storage of 900m^3	2018

10 Comparison of Strategies for Satellite Towns

The three Options for Water Supply to the Satellite Towns have been elaborated in detail giving an outline description and conceptual engineering design of the Key Components. The Implementation Schedule is based on meeting the water demand for the target areas.

Based on the conceptual engineering estimates, Capital and Operation & Maintenance Costs for the three Options have been prepared.

The following sections outline the Least Cost Analysis for all three Options which have been used to determine the key Economic Parameters which have then been imported into the Multicriteria Analysis to select the best Option for development of Water Supply to the Satellite Towns.

11 Least Cost Analysis of Satellite Towns

This section describes the Least Cost Analysis for the development of water supply to meet the projected bulk water demand for the 13 Satellite Towns around Nairobi City for the period 2013 to 2035. Three options were considered for increasing the supply of water to meet projected demand: (i) independent – developing independent supplies for each town; (ii) strategic – bulk supply from a central provider integrated with the Nairobi City water supply system; and (iii) a mixed system – combining features of an independent supply with bulk supply. Each alternative Option was designed to meet the projected water demand over the study period 2013– 2035 and costed using the unit rates for capital expenditure applicable in mid 2012 allowing for all costs of providing a bulk supply of water to meet the projected demand.

Investments considered in the analysis include: (i) water resource abstraction infrastructure (dams, diversion weirs, tunnels, etc.); (ii) raw water mains, treated water mains and booster pumping stations; (iii) water treatment works; (iv) storage reservoirs; and (v) boreholes and their associated pipe works and storage. Distribution network costs and additional Service Reservoirs were not considered in the analysis and are regarded as being similar for each option.

A Multicriteria Least Cost Analysis was carried out to compare each of three potential water resources development Options. As each alternative provides a slightly different raw water output over the time period, a normalization procedure was applied to allow for comparison of costs of the options for a similar water output with the results expressed as the Average Incremental Economic Cost of water (AIEC). Six key sustainability issues were used for the multicriteria analysis taking account of natural resources, economic performance, technical issues, O&M institutional and policy issues, environmental issues and social sustainability to produce an overall weighted score for the three Options.

11.1 Capital Costs

Costs of the three Options were built up from the component parts of each Town's proposed water supply system combined with the current unit rates for the main scheme components – dams, pumps, pipes, storage and water treatment works (WTWs). In preparing the costs the following assumptions were applied:

- Costs are expressed in US$ using the rates applicable in mid 2012, and where necessary foreign costs are converted to KES at the rate of KES 90 = US$1.0 and KES117 = 1.0 Euro.

- Costs are assumed to be free of Kenyan customs and excise duty, unless stated otherwise.
- Costs are assumed to be free of VAT of 16%, unless stated otherwise
- An allowance of 15% is applied to all construction costs to allow for preliminaries and general items.
- An allowance of 9% of construction costs is applied to allow for engineering and works supervision services. A higher allowance of 12% is applied for boreholes to allow for the greater degree of uncertainty for the costs of developing ground water
- A physical contingency of 10% is applied to all construction costs to allow for underestimation in bill of quantities and unforeseen costs.
- No allowance for price escalation (financial contingency) is included at the costs which are expressed in constant 2012 price terms.
- A discount factor of 5% is used in the analysis for discounting costs to their present values.

Details of the Scheme Components for each Satellite Town have already been described in Sections 6, 7, 8 & 9.

11.2 Dam Costs

Costs for dams were prepared for each dam as they relate to each of the three Options. A summary of the main features and base cost for each is shown in Table 9-29. An additional 34% is added to these base costs to allow for preliminaries and general costs (15%, engineering services (9%), and physical contingencies (10%). For the Strategic Supply Option the four dams contribute to the bulk water supply for the Satellite Towns.

Table 9.29: Summary of Dam Costs

Satellite Town Number	Dam Site	Actual / Design Dam Height (m)	Gross yield (m^3/s)	Net yield (m^3/s)	Net yield (m^3/d)	Total Dam Base Cost MUSD
NDEPENDENT OPTION						
1. Kikuyu	Ndarugu 3	50	0.395	0.240	20736	90.05
	Kamiti 1	50	0.227	0.188	16226	44.86
2. Kiambu	Riara	30	0.171	0.141	12165	18.46
	Komothai 2	30	0.297	0.177	15250	13.43
3. Karuri	Ruiru 2	50	0.781	0.461	39866	52.36
4. Ruiru-Juja	Karimenu 2	40	0.835	0.535	46219	34.54
	Gatamayu 2	50	0.68	0.370	31973	50.45
	Thiririka	50	0.460	0.392	33868	66.05
5. Mavoko	Stony Athi	25	0.940	0.7	60480	40.86
	Mbagathi	35	0.748	0.638	55123	67.52
6. Ngong, Ongata Rongai & Kiserian	Ruabura	65	0.537	0.437	37794	120.88
10.Thika Town	Thika 3A	40		0.460	39744	36.30
STRATEGIC SUPPLY OPTION						
NAIROBI Bulk	Ruiru 2	70	0.98	0.90	77760	146.33

Satellite Town Number	Dam Site	Actual / Design Dam Height (m)	Gross yield (m^3/s)	Net yield (m^3/s)	Net yield (m^3/d)	Total Dam Base Cost MUSD
Supply	Dam with Ndurire Transfer					
	Karimenu 2	40	0.835	0.535	46219	34.54
	Thiririka	50	0.460	0.392	33868	66.05
	Ruabura	65	0.537	0.437	37794	120.88
10. Thika Town	Thika 3A	40		0.460	39744	36.30
MIXED OPTION						
1. Kikuyu	Kamiti 1	50	0.227	0.188	16,226	44.86
2. Kiambu **3. Karuri** **4. Ruiru-Juja**	Ruiru 2 (Shared)	70	0.980	0.900	77,760	146.33
4. Ruiru-Juja	Karimenu 2	40	0.835	0.535	46,219	34.54
5. Mavoko	Stony Athi	25	0.940	0.700	60,480	40.86
10. Thika Town	Thika 3A	40		0.460	39,744	36.30

11.3 Borehole Costs

Boreholes (tubewells) are costed on the basis of US$50,000 for drilling and lining the borehole, and US$7,500 for the pump. Storage is allowed for at half of the daily demand with a capital cost of KES16,200 per m^3 (US$180). This cost is assumed to also include the cost of the collection manifold system and chlorination unit. A transmission main for delivery of water to the storage reservoir is allowed for with an average length of 5 km, with pipe diameter related to the flow. Five Satellite Towns have extra ground water development in the Independent Option, four under the Strategic Option and six under the Mixed Option.

11.4 Pipe costs

The costs for the distribution pipes are based on current unit rates for various pipe sizes as shown in Table 9-30. All pipes are assumed to be made of steel with nominal pressure 25 Bar (NP 25), except for the Chania-Komu transfer main where because of the high pumping head involved some of the pipes are required to be NP40.

Table 9.30: Summary of Pipe Unit Rate Costs

Unit Costs of Pipelines - Steel Pipelines **ExRate US$: KES90**

Nominal Diameter (mm)	Total Rate including Transport, Laying and Fittings			
	NP 25 Ksh/m	NP 40 Ksh/m	NP 25 US$/m	NP 40 US$/m
100	6,500.00	8,600.00	72.22	95.56
150	9,500.00	13,500.00	105.56	150.00
200	12,200.00	16,410.00	135.56	182.33
250	15,350.00	19,120.00	170.56	212.44
300	18,600.00	21,420.00	206.67	238.00
400	20,100.00	23,330.00	223.33	259.22
450	23,269.00	27,480.00	258.54	305.33
500	24,500.00	29,200.00	272.22	324.44
600	26,480.00	30,240.00	294.22	336.00

Unit Costs of Pipelines - Steel Pipelines **ExRate US$: KES90**

Nominal Diameter (mm)	Total Rate including Transport, Laying and Fittings			
	NP 25 Ksh/m	NP 40 Ksh/m	NP 25 US$/m	NP 40 US$/m
700	32,360.00	40,280.00	359.56	447.56
800	38,240.00	50,320.00	424.89	559.11
900	47,760.00	64,640.00	530.67	718.22
1000	59,700.00	80,480.00	663.33	894.22
1100	61,680.00	97,680.00	685.33	1,085.33
1200	76,800.00	106,400.00	853.33	1,182.22
1300	88,000.00	122,960.00	977.78	1,366.22
1400	101,440.00	155,520.00	1,127.11	1,728.00
1500	111,920.00	170,000.00	1,243.56	1,888.89
1600	132,400.00	199,120.00	1,471.11	2,212.44

11.5 Booster pumps

The costs of booster pumps for water transfer pumping station are costed according to the volume of water to be pumped with a unit cost of US$100,000 per pump for larger capacity pumps with a delivery of over 1,000m^3/h, US$60,000 for medium size pumps (capacity 500 to 1,000m^3/h) and US$50,000 for lower capacity pumps with less than 500m^3/h delivery. The pump costs are assumed to include the cost of pipework and necessary electricity supply. An amount of US$75,000 is allowed for a larger pump house and US$50,000 for a smaller pump house. The number of pumps to be installed depends on the projected daily maximum volume and allows for necessary standby pumps on the basis of one standby pump for every two duty pumps.

11.6 Water Treatment Works and storage

The capital costs of water treatment works (WTWs) and associated storage reservoirs are based on the same unit rates used for the Nairobi City water supply least-cost analysis of US$320,000 per 1000m^3/day for WTWs installed capacity, and US$111,000 per 1000m^3 of capacity for storage reservoirs. The capacity of the storage reservoirs associated with WTWs is based on half of the daily capacity of the treatment works.

11.7 O&M Costs

Annual Maintenance Costs – Fixed Items

Rates for the annual maintenance and replacement, intervals for fixed items associated with water supply based on the guidelines of the Design Manual for Water Supply Services in Kenya, MoWI, 2005 are shown in Table 9-31. The rates are calculated as a percentage of the initial capital cost and where appropriate these rates have been used for the estimation of annual maintenance and replacement costs for the capital assets discussed above.

Table 9.31: Annual Maintenance Rates

Asset		Economic Lifetime	Fixed Annual Maintenance Costs
		Years	% per year
1	Dams	40	0.5
2	Boreholes and wells	20	1.0
3	Pumps	10	5.0
4.	Electric motors, cables and switch gears	10	5.0
5.	Pipes (all types)	30	1.0
6.	Water treatment works	30	1.0
7.	Reservoirs	30	1.0
8.	Storage tanks in masonry or reinforced concrete	30	1.0
9.	Tunnels	40	0.5

Source: MoWI, Practice Manual for water supply services in Kenya, Dec. 2005

Replacement costs for all investments are considered at 90% of the initial capital investment costs and allowance is made for pump replacement every 10 years.

For the economic analysis a salvage value is included in the cash flows to allow for the remaining years left at the end of the analysis period for the economic lifetime of the asset.

11.8 Variable Operation & Maintenance Costs

Water Treatment Works

For the water treatment works the variable operating costs are derived from: (i) the average 2010 variable operation costs of NCWSC for its existing Water Treatment Works (WTW), namely Ngethu WTW, Kabete / Kikuyu WTW and Sasumua WTW, and (ii) other relevant WTW operation costs in Kenya.

The variable operation costs of NCWSC operations (staffing, electricity, chemicals and repairs and maintenance etc.) based on information in the Company's Annual Accounts and other information sources. In 2010, the average variable costs per m^3 of water produced of all NCWSC WTW was KES2.20/m^3 including the costs of chemicals, personnel and electricity/fuel oil costs. This value has been used.

Pumps Variable Operating Costs

Costs of pumping for boreholes have been estimated based on the lift (head) and the pump discharge with the electricity requirement based on a pump efficiency of 70%.

Energy cost has been calculated at a rate of KES 20/KWh (US$0.20) corresponding to the 2010 industrial rate for electricity provided by Kenya Power and Lighting Company (KPLC).

11.9 Comparison of Strategies

Introduction

As mentioned earlier, three Options were considered for developing water resources to meet the projected demand for each Satellite Town up to Year 2035. Each Option has been designed to meet the water demand from a variety of sources over the study period (Year 2013 to 2035), although they have different outputs at different times depending on the scheduling of the new infrastructure over the time period, and the volume of supply that continues to be supplied from existing water sources and infrastructure. The Least Cost Analysis uses a normalising procedure discounting the CAPEX and OPEX cost streams over the project life to present

values (PV) at a stipulated discount rate. The PV of the costs is divided by the discounted value of the annual increases in water supply with the results expressed as the Average Incremental Economic Cost of water (AIEC). The results, KES/m^3 and US$/$m^3$ allow the economic performance of each Option to be evaluated to a common yardstick. Schemes having a lower AIEC are more favourable.

As the period of the analysis (Year 2013 – 2035) is shorter than the economic lifespan of some of the infrastructure investments, particularly for capital investment made later in the period, a salvage value has been included for the investment that still has a residual economic life after Year 2035.

Description of Options

Three Options, each capable of meeting the projected water demand for each of the 13 Satellite Towns have been compared.

1. Independent Supply Option

This Option allows for the development of water supply resources for each satellite town independently, with little or no linkages to other water delivery systems and with the assumption that water services would probably be managed for each town by its own water services provider (WSP).

2. Strategic Water Supply Option

Under this Option water would be provided to each town from a centralised bulk supply that is closely integrated with the Nairobi City supply, with water delivered to each town according to need by a central bulk water provider. The infrastructure for this option includes the development of four dams and associated transmission mains that would be fully utilised for the Satellite Towns.

3. Mixed Supply Option

This Option represents a combination of independent and bulk supply taking account of the technically most efficient Option for developing water supply for each satellite town taking a more pragmatic approach with a portion of the demand met from bulk water supplied from transfers within the supply system.

Summary of Costs for Each Option

The following tables present a summary of the capital expenditure for the three Options in constant 2012 prices.

Table 9-32: Summary of Capital Expenditure for Independent Option

	Satellite Town	US$'000
1.	Kikuyu	238,896
2.	Kiambu	61,425
3.	Karuri	96,444
4.	Ruiru-Juja	317,872
5.	Mavoko	202,079
6.	Ngong, Ongata Rongai & Kiserian	220,006
7.	Thika Town	64,423
8.	Limuru	5,476
9.	Githunguri	3,261
10.	Gatundu	977
11.	Tala-Kangundo	3,316
	TOTAL	**1,214,173**

Notes

(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision

(ii) No financial contingencies included

Table 9-33: Summary of Capital Expenditure for Strategic Option

	Satellite Town	Total capital cost US$'000
	Nairobi Bulk Supply	**696,349**
	Dams	510,552
	Chania-Komu Transfer	185,797
1.	Kikuyu	77,975
2.	Kiambu	112,574
3.	Karuri	30,850
4.	Ruiru-Juja	62,349
5.	Mavoko	26,675
6.	Ngong, Ongata Rongai & Kiserian	12,705
7.	Thika Town	64,178
8.	Limuru	5,476
9.	Githunguri	3,261
10.	Gatundu	977
11.	Tala-Kangundo	3,316
	TOTAL	**1,096,686**

Notes

(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision

(ii) No financial contingencies included

Table 9-34: Summary of Capital Expenditure for Mixed Option

	Satellite Town	Total capital cost US$'000
NAIROBI BULK SUPPLY		**185,796**
	Chania-Komu Transfer	107,124
	Chania-Komu WTW	78,672
1.	Kikuyu	87,983
2.	Kiambu	70,215
3.	Karuri	125,139
4.	Ruiru-Juja	205,375
5.	Mavoko	110,417
6.	Ngong, Ongata Rongai & Kiserianl	9,173
7.	Thika town	64,178
8.	Limuru	5,476
9.	Githunguri	3,261
10.	Gatundu	977
11.	Tala-kangundo	3,316
	TOTAL	**871,306**

Notes

(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision

(ii) No financial contingencies included

The total costs for the three Options vary considerably; the Independent Option is the highest at US$1.214 billion (KES109 billion) over the 23 year period (2013 to 2035), in constant 2012 prices; the Mixed Supply Option has the lowest capex cost of US$871.3 million (KES78 billion) while the Strategic Supply Option has a capex cost in the middle with US$1.097 billion (KES99billion).

For the Strategic Supply Option the full cost capital cost of US$510.6 million of the four new supply dams (Ruiru 2, Karimenu 2, Thiririka and Ruabura) required to provide water to the Satellite Towns has been allocated to this Option as the full additional yield from these dams will be needed to satisfy the projected demand from Satellite Towns by 2035. In addition the full cost of the Chania-Komu transfer system (tunnel, pipe line and booster pumps) amounting to US$107.12 million and the Chania-Komu WTW (capacity 181,440 m^3/d) with a capex cost of US$78.67 million has been allocated to the Strategic Supply Option on the assumption that this infrastructure would be used exclusively for the Nairobi City bulk supply system to supply water to the Satellite Towns.

For the Mixed Supply Option, no additional dams are required to supply bulk water and the demand can be met by the infrastructure developed for each satellite town and with internal transfers within the system. In addition the full cost of the Chania-Komu transfer tunnel and pipes of US$107.12 million and the cost of the Chania-Komu WTW of US$78.67 million is also allocated to this Option. A similar apportionment for the O&M costs for the dams and the Chania-Komu transfer system and WTW is assumed for these two options.

The Independent Supply Option does not receive any additional bulk supply water from the Nairobi City system and so there are no additional costs associated with bulk water supply for this Option.

The capex costs include the replacement of pumps at 10 year intervals.

Implementation / Expenditure Schedules

The following three tables show the planned implementation and expenditure for each of the Options over the design period 2013– 2035, in constant 2012 prices.

Table 9-35: Summary of Implementation & Capital Expenditure for Independent Supply

Item	Satellite Town	Capacity	Unit	INDEPENDENT Total initial capital cost US$'000	Expenditure accounts by years 2012 constant prices *Totals including contingencies & replacement costs* 2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1.	**KIKUYU**			**238,896**	**3,498**	**29,151**	**29,151**	**20,261**	**0**	**0**	**0**	**0**	**3,498**	**0**	**140**	**0**	**55,162**	**55,162**	**42,323**	**0**	**0**	**271**	**140**	**0**	**140**	**0**	**0**
	Boreholes																										-
	Stage 1	9,000	m3/d	3,498	3,498	0	0	0																			-
	Stage 2	9,000	"	3,498								0	3,498	0													-
	Pump replacement			421											140								140		140		-
	Dams																										-
	Kamiti 1 dam	16,416	m3/d	60,783	0	20,261	20,261	20,261		0	0																-
	Ndarugu 3 dam	20,736	"	126,969												0	42,323	42,323	42,323	0	0						-
				187,752																							
	Pipes & booster pump																										-
	Kameti Dam	684	m3/h	9,459		4,729	4,729	0		0																	-
	Ndarugu Dam	705	"	17,143													8,571	8,571	0	0	0						-
	Booster pumps	16,908	m3/d	271																		271					-
				26,873																							
	WTW & Storage																										-
	Kamiti Dam 1 - WTW	16,416	m3/d	7,118.0		3,559	3,559	0		0	0																-
	Ndarugu 3 Dam - WTW	16,908	"	7,331.3													3,666	3,666	0			0					-
	Kamiti Dam 1 - storage	8,000	m3	1,203.2		602	602	0		0	0																-
	Ndarugu 3 Dam - storage	8,000	"	1,203.2													602	602									-
				16,855.8																							
2.	**KIAMBU**			**61,425**	**0**	**12,878**	**12,878**	**8,339**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**10,509**	**10,509**	**6,312**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Dams																										-
	Riara	12,096	m3/d	25,016	0	8,339	8,339	8,339		0	0															-	**0**
	Komathai 2	15,552	"	18,937													6,312	6,312	6,312	0	0	0				-	**0**
				43,952																							
	Pipes																										-
	Riaradam + Kiam bu	504	m3/h	2,932		1,466	1,466	0		0	0																-
	Komothai 2 Dam	232	"	5,601													2,800	2,800	0	0	0	0					-
				8,533																							
	WTW & Storage																										-
	Riara WTW	12,096	m3/h	5,245		2,622	2,622	0		0	0																-
	Komathai WTW	5,574	"	2,417												0	1,208	1,208	0	0							-
	Riara storage	6,000	m3	902		451	451																				-
	Komathai storage	2,500	'	376													188	188									-
				8,940																							
3.	**KARURI**			**96,444**	**0**	**33,365**	**33,365**	**23,650**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**366**	**0**	**2,849**	**2,849**	**0**	**0**	**0**	**0**	**0**	**0**
	Dam - Ruiru 2	39,744	m3/d	70,949		23,650	23,650	23,650		0	0																-
	Pipes & booster pump	1,190	m3/h	10,638		5,319	5,319	0		0	0								0			0					-
	Pump replacement			366														366									-
	WTW & Storage																										-
	WTW works I	17,332	m3/d	7,515		3,758	3,758	0		0	0	0															-
	WTW works 2	11,232	"	4,870											0	0	0			2,435	2,435						-
	Storage 1	8,500	m3	1,278		639	639																				-
	Storage 2	5,500	"	827																414	414						-
				14,491																							
4.	**RUIRU-JUJA**			**317,872**	**0**	**39,027**	**39,027**	**15,601**	**0**	**0**	**0**	**0**	**35,719**	**35,719**	**23,710**	**0**	**0**	**0**	**0**	**49,012**	**49,012**	**31,044**	**0**	**0**	**0**	**0**	**0**
	Dams																										-
	1. KARIMENU 2			46,803		15,601	15,601	15,601		0	0																-
	2. GATAMAYU 2			71,129									23,710	23,710	23,710	0	0										-
	3. THIRIRIKA			93,133															0	31,044	31,044	31,044	0				-
				211,064																							
	Pipes & tunnel																										-
	Karimenu 2 Dam	1,925	m3/h	23,163		11,581	11,581	0		0	0							0									-
	Ruiru-Juja Storage	688	"	7,377									3,689	3,689	0	0											-
	Thririka Dam	1,375	'	19,216																9,608	9,608	0	0				-
				49,756																							
	WTW & Storage																										-
	WTW stage 1	46,656	m3/d	20,230		10,115	10,115	0		0	0	0															-
	WTW stage 2	32,832	"	14,236									7,118	7,118				0	0								-
	WTW stage 3	33,010	"	14,313																7,157	7,157	0	0				-
	NCWSC Storage 1	23,000	m3	3,459		1,730	1,730																				-
	NCWSC Storage 2	16,000	"	2,406									1,203	1,203													-
	NCWSC Storage 3	16,000	"	2,406																1,203	1,203						-
				57,051																							

Item	Satellite Town	Capacity	Unit	INDEPENDENT Total initial capital cost US$'000	Expenditure accounts by years 2012 constant prices *Totals including contingencies & replacement costs* 2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
5.	**MAVOKO**			**202,079**	**0**	**36,414**	**36,414**	**18,963**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**457**	**0**	**38,912**	**38,912**	**32,007**	**0**	**0**	**0**	**0**	**0**
	Dams	60,480	m3/d																								-
	Stony Athi			55,364		18,455	18,455	18,455	0	0																	-
	Mbagathi			95,207															0	31,736	31,736	31,736	0				-
				150,571																							
	Pipes & Booster Pump																										-
	Pipes & storage1	2,520	m3/h	5,182		2,591	2,591																				-
	Pipes & storage 2	753	"	5,164																2,582	2,582	0	0	0			-
	Booster pump #1	2,520	"	508				508																			-
	Booster pump #2	753	"	271																		271					-
	Pump replacement			457														457									-
	WTW & Storage																										-
	WTW 1	60,480	m3/d	26,224		13,112	13,112																				-
	WTW 2	18,072	"	7,836																3,918	3,918		0	0			-
	Storage 1	30,000	m3	4,512		2,256	2,256																				-
	Storage 2	9,000	"	1,354																677	677						-
				38,572																							-
6.	**NGONG ET AL**			**220,006**	**0**	**82,408**	**82,408**	**54,910**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**280**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Dams																										-
	Ruabura dam	38,016	m3/d	163,795		54,598	54,598	54,598																			-
	Kiserian dam (under construc	15,000	"	zero																							
																											-
	Pipes & Pumps																										-
	All pipes	1,458	m3/h	37,735		18,868	18,868																				-
	Booster pump #2	1,458	"	592				312										280	0	0	0	0	0				-
				38,327																							
	WTW & Storage																										-
	Kiserian dam WTW	-	m3/d	Zero																							
	Ruabura dam WTW	35,000	"	15,176		7,588	7,588																				-
	Kiserian storage	-	m3	zero																							
	Ruabura storage	18,000	"	2,707		1,354	1,354																				-
				17,883		**82,408**	**82,408**	**54,910**																			
7.	**THIKA TOWN**			**64,423**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**23,892**	**23,892**	**16,395**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**244**	**0**	**0**	**0**	**0**
	Thika 3A dam	40,000	m3/d	49,185								16,395	16,395	16,395	0	0	0	0									-
	Pipes & pump	1,000	m3/h	3,027								1,391	1,391	0	0	0	0	0					**244**				-
	WTW & Storage																										-
	WTW	24,000	m3/d	10,406								5,203	5,203	0	0												-
	Storage	12,000	m3	1,805								902	902														-
				12,211																							
8.	**LIMURU**			**5,476**	**2,543**	**0**	**0**	**0**	**0**	**0**	**2,543**	**0**	**0**	**0**	**130**	**0**	**0**	**0**	**0**	**0**	**130**	**0**	**0**	**0**	**130**	**0**	**0**
	Boreholes & Storage																										-
	Stage 1	4,000	m3/d	2,543	2,543	0	0	0																			-
	Stage 2	4,000	"	2,543							2,543	0															-
	Pump replacement			390											130						130				130		-
9.	**GITHUNGURI**			**3,261**	**1,533**	**0**	**1,533**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**65**	**0**	**65**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**65**	**0**	**0**
	Boreholes & Storage																										-
	Stage 1	2,000	m3/d	1,533	1,533																						-
	Stage 2	2,000	"	1,533			1,533																				-
	Pump replacement			195											65		65					0			65		-
10.	**GATUNDU**			**977**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**977**	**0**	**0**	**0**	**0**	**0**
	Boreholes & Storage																										-
	Stage 1	740	m3/d	977																		977	0				-
11.	**TALA-KANGUNDO**			**3,316**	**1,553**	**0**	**0**	**0**	**1,553**	**0**	**0**	**0**	**0**	**0**	**70**	**0**	**0**	**0**	**70**	**0**	**0**	**0**	**0**	**0**	**70**	**0**	**0**
	Boreholes & Storage																										-
	Stage 1	1,800	m3/d	1,553	1,553		0						0														-
	Stage 2	1,800	"	1,553					1,553																		-
	Pump replacement			210											70				70						70		-
	TOTAL			**1,214,173**	**9,127**	**233,243**	**234,776**	**141,723**	**1,553**	**0**	**2,543**	**23,892**	**63,109**	**52,114**	**24,115**	**0**	**65,736**	**66,774**	**48,705**	**90,773**	**90,903**	**64,299**	**384**	**0**	**405**	**0**	**0**

Notes

(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision

(ii) No financial contingencies included

Table 9-36: Summary of Implementation & Capital Expenditure for Strategic Supply

Item	Satellite Town	Capacity	Unit	BULK SUPPLY Total initial capital cost US$'000	Expenditure accounts by years 2012 constant prices *Totals including contingencies & replacement costs* 2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
	NAIROBI BULK SUPPLY TO SATELLITE TOWNS			**696,349**	**0**	**82,325**	**82,325**	**170,184**	**87,859**	**87,859**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**34,265**	**77,930**	**73,601**	**0**	**0**	**0**	**-446,917**
	Dams																										
	Ruiru 2	77,760	m3/d	198,273		66,091	66,091	66,091																			
	Karimenu 2	46,656	"	48,702		16,234	16,234	16,234																			
	Thiririka	33,869	"	93,133				31,044	31,044	31,044																	
	Ruabura	38,016	"	170,443				56,814	56,814	56,814																	
		196,301	"	**510,552**																							
	Chania-Komu Transfer																										
	Tunnel	7,560	m3/h	17,314																	4,328	8,657	4,328				
	Pipes	7,560	"	72,205																	24,068	24,068	24,068				
	Pumps	181,440	m3/d	9,756																	3,252	3,252	3,252				
	Storage	50,000	m3	7,849																	2,616	2,616	2,616				
				107,124																							
	Chania-Komu WTW																										
	WTW	181,440	m3/d	**78,672**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39,336	39,336	0	0	0	-70,805
1.	**KIKUYU**			**77,975**	**0**	**38,591**	**38,591**	**356**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**119**	**320**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-28,430**
	Pipes	2,995	3/h (max)	40,606		20,303	20,303																				
	Pumps - PS 1	52,000	m3/d	676				356											320	0							
	Pumps - PS 2 booster			119														119									
	WTW & Storage																										
	Ruabura Dam - WTW	38,016	m3/d	16,483.7		8,242	8,242	0																			
	Thirirka Dam - WTW	33,869	"	14,685.6		7,343	7,343	0																			
	Ruabura Dam - Storage	19,008	m3	2,858.9		1,429	1,429	0																			
	Thirirka Dam - Storage	16,935	"	2,547.0		1,274	1,274	0																			
				36,575.3																							
2.	**KIAMBU**			**112,574**	**0**	**55,610**	**55,610**	**0**	**0**	**0**	**677**	**677**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-41,503**
	Pipes	**5,184**	**i/h (max)**	46,563		23,282	23,282	0	0	**0**																	
	WTW & Storage																										
	Karimenu Dam WTW	46,656	m3/d	20,230		10,115	10,115																				
	Ruiru Dam WTW	77,760	"	33,717		16,858	16,858																				
	Karimenu Dam Storage	23,328	m3	3,509		1,754	1,754																				
	Ruiru Dam Storage	38,880	"	5,848		2,924	2,924																				
	NCWSC I Storage	9,000	"	1,354		677	677																				
	NCWSC II Storage	9,000	"	1,354							677	677						0									
				66,010																							
3.	**KARURI**			**30,850**	**0**	**8,811**	**8,811**	**0**	**0**	**0**	**6,614**	**6,614**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-13,517**
	Pipes	**1,083**		8,512		4,256	4,256	0	0	0																	
	WTW & Storage																										
	WTW works I	16,500	m3/d	7,154		3,577	3,577																				
	WTW works 2	26,000	"	11,274							5,637	5,637															
	Storage 1	13,000	m3/d	1,955		978	978																				
	Storage 2	13,000	"	1,955							978	978															
				22,339																							
4.	**RUIRU-JUJA**			**62,349**	**0**	**22,661**	**22,661**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8,514**	**8,514**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-32,470**
	Pipes & tunnel																										
	NCWSC I	2,417	m3/h	16,120		8,060	8,060																				
	NCWSC II	2,417	"	12,666												6,333	6,333										
	Transfer tunnel	2,417	"	24,839		12,420	12,420																				
				53,625																							
	Storage																										
	NCWSC Storage 1	29,000	m3/h	4,362		2,181	2,181																				
	NCWSC Storage 2	29,000	"	4,362												0	2,181	2,181	0								
				8,723																							

Item	Satellite Town	Capacity	Unit	BULK SUPPLY Total initial capital cost US$'000	Expenditure accounts by years 2012 constant prices *Totals including contingencies & replacement costs* 2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
5.	**MAVOKO**			**26,675**	**0**	**6,138**	**6,138**	**0**	**0**	**0**	**0**	**0**	**0**	**7,200**	**7,200**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	-13,621
	Pipes																										
	NCWSC I	917	m3/h	9,568.1		4,784	4,784	0	0	0																	
	NCWSC II	1,500	"	11,692.7										5,846	5,846	0											
				21,261																							
	Storage																										
	NCWSC Storage 1	18,000	m3/h	2,707		1,354	1,354	0	0	0																	
	NCWSC Storage 2	18,000	"	2,707										1,354	1,354	0	0										
				5,415																							
6.	**NGONG ET AL**			**12,705**	**0**	**3,172**	**3,172**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3,045**	**3,316**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-6,792**
	Pipes & Pumps																										
	NCWSC I	750	m3/h	6,344.4		3,172	3,172	0	0	0																	
	NCWSC II	750	"	6,090.0												0	3,045	3,045	0								
	Booster pump #2	18,000	m3/d	271.0													**0**	**271**									
				12,705																							
7.	**THIKA TOWN**			**64,178**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**23,776**	**23,776**	**16,625**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-41,565**
	Thika 3A dam	40,000	m3/d	49,185								16,395	16,395	16,395													
	Pipes & pump	1,000	m3/h	2,782								1,276	1,276	230	0	0	0	0									
	WTW & Storage																										
	WTW	24,000	m3/d	10,406								5,203	5,203	0	0			0									
	Storage	12,000	m3	1,805								902	902														
8.	**LIMURU**			**5,476**	**2,543**	**0**	**0**	**0**	**0**	**0**	**2,543**	**0**	**0**	**0**	**130**	**0**	**0**	**0**	**0**	**0**	**130**	**0**	**0**	**0**	**130**	**0**	**-636**
	Boreholes & Storage																										
	Stage 1	4,000	m3/d	2,543	**2,543**	**0**	0																				
	Stage 2	4,000	"	2,543							2,543	0															
	Pump replacement			390											130		0				130	0			130		-636
9.	**GITHUNGURI**			**3,261**	**1,533**	**0**	**0**	**0**	**1,533**	**0**	**0**	**0**	**0**	**0**	**65**	**0**	**0**	**0**	**65**	**0**	**0**	**0**	**0**	**0**	**65**	**0**	**-230**
	Boreholes & Storage																										
	Stage 1	2,000	m3/d	1,533	1,533																						
	Stage 2	2,000	"	1,533					1,533			0															
	Pump replacement			195											65		0		65			0			65		
10.	**GATUNDU**			**977**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**977**	**0**	**0**	**0**	**0**	**-781**
	Boreholes & Storage																										
	Stage 1	740	m3/d	977																		977	0				
11.	**TALA-KANGUNDO**			**3,316**	**1,553**	**0**	**0**	**0**	**1,553**	**0**	**0**	**0**	**0**	**0**	**70**	**0**	**0**	**0**	**70**	**0**	**0**	**0**	**0**	**0**	**70**	**0**	**-233**
	Boreholes & Storage																										
	Stage 1	1,800	m3/d	1,553	1,553		0																				
	Stage 2	1,800	"	1,553					1,553				0														
	Pump replacement			210											70		0		70						70		
	TOTAL			**1,096,686**	**5,629**	**217,307**	**217,307**	**170,540**	**90,945**	**87,859**	**9,835**	**31,068**	**23,776**	**23,825**	**7,465**	**8,514**	**11,677**	**3,636**	**135**	**0**	**34,395**	**78,907**	**73,601**	**0**	**265**	**0**	**-626,695**

Notes

(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision

(ii) No financial contingencies included

Table 9-37: Summary of Implementation & Capital Expenditure for Mixed Supply

Item	Satellite Town	Capacity	Unit	MIXED Total initial capital cost US$'000	Expenditure accounts by years 2012 constant prices *Totals including contingencies & replacement costs* 2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
NAIROBI BULK SUPPLY TO SATELLITE TOWNS				**185,796**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**34,265**	**77,930**	**73,601**	**0**	**0**	
	Chania-Komu Transfer																										
	Tunnel	7,560	m3/h	17,314																		4,328	8,657	4,328			
	Pipes	7,560	"	72,205																		24,068	24,068	24,068			
	Pumps	181,440	m3/d	9,756																		3,252	3,252	3,252			
	Storage	50,000	m3	7,849																		2,616	2,616	2,616			
				107,124																							
	Chania-Komu WTW																										
	WTW	181,440	m3/d	**78,672**																			39,336	39,336			
1.	**KIKUYU**			**87,983**	**3,498**	**29,188**	**29,188**	**20,261**	**0**	**0**	**0**	**0**	**3,498**	**0**	**140**	**0**	**830**	**830**	**271**	**0**	**0**	**0**	**140**	**0**	**140**	**0**	**-40,899**
	Boreholes																										
	Stage 1	9,000	m3/d	3,498	3,498	0	0	0																			
	Stage 2	9,000		3,498								0	3,498	0													
	Pump replacement			421											140								140		140		
	Dam - Kamiti	16,416	m3/d	**60,783**		20,261	20,261	20,261	0	0																	
	Pipes & booster pump	833	m3/h	11,390		4,729	4,729		0								830	830	271	0	0	0					
	WTW & Storage																										
	Kamiti Dam 1 - WTW	16,500	m3/d	7,154.4		3,577	3,577			0																	
	Kamiti Dam 1 - storage	8,250	m3	1,240.8		620	620																				
				8,395.2																							
2.	**KIAMBU**			**70,215**	**0**	**21,631**	**21,631**	**17,849**	**0**	**0**	**0**	**0**	**0**	**0**	**4,553**	**4,553**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-36,955**
	Dam - Ruiru (27% share)			53,546		17,849	17,849	17,849	0	0																	
	Pipes	875	n3/h (max	1,120		560	560	0	0	0																	
	WTW & Storage																										
	Ruiru WTW (share)	12,000	m3/d	5,203		2,602	2,602																				
	Ruiru Dam WTW	21,000	"	9,106											4,553	4,553	0										
	Karimenu Dam Storage	8,250	m3	1,241		620	620																				
				15,550																							
3.	**KARURI**			**125,139**	**0**	**43,530**	**43,530**	**25,810**	**0**	**0**	**0**	**0**	**0**	**0**	**5,994**	**5,994**	**280**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-61,375**
	Dam - Ruiru (39% shar	30,000	m3/d	76,494		25,498	25,498	25,498	0	0																	
	Pipes	3,238	n3/h (max	27,669		13,835	13,835		0	0									0								
	Pumps	1,250	m3/h	592				312									280										
	WTW & Storage																										
	WTW works 1	16,500	m3/d	7,154		3,577	3,577	0	0	0																	
	WTW works 2	26,000	"	11,274											5,637	5,637											
	Storage 1	8,250	m3	1,241		620	620																				
	Storage 2	4,750	"	714											357	357											
4.	**RUIRU-JUJA**			**205,375**	**0**	**40,481**	**40,481**	**16,234**	**0**	**0**	**0**	**0**	**0**	**35,113**	**41,905**	**29,486**	**0**	**0**	**837**	**837**	**0**	**0**	**0**	**0**	**0**	**0**	**-121,112**
	Dams																										
	Ruiru dam (34% share)		m3/d	68,080										22,693	22,693	22,693											
	Karimenu dam	46,656	"	48,702		16,234	16,234	16,234	0																		
				116,782																							
	Pipes & tunnel																										
	Karimenu 2	1,944	m3/h	24,755		12,377	12,377																				
	Ndarugu Pipeline	1,583	"	1,674															837	837							
	Nduire Transfer Tunnell	2,000	"	24,839										12,420	12,420	0											
				51,268																							
	WTW & Storage																										
	WTW stage 1	46,656	m3/d	20,230		10,115	10,115	0	0	0	0																
	WTW stage 2	26,700	"	11,577										-	5,789	5,789	0	0									
	NCWSC Storage 1	23,328	m3	3,509		1,754	1,754	0	0	0																	
	NCWSC Storage 2	13,350	m3	2,008											1,004	1,004	0	0									
				37,324																							

Item	Satellite Town	Capacity	Unit	MIXED Total initial capital cost US$'000	Expenditure accounts by years 2012 constant prices *Totals including contingencies & replacement costs* 2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
5.	**MAVOKO**			**110,417**	**0**	**31,291**	**31,291**	**18,963**	**0**	**0**	**0**	**0**	**0**	**0**	**13,868**	**13,868**	**0**	**457**	**0**	**0**	**0**	**0**	**678**	**0**	**0**	**0**	-57,157
	Dam - Stony Athi	60,480	m3/d	55,364		18,455	18,455	18,455	0	0																	
	Pipes & Booster Pump																										
	Stony Dam	2,520	m3/h	5,744		2,533	2,533			0													678				
	Booster pump 1	2,520	"	965				508							0	0	0	457	0								
	WTW & Storage																										
	WTW 1	40,500	m3/d	17,561		8,780	8,780																				
	WTW 2	60,500	"	26,233											13,116	13,116	0										
	Storage 1	20,250	m3	3,046		1,523	1,523																				
	Storage 2	10,000	"	1,504										0	752	752											
6.	**NGONG ET AL**			**9,173**	**0**	**0**	**2,268**	**3,429**	**3,429**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**49**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-2,971**
	Wellfield	2,500	m3/d	2,268		0	2,268	0	0	0																	
	Pipes & Pumps																										
	Kiserian Dam	625	m3/h	-																							
	Kabete Tank	1,375	"	6,857			0	3,429	3,429	0	0	0								0	0	0	0	0			
	Booster pump #1	15,000	"	49													49										
7.	**THIKA TOWN**			**64,178**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**23,776**	**23,776**	**16,625**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-41,719**
	Thika 3A dam	40,000	m3/d	49,185								16,395	16,395	16,395	0	0	0	0									
	Pipes & pump	1,000	m3/h	2,782								1,276	1,276	230	0	0	0	0									
	WTW & Storage																										
	WTW	24,000	m3/d	10,406								5,203	5,203	0	0	0	0	0									
	Storage	12,000	m3	1,805								902	902														
8.	**LIMURU**			**5,476**	**2,543**	**0**	**0**	**0**	**0**	**0**	**2,543**	**0**	**0**	**0**	**130**	**0**	**0**	**0**	**0**	**0**	**130**	**0**	**0**	**0**	**130**	**0**	**-636**
	Boreholes & Storage																										
	Stage 1	4,000	m3/d	2,543	**2,543**	**0**	0																				
	Stage 2	4,000	"	2,543							2,543	0															
	Pump replacement			390											130		0				130	0			130		-636
9.	**GITHUNGURI**			**3,261**	**1,533**	**0**	**0**	**0**	**1,533**	**0**	**0**	**0**	**0**	**0**	**65**	**0**	**0**	**0**	**65**	**0**	**0**	**0**	**0**	**0**	**65**	**0**	**-230**
	Boreholes & Storage																										
	Stage 1	2,000	m3/d	1,533	1,533		0																				
	Stage 2	2,000	"	1,533					1,533			0															
	Pump replacement			195											65		0		65			0			65		
10.	**GATUNDU**			**977**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**977**	**0**	**0**	**0**	**0**	**-781**
	Boreholes & Storage	740	m3/d	977																		977	0				
11.	**TALA-KANGUNDO**			**3,316**	**1,553**	**0**	**0**	**0**	**1,553**	**0**	**0**	**0**	**0**	**0**	**70**	**0**	**0**	**0**	**70**	**0**	**0**	**0**	**0**	**0**	**70**	**0**	**-233**
	Boreholes & Storage																										
	Stage 1	1,800	m3/d	1,553	1,553		0						0														
	Stage 2	1,800	"	1,553					1,553																		
	Pump replacement			210											70				70						70		
	TOTAL			**871,306**	**9,127**	**166,121**	**168,388**	**102,545**	**6,515**	**0**	**2,543**	**23,776**	**27,274**	**51,738**	**66,726**	**53,901**	**1,159**	**1,287**	**1,243**	**837**	**130**	**35,242**	**78,748**	**73,601**	**405**	**0**	**-364,069**

Notes

(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision

(ii) No financial contingencies included

Comparison of Investment Options

The results of the Least Cost Analysis of the three Options are shown in Table 9-38. This is based on the estimated capital and O&M costs for supplying sufficient water to meet the projected demand over the economic planning period 2013– 2035. The cash flow of costs and the additional quantity water supplied per year have been discounted to a present value using a discount rate of 5%, the rate that was stipulated by the World Bank to use for the analysis as being representative of the long-run opportunity cost of capital for water supply development in Kenya.

Table 9-38: Results of Least Cost Analysis

Item		Independent	Strategic	Mixed
Capital costs	US$ mill	1,214.17	1,096.69	871.31
PV of Capex	US$ mill	601.38	615.46	434.09
PV of O&M costs				
PV of O&M costs fixed	US$ mill	80.75	95.63	66.28
PV of O&M variable	"	55.89	41.77	51.18
PV of O&M all	"	136.64	137.40	117.46
PV of all Costs	**US$ mill**	**738.02**	**752.85**	**551.55**
PV of additional water supply	US$ mill	743.11	769.87	765.41
AIEC	**US$/m^3**	**0.99**	**0.98**	**0.72**
	KES/m^3	89	88	65

Notes

i) PVEC= Present Value of economic costs

ii) AIEC = Average Incremental Economic Cost = discounted cost/discounted value of water

iii) USD:Ksh exchange rate 90

iv) Discount Rate = 5%

The Independent Option has the highest total capital costs almost US$1.214 billion, 39% more than the Mixed Option, which has the lowest capital costs of US$871.3 million. The Strategic Option has total capital costs of US$1.097 billion. In terms of the present value of capex the lowest is for the Mixed Option. The Independent Option is less than the Strategic Option on account of slower build-up of capital costs for independent supply as the infrastructure is developed on a more piecemeal basis over a longer time to meet increasing demand for water. On the other hand the capital cost of building the four dams needed to supply bulk water for the Strategic Option is front-loaded and incurred in the first five years of the programme.

The PV of O&M costs is also lowest for the Mixed Supply Option, while the Independent and Strategic Supply Options have a similar PV. The Strategic Supply Option does incur relatively high pumping costs for Chania-Komu transfer system because of the high pumping heads involved, but as these pumping costs would not begin until 2032 when the transfer scheme comes on stream, consequently these higher variable costs do not affect the PV of variable O&M costs significantly.

The PV of the additional water supplied is highest for the Strategic and Mixed Supply Options, mostly because of the higher additional volumes provided from new schemes as other existing sources are retired. The PV of all costs (capex and opex) is highest for the Strategic Supply Option and lowest for the Mixed Supply Option, varying between US$552 million for this Option to US$752 million for the Strategic Supply Option.

The AIEC, expressed as US$/m^3 is markedly lower for the Mixed Option at US$0.72 (KES65), compared with values similar values of US$0.99 and US$0.98/m^3 for the Independent and Strategic Options respectively.

Overall the results of the least cost analysis clearly shows that the Mixed Supply Option is the most favourable having an AIEC that is 27% less than the other two Options. Therefore it can be concluded that Mixed Supply Option is preferred by the least cost analysis.

11.10 Sensitivity Analysis

A sensitivity test has been carried out on the key factors, capex and opex costs and the discount factor. The base case has been analysed with a discount factor of 5%, being considered as the economic opportunity cost of capital for water supply projects in Kenya by international funding agencies. To test the effect of a range of discount rates the AIEC for each scenario has been calculated for discount factors of both 3% and 8%. The sensitivity to changes in capital and operating costs is also tested. The results are shown in Table 9-39.

Table 9-39: Results of Sensitivity Analysis

Item		Independent	Strategic	Mixed
Discount factor	*5%*			
Present value of cost (PVEC)	MUSD	738	752	552
Present value of water	Mm^3	743	769	765
Ave. incremental economic cost (AIEC)	US$/m^3	0.99	0.98	0.72
Capex increase 20% AIEC	US$/m^3	1.16	1.14	0.83
Capex decrease 20% AIEC	"	0.83	0.82	0.61
Opex increase 20% AIEC	US$/m^3	1.03	1.01	0.75
Opex decrease 20% AIEC	"	0.96	0.94	0.69
AIEC with discount factor of 8%	US$/m^3	1.34	1.33	0.96
AIEC with discount factor of 3%	"	0.78	0.76	0.57

For each of the factors considered, the ranking of the Options remains similar, with the Mixed Supply Option maintaining its advantage over the other two Options at all the three discount rates applied.

12 Environmental Impacts

12.1 Introduction

The development of bulk water sources to supply Nairobi and Satellite Towns will impact on the general water resources balance in the region as a whole. In particular, upstream abstraction or storage of water will inevitably result in a reduction of available water resources in downstream areas. The chosen development scenario, considered as the priority strategy to meet the 2017 water demand for Nairobi, includes two initial phases for which potential environmental impacts are assessed in the Preliminary Design and Feasibility Study (2012). These are:

- Phase 1: Groundwater development in Kiunyu area (2014) then in Ruiru area (2015);
- Phase 2: Northern Collector Tunnel Phase I from Maragua, Gikigie and Irati Rivers to Thika reservoir (2016)

Further development following 2017 includes the development of the Northern Collector Tunnel Phase 2, Maragua 4 Dam, Ndarugu 1 Dam and Chania-Komu transfer to Ndarugu 1 Dam, as well as a range of options for the development of additional water sources for the Satellite Towns. The potential development options for the Satellite Towns are summarised according to three potential development strategies:

1. Independent Water Supply Option
    - No sharing of resource developments between the demand centres.
    - Existing connections from Nairobi transmission pipelines to Satellite Towns to be disconnected.
    - Independent sources to be developed for each of the demand centres.
    - Groundwater development considered where no local surface water sources are available
2. Strategic Water Supply Option
    - Existing local water supply schemes maintained but unreliable and uneconomical schemes to be abandoned where there is a capacity for supply from strategic sources.
    - Future supplies limited to strategic sources.
    - Groundwater development considered in areas where found uneconomical to supply from strategic sources (e.g. higher altitude or remote demand centres)
3. Mixed Water Supply Option
    - Supply from local sources to be considered as a priority.
    - Storage (e.g. in local reservoirs) to augment existing local run of river schemes.
    - Groundwater development considered where inadequate or no local surface water sources are available.
    - Supply from strategic sources provided to supplement the local sources. Existing NCWSC Bulk Supply water sources via pipelines to some satellite towns water supply schemes will be continued and developed.

The strategic water sources are the major resource developments which can provide bulk supply to demand centres economically when compared to the alternative local sources. They have a high capital investment but will offer a good return of capital. These strategic sources will require an extensive network of distribution pipelines, with pumping necessary where gravity feed is not possible. The proposal is that the strategic sources are to be developed and

operated under the Nairobi City Water and Sewerage Company which will then provide bulk sales to the various water supply operators in the Satellite Towns surrounding Nairobi.

12.1.1 Sustainable Development

Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future. The underlying concept of sustainable development is an essential component and needs to form the background to development strategies that have long-term time frames. The concept of sustainability considers three inter-related pillars of sustainable development: the social, economic and biophysical or environmental dimensions (Figure 9-34). For any given development option or project to be sustainable, it must (i) incorporate a sound economic basis, (ii) demonstrate social acceptability and soundness, and (iii) maintain long-term ecological integrity within a framework of good governance. All three of these essential dimensions of sustainability need to be taken into account when assessing proposed options or project components. These three dimensions are seldom in perfect balance, often dictated by local circumstances. Nevertheless, the balance between these three dimensions needs to be maintained. In particular, if subsequent restoration of environmental functions is required (e.g. correcting inadequate release of downstream flows), this may be both costly and time consuming. Restoration is an expensive and time-consuming process that can itself cause further damaging changes if not managed correctly. An internationally important case study related to Payment for Environmental Services, from the Lake Naivasha Basin, outlined in Box 1, is also highly relevant.

Key sustainability principles include:

- Development must not irretrievably degrade the natural, built, social, economic and governance resources on which it is based. It must also be recognised that once critical environmental functions are degraded it is both difficult and costly to restore them.
- Development activities should not cause irreversible damage to natural and other resources, including for example watershed protection or agricultural development, as this potentially precludes sustainable options.
- Where there are uncertainties about the impact of activities on the environment, caution should be exercised in favour of the environment.
- Land use and environmental planning need to be integrated.
- Immediate and long-term actions need to be identified and planned for, so that urgent needs can be met while still progressing towards longer-term sustainable solutions.

Water resources are key components of sustainable development, and sustainable development goals will need to be incorporated in the long-term development strategies for water supplies for Nairobi City and Satellite Towns. At Rio+20, the United Nations Conference on Sustainable Development (Rio de Janeiro, Brazil, 20-22 June 2012), a set of sustainable development goals, principles, and international commitments in the area of water and sanitation were developed that will pave the way toward a global framework built on lessons learned from the Millennium Development Goals (which expire in 2015).

As part of the Outcome of the Rio+20 Conference, “The Future we want” (June 2012), within the thematic areas and cross-sectoral issues developed under the framework for action and follow-up, a number of key points related to Water and Sanitation are included (see Box 2).

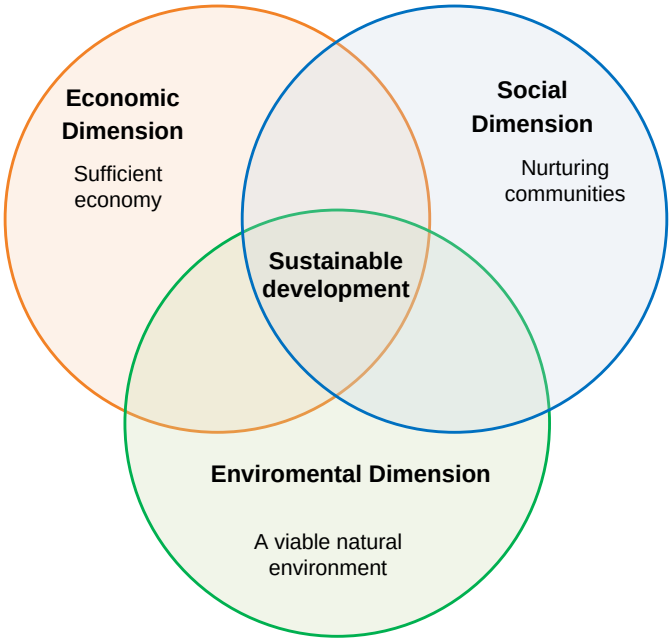


Figure 9-34: The Three Pillars of Sustainable Development

Box 1.
Payment for Environmental Services (PES) pilot project in Lake Naivasha Basin, Kenya

Significant environmental threats result from poor land-use practices within the watershed, unregulated and excessive water abstraction for domestic and agricultural and horticultural use, and population pressure on natural resources, and water pollution. These have resulted in degradation of ecosystem services, economic losses, worsening poverty and reduction of biodiversity.

In an important pilot PES project in Lake Naivasha basin, the local water resources users association, formed mainly of flower and vegetable growers, compensates upstream small-scale landowners for managing their land to provide good quality water to downstream users. The scheme has reduced environmental threats as well as provided livelihood improvements to participating communities.

Payment for Environmental Services (PES) is a market-based mechanism where land owners are rewarded by service beneficiaries. It is based on the premise that land owners undertake land use transformations that provide agreed ecosystem services. For these services, they are rewarded financially by the beneficiaries. This case study demonstrates how economic incentives for both ecosystem service buyers and sellers can be used to achieve significant land and water-management improvements.

It is recommended that a similar set of PES mechanisms be developed in order to improve water quality and provide improved ecosystem services for both the existing water sources and the proposed water sources for the satellite towns, including the watersheds of the proposed storage reservoirs.

Upstream abstractions of water for supply of water resources to Nairobi and satellite towns will result in a loss of water resources available for use by downstream communities, and in reduced environmental services. Similar market-based mechanisms should therefore also be used to compensate losses to downstream communities and as a mechanism for preservation of ecosystem services.

Box 2
Rio+20 Conference on Sustainable Development
Outcome of the Conference,
the Future we want,
June 2012.

Action points related to water resources.

Water and Sanitation

119. We recognize that water is at the core of sustainable development as it is closely linked to a number of key global challenges. We therefore reiterate the importance of integrating water in sustainable development and underline the critical importance of water and sanitation within the three dimensions of sustainable development.

120. We reaffirm the commitments made in the Johannesburg Plan of Implementation and the Millennium Declaration regarding halving by 2015 the proportion of people without access to safe drinking water and basic sanitation and the development of integrated water resource management and water efficiency plans, ensuring sustainable water use. We commit to the progressive realization of access to safe and affordable drinking water and basic sanitation for all, as necessary for poverty eradication, the empowerment of women and to protect human health, and to significantly improve the implementation of integrated water resource management at all levels as appropriate. In this regard, we reiterate the commitments to support these efforts, in particular for developing countries, through the mobilization of resources from all sources, capacity-building and technology transfer.

121. We reaffirm our commitments regarding the human right to safe drinking water and sanitation, to be progressively realized for our populations with full respect for national sovereignty. We also highlight our commitment to the 2005-2015 International Decade for Action, “Water for Life”.

122. We recognize the key role that ecosystems play in maintaining water quantity and quality and support actions within respective national boundaries to protect and sustainably manage these ecosystems.

123. We underline the need to adopt measures to address floods, droughts and water scarcity, addressing the balance between water supply and demand, including, where appropriate, non-conventional water resources, and to mobilize financial resources and investment in infrastructure for water and sanitation services, in accordance with national priorities.

124. We stress the need to adopt measures to significantly reduce water pollution and increase water quality, significantly improve wastewater treatment and water efficiency and reduce water losses. In order to achieve this, we stress the need for international assistance and cooperation.

The Future We Want: Outcome document adopted at Rio+20, available at:
http://www.un.org/en/sustainablefuture/index.shtml

The importance of food security is of increasing concern, both nationally and internationally. A recent report on the future of food and farming[1] highlighted the importance of maintaining biodiversity as one of the five major challenges for policy makers.

There is an important and critical interrelationship between food production, biodiversity and ecosystem services. The report emphasises how land and aquatic ecosystems used in food production need to be managed to achieve multiple goals, including biodiversity and ecosystem services. It also argues for the need to improve linkages between policies relating to the food system, and to the environment, at all levels – from landscape to global systems – and the critical importance of developing incentives for best practice. Food production requires ecosystem services, which are typically uncosted, and these are provided by land and aquatic ecosystems that are not primarily managed for food production.

The role of aquatic ecosystems is clearly important for food production and the mitigation of potential impacts of upstream abstraction and diversion of water to the Northern Collector Tunnel (Phases 1 and 2) will need to recognise the future requirements for food production in the Nairobi area.

The Future of Food and Farming Report also emphasises the importance of implementing realistic minimum environmental flows. The requirement to maintain minimum environmental flows in rivers is considered as the single most important competing demand for water that agriculture faces. Minimum flows are needed both to maintain aquatic ecosystem services and to preserve biodiversity. Often they are set at only a small percentage of the original natural flow (and may involve periods of no or very little flow). Many scientists argue that they need to be raised, often significantly so, hence increasing the need for water efficiency in agriculture and other demands on the water supply systems. The development of integrated water management can provide multiple benefits for food production, rural incomes and biodiversity.

Box 3.
The Future of Food and Farming.
Key conclusions and challenges for policy makers.

A. Balancing future demand and supply sustainably – to ensure that food supplies are affordable.
B. Ensuring that there is adequate stability in food supplies – and protecting the most vulnerable from the volatility that does occur.
C. Achieving global access to food and ending hunger. This recognises that producing enough food in the world so that everyone can potentially be fed is not the same thing as ensuring food security for all.
D. Managing the contribution of the food system to the mitigation of climate change.
E. Maintaining biodiversity and ecosystem services while feeding the world

[1] Forecast (2011). The Future of Food and Farming: Challenges and choices for global sustainability. Final Project Report. The Government Office for Science, London.

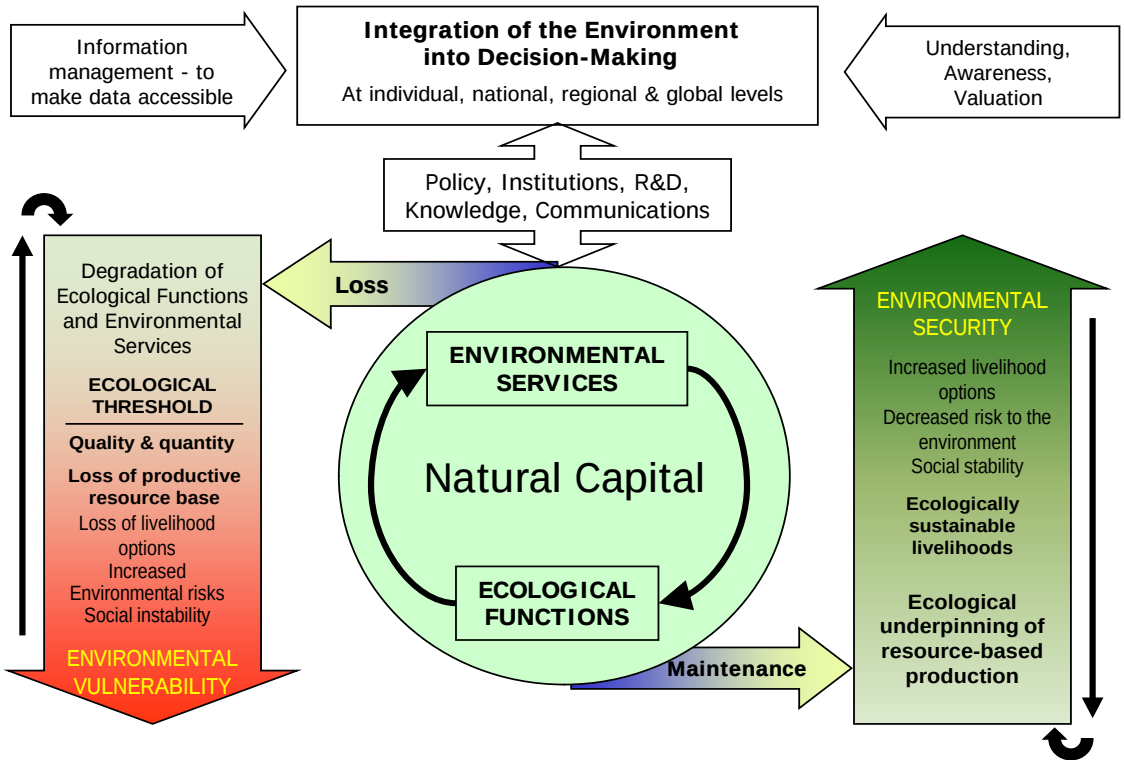
The following Policy Message and Recommendation from the "Kenya, State of the Environment and Outlook 2010" Report[2] are also particularly relevant when considering the requirements for operating rules for downstream Reserve Flows below the abstraction sites, and below storage reservoirs.

Policy message: *Given the linkages between water and human and environmental health as well as the major sectors of the economy, access to clean and safe water in adequate quantities is a prerequisite for the attainment of Vision 2030. It is therefore vital that measures are urgently instituted to address the water scarcity challenge that the country is currently grappling with especially in light of the fact that this crisis is projected to rapidly worsen as population increases and climate change and their derivative effects take their toll.*

Recommendation: *Ground the concept of integrated water resources management (IWRM) which takes cognizance of the multi-faceted nature of water problems and calls for comprehensive management of water resources based on an ecosystem approach and an appreciation of the needs of the diverse users and the broad range of potential impacts of water use.*

The importance of integration of the environment into decision making is also illustrated in the following diagram that outlines the importance of environmental services and ecological functions.

Figure 9-35: Integration of the Environment into Decision Making



[2] NEMA (2011). KENYA State of Environment and Outlook 2010. Supporting the Delivery of Vision 2010. Summary for Decision Makers. National Environment Management Authority, Kenya

12.2 Potential Environmental Impacts

Initial options for Phases 1 and 2 involve the development of two well fields at Kiunyu and Ruiru to supply groundwater and development of the Northern Collector Phase 1. Groundwater can be developed faster, but it is not yet a proven resource and requires further investigation that will be funded under WaSSIP additional financing. Phase 2 involves the development of the Northern Collector Tunnel and intake sites on the three rivers: Maragua, Gikigie and Irati, with abstraction and diversion of water to Thika Reservoir. These developments are expected to increase Nairobi water supply by 50% over current supply levels by 2017. Subsequent developments for Nairobi City and Satellite Towns include the development of additional groundwater resources, river diversions and storage reservoirs, according to three different long-term development strategies.

Environmental and social impacts resulting from the proposed groundwater wells, the proposed diversion of water for the Nairobi water supply via the Northern Collector Tunnel, and the construction of a series of storage reservoirs, will include a variety of impacts related to:

i. Impacts from drilling for groundwater, including noise, and accidental spillage, as well as the clearance of vegetation for site establishment and associated impacts on agricultural land;

ii. Long-term degradation of aquifers, and changes in groundwater contribution to base flows in rivers, as well as consequent reduction in local water sources available from springs and dug wells;

iii. Construction of weirs, tunnels and associated structures for the Northern Collector Tunnel, including the disposal of spoil;

iv. Construction of a number of storage dams, resulting in loss of land areas through flooding,

v. Construction of transmission pipelines, as well as maintenance of these facilities;

vi. Construction of treatment works;

vii. Operation of these systems, including upstream impacts that may be necessary to maintain watersheds in appropriate condition (watershed maintenance should result in positive environmental impacts);

viii. Changes to the downstream hydrology of the river basins as a result of reduced flow in the rivers downstream of the intakes, and downstream of reservoirs, in particular a significant reduction in the availability of downstream water resources, and

ix. Cumulative impacts. Effects from different activities may interact to cause additional effects not initially apparent when considering the individual developments, and there may also be synergistic interaction between a range of different factors.

Of these, the major environmental and social impacts are considered to be related to the reduced downstream flows. Proposed Compensation Flows from intakes along the Northern Collector Tunnel (Phase I) are set at Q95 levels. This level of flow is equivalent to extreme low flow conditions in impacted downstream areas.

Cumulative impacts are important considerations and may arise from additional factors or developments not directly related to the development of water sources. Effects from a wide range of different activities may interact to cause additional effects not initially apparent when considering the individual changes. There may also be synergistic interaction between different factors. For example, it is considered likely that long-term increases in the international cost of

crude oil, and hence fuel costs, will result in reduced travel between Nairobi and adjacent residential areas, with changes in demands for water resources (doubling time for crude oil costs is currently about 5 years). Similarly, climate change is likely to result in long-term changes and it is considered essential that mechanisms for dealing with such changes are incorporated in future environmental monitoring and management plans.

Impacts considered to be related to Phases 1 and 2 and the chosen development scenario considered as the priority strategy to meet the 2017 water demand for Nairobi are discussed in detail in the reports on Preliminary EIA for the Selected Scenario: Nairobi Water Sources, Phases 1 & 2 (2011), and in the Preliminary Design and Feasibility Study (2012). Summaries are presented below. Potential impacts related to subsequent phases of development for water supplies for Nairobi City, Nairobi effective water demand area, and Satellite Towns, up to the year 2035 are discussed below as environmental impact scoping of potential development options.

A key concern is the requirement to maintain adequate downstream Reserve Flows. In order that this can be accomplished it is considered very important that the flows from all water sources are monitored on a regular (daily) basis, including both upstream and downstream flows. The existing network of river gauges is considered inadequate for this task, especially when considering the potential extensive network of reservoirs and river diversions required in order to satisfy the water supply demands for Satellite Towns. It is therefore considered essential that there is a comprehensive development programme designed and implemented to update the existing river gauge network and extend this so that all rivers are fully monitored both upstream and downstream of all potential developments.

The water supplies for rural households are often overlooked in the development of adjacent urban water supplies. In 2008, open surface water was recorded as a major source of drinking water for Kenyan rural households[3], with 31.3% of rural households recorded as using surface water as the source of drinking water. As an example, those Districts directly impacted by the reduced downstream flows in Maragua, Gikigie and Irati Rivers (resulting from the development of the Northern Collector Phase I) will be Muranga North and Muranga South. Within these districts the 2009 National Census recorded 49.5% and 38.3% of households using rivers and streams as their water source. Reduced downstream flows resulting from the release of Reserve Flows based on Q95 flow levels will result in inevitable and potentially serious negative impacts on those households that rely on these open surface water sources. Impacts will include reduced availability of water as well as health risks resulting from potential changes in water quality linked to lower flow rates.

It is therefore considered important that the requirements of all rural households are fully incorporated in the long-term plans for water supplies for Nairobi and satellite towns.

The key construction impacts relate to the loss of terrestrial habitat, much of it on a permanent basis, and disruptions to riverine ecosystems at potential reservoir sites and downstream of each of these for some distance. While these construction impacts can be managed and mitigated, the effects are real. Furthermore, during construction, there are a range of potential impacts, including an influx of people and related social problems (for example, informal housing and inadequate services) and anti-social behaviour (for example, prostitution, and

[3] Kenya Demographic and Health Survey 2008-09. Central Bureau of Statistics, Nairobi, Kenya

crime), increased road traffic, including heavy construction vehicles, dust and noise for nearby landowners, including communities living adjacent to pipeline routes.

Compensation will be required for those landowners within potential reservoir areas and for those with infrastructure and/or agricultural land areas affected by the construction of the pipelines. This will require significant administration and negotiation in order not to delay progress.

12.3 Environmental Flows

Environmental flows provide the flow regime required for maintaining downstream river ecosystems in a healthy condition, and for maintaining riverine ecosystems and their ecosystem benefits. Natural flow variability is one of the most important components of any healthy river. It is not only the amount of water in a stream, but its variability that supports species, habitats, and environmental processes. Earlier efforts at defining in-stream flow requirements led to the development and setting of minimum flows. Application of these methods usually resulted in a single fixed minimum flow value, below which water may not be withdrawn for consumptive use.

In practice these minimum flow values are almost always less than optimal. There is a growing international consensus (Hirji and Lintner, 2010)[4] that environmental flows should be described in terms of seasonal low flows, as well as the magnitude, timing and duration of flood events. It is the variable flow regime that is important, rather than a fixed minimum flow. A full range of natural hydrologic regimes is considered as an essential element for sustaining the riverine environment.

It is now also recognised that *Minimum Flow Standards tend to provide Minimum Protection*.

Four guiding principles about the influence of flow regimes on aquatic biodiversity are recognised.

- *Principle 1:* Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biological composition.
- *Principle 2*: Aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes.
- *Principle 3*: Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species.
- *Principle 4*: Alteration of flow regimes is likely to facilitate the invasion and success of exotic and introduced species in rivers. Increase in exotic species is likely to have a negative impact on indigenous species.

The presence of adequate high and low flow pulses is an important indicator of the health of an aquatic community. A single, minimum, threshold flow, with the exclusion of other ecologically relevant flows, is no longer a scientifically accepted approach to instream flow management. “Flatlining” is a descriptive term that illustrates the removal of the flow variation in a river, thereby reducing it to a low, constant flow, essentially a permanent drought flow. By removing variability in stream flow, aquatic habitats and water quality are degraded. Reduced flows, and

[4] Rafik Hirji and Stephen F. Lintner (2010) Environmental Flow Assessments to Conserve Aquatic Ecosystems: World Bank Experience, Washington, DC: The World Bank.

the reduced variability of flow, also affect a stream's ability to provide a range of ecosystem services, including the ability to assimilate pollutants.

Ecosystem services are defined as a variety of culturally and socially valued goods and services that human society derives from natural ecosystems. The important ecosystem services provided by rivers are disrupted by changes in the volume, quality, and pattern of flows downstream of development activities. It is now recognised that subjecting an environment to constant low flow conditions, will have inevitable negative consequences for all downstream environments and users dependent on these systems, resulting in reduced availability of water, deterioration of habitats, significant loss of aquatic life, both plant and animal, and in reduced ecosystem services such as regulation of water quality.

Water management problem solving has now matured from the setting of fixed minimum flows to a recognition of the need to set incremental methods in which the requirement of aquatic habitats are quantified as a function of discharge.

In the absence of detailed long-term ecological studies (often focused only on individual species) the widely used index for determining minimum Environmental Flow Release (EFR) requirements is the index of natural low flow, Q95. However, release of a constant Q95 flow is similar to a constant extreme low flow – or a constant drought flow. Q95 flows are therefore seen as the minimum flow, beyond which abstraction must not occur, and it is strongly recommended that environmental flows should not be defined as constant releases but should be variable in a manner that is similar to the natural hydrograph on a seasonal basis.

Inevitably, in relatively dry periods, for example 1975 – 1976, dry season natural flows may at times be less than the required downstream environmental flow and compensation flow release. Under such conditions abstraction at intake sites should not be allowed.

In contrast during normal or relatively wet periods, for example 1997-1998, almost all daily flows can be expected to be greater than the Q95 flow, including for much of the dry season. Under these circumstances significant downstream flows may be available during the wet seasons after all diversions and extractions have been accounted for.

If the release of environmental flows is limited to only Q95 flows, without supplementary higher flows, there will be unacceptable negative environmental impacts downstream of the intakes along the Northern Collector tunnel.

Natural flows include the following components:

1. Extreme Low Flows, (also known as Subsistence Flows)
2. Low flows, (also known as Base flows)
3. High flow pulses
4. Small floods
5. Large Floods

The characteristics of each component of natural flows, together with major influences on ecosystems are outlined below.

The Extreme Low Flow Environmental Flow Components are defined as those that comprise a total of 10% of overall daily flows. In the rivers examined in detail in relation to impacts associated with the Northern Collector Phase 1, Extreme Low Flows are only experienced during about 50% of the years. For example at Maragua (at RGS:4BE9) Extreme Low Flows were only recorded during 22 out of 41 years. However, in the driest years a significant number of all daily flows may be Extreme Low Flows. For example, in 1984, 106 days were classified as Extreme Low Flows.

Q95 flows are similar to extreme low flows. If upstream abstraction of water for the Nairobi water supply is based on the release of Q95 flows as a Reserve Flow (Environmental Flow plus Compensation Flows) this will result in Extreme Low Flows being the normal situation for all downstream users. In addition, after the abstraction of required compensation flows, parts of the downstream reaches may run dry during periods of the dry season. In addition, all flows after abstraction will be lower flows than the natural situation, with significant reduction in the frequency of high flow pulses, small floods and large floods.

Long-term impacts on the environment and on all downstream users are therefore likely to be significant, including negative impacts on the increasing demands for agricultural production in downstream areas.

Common Characteristics for each Flow Component for different disciplines include:

	Hydrology	**Geomorphology**	**Biology**	**Water Quality**
Extreme Low Flows	Infrequent, low flows	Increased deposition of fine & organic particles	Restricted aquatic habitat. Limited connectivity	Elevated temperature Reduced levels of dissolved oxygen Reduced water quality
Low flows	Normal flow conditions with variability	Maintain soil moisture & groundwater table Maintain diversity of habitats	Suitable aquatic habitat. Connectivity along river channel corridor	Maintains suitable in-channel water quality
High flow pulses	In-channel, short duration, high flows	Maintain channel & substrate characteristics Prevent encroachment of riparian vegetation	Recruitment events for aquatic organisms. Connectivity to near-channel water bodies	Restore in-channel water quality after low-or extreme low flow
Small Floods and Large Floods	Infrequent, high flows that may exceed the normal channel	New habitat Construction Flush organic material into channel Lateral channel Movement	Life phase cues for aquatic and riparian organisms. Riparian recruitment & maintenance	

The important environmental Influences of different flow components of natural riverine systems include the following:

Extreme low flows *(initial low flow below 10% of natural daily flows for the period)*	• Stress and mortality due to water chemistry, temperature, and reduced dissolved oxygen availability, but may concentrate available prey in limited areas to benefit some predators (but only if these flows do not occur over extended periods), • Enable recruitment of certain floodplain and riparian plant species, • Helps to purge some invasive, introduced species from aquatic and riparian communities.

Low flows or Monthly low flows *This is the dominant flow under natural conditions*	• Provide adequate habitat for aquatic organisms, including feeding and breeding, • Maintain suitable water temperatures, dissolved oxygen, and water chemistry, • Maintain water tables in riparian zone and floodplains, soil moisture for plants, • Provide water suitable for household use, and for animals including livestock, • Enable fish and other aquatic organisms to move to feeding and breeding areas,
High flow pulses	• Shapes physical character of river channel, including pools, riffles, • Determines size and distribution of streambed (sand, gravel, stones), • Prevents riparian vegetation from encroaching into channel, • Restores normal water quality conditions after prolonged low flows, flushing away waste products and pollutants, • Prevents siltation, • Flushes and controls some pests, including mosquitoes, bilharzia, and liver fluke.
Small floods	• Provide migration and spawning cues for fish, and enable fish to breed, • Trigger new phase in life cycle (e.g. insects), • Provide new feeding opportunities for fish, waterfowl, and other aquatic species, • Recharge floodplain and riparian water table, • Maintain diversity in riparian forest types through inundation (different plant species have different tolerances), • Control distribution and abundance of plants on floodplains, • Deposit nutrients on floodplains.
Large floods	• Maintain balance of species in aquatic and riparian communities, • Create sites for recruitment of colonizing plants, • Shape physical habitats. Deposit gravel and stones. Drive lateral movement of river channel, forming new habitats. Flush organic materials (food) and woody debris (habitat structures) into the channel, • Recharge floodplain and riparian water table, • Purge invasive, introduced species from aquatic and riparian communities, • Disburse seeds and fruits of riparian plants, • Provide plant seedlings with prolonged access to soil moisture.

12.4 Potential Impacts: Phases 1 and 2

12.4.1 Phase 1: Groundwater Development in Kiunyu Area (2014) then in Ruiru Area (2015)

The availability of potential groundwater resources was presented in the Review of Groundwater Resources, June 2011. A program of exploratory drilling is required in order to locate suitable high yielding formations and to give precise estimation of the well-fields' potential and to confirm the availability and suitability of this resource, significant use of this groundwater resource as part of the Nairobi water supply is expected. In the absence of more detailed plans, a full environmental assessment is not currently feasible. However, a scoping of potential impacts from the potential development of these well fields and associated distribution pipelines is presented. Potential impacts include:

1. Changes in groundwater contribution to base flows in rivers, and reduction in local water supplies available from springs and dug wells;
2. Degradation of aquifers;
3. An increase in the abstraction of groundwater resources from the Nairobi Groundwater Body is likely to have a negative impact on the contribution of the aquifers to the base flow in rivers draining this area;
4. Clearance of vegetation as a result of site establishment and associated impacts on agricultural land;
5. Impacts from drilling activities themselves, including noise, and accidental spillage.

Important mitigation measures include the installation of an increased network of river gauges and recording stations in order to fully cover the potentially impacted areas. Regular, daily monitoring and reporting of these river gauges will be necessary. At times when reduced base flows are considered to have occurred, or are likely, and where these fall below accepted Reserve Flow limits, it will be necessary to supply an increased flow from upstream resources in order to compensate for the reduced flow and to ensure adequate downstream flows (environmental flows and compensation flows). Springs and wells in the areas within the geological strata affected by the proposed groundwater well fields also need to be identified and the yields monitored. Alternatively, piped water supplies may need to be provided in cases where these water sources are impacted by reduced groundwater levels resulting from abstraction.

Longer term impacts will subsequently result from the operation of each of the well sites together with associated transmission and distribution pipelines. This will include:

- Compensation for loss of land;
- Compensation for loss of agricultural production and livelihoods;
- Operation of the pipeline wayleave in private land;
- Impacts resulting from potential pipeline leakage.

12.4.2 Phase 2: Northern Collector Tunnel Phase 1: Maragua, Gikigie and Irati Rivers to Thika Reservoir

Phase 2 of the selected scenario for development of water sources for Nairobi includes the development of the Northern Collector Tunnel Phase 1. This will enable the abstraction and diversion of water from Maragua, Gikigie and Irati Rivers to Thika reservoir. Implementation is planned by 2016.

The main environmental and socioeconomic impacts resulting from the Northern Collector Tunnel Phase 1 will be related to the diversion of water, and the resulting reduction in downstream flows in these rivers. This requires the assessment of the required downstream Reserve Flows, including both environmental flows and compensation flows. Such impacts are expected to be long-term. Additional impacts are related to the construction of the facilities themselves. However, these are expected to be local-level and relatively short-term impacts.

Options for environmental flow release include (i) the release of Q95 Reserve Flows and (ii) the adoption of an alternative strategy that depends on the volume of incoming flow, with greater proportions being abstracted from higher flows together with the specification of a "hands off" flow below which no abstraction is allowed. This alternative strategy is the preferred option for management of downstream social and environmental impacts. The details of variable abstraction rates can be adapted at individual intake sites to cater for the needs of all users. Results of flow modelling show that abstractions will reduce the frequency of middle-level and high-level flows and increase the frequency of low-level flows. The Extreme Low Flows and the general absence of small floods and large floods, associated with release of Q95 Reserve Flows will result in inevitable long-term changes to downstream riverine and riparian environments, and negative social and environmental impacts.

Operational procedures will need to be established so that, under periods with naturally low flows, sufficient flows are allocated to:

a) Provide water supplies to meet downstream demands from communities, households, agriculture (both crops and livestock), as well as commercial or industrial requirements;

b) Provide environmental flows of sufficient quantity to prevent critical decline of downstream aquatic environments;

c) Provide flows to ensure the maintenance of water quality, including the maintenance of natural systems and the requirements related to sewage treatment and disposal;

d) Provide flow for Nairobi water supplies whilst taking account of available storage in reservoirs. Rationing of water to all consumers may need to be considered under such circumstances.

An important recommendation is that all river flows must be monitored and reported on a regular daily basis both above and below each of the weirs and intake structures, as well as at an increased number of sites downstream. Improved information on flows will then be available to form the basis for day-to-day operational management decisions.

Regular monitoring and updating of downstream water abstraction and use will need to be carried out. This includes, for example, the use of water by households and communities, or for use as irrigation supplies and commercial/industrial use. This should include both currently licensed and unlicensed abstractions. This information will need to be fed into regular operating procedures in order to optimise the use of available water resources and continue to provide environmental flows capable of maintaining downstream environments and critical environmental services.

Cumulative impacts are expected to include the following primary considerations:

- Reduced flows as a result of diversion of a majority of the flows originating from the Aberdares at Irati, Gikigie and Maragua intakes to the Northern Collector, resulting in:
- Reduction in the flow reaching Masinga Reservoir of 2.32% on an annual basis (based on daily flow data from 1995-1997), and therefore a reduced flow available for

hydroelectric power generation. Installation of mini-hydro at the tunnel outlet may be a viable option. (Note that the Northern Collector tunnel Phase 2 and Maragua 4 Dam will result in additional reduction in flows reaching Masinga Reservoir).

- Some short periods or single days with potentially zero flow. These periods can be mitigated by the release of higher flows from the Northern Collector intake sites over relevant periods in order to prevent unacceptable low flows downstream. Improved and timely monitoring and reporting of downstream flows, using an extended river gauge network, will be required in order to manage these flow releases.
- Less flow available for use by future agricultural activities in selected downstream areas (including both irrigation and non-irrigated riparian agricultural activities) that can be expected to be in increasing demand in order to provide some of the additional food required by the increasing population of Nairobi.

When considering cumulative impacts and the downstream requirements of agriculture, it is worth recognising the outcomes of the Rio+20 Earth Summit, where the event organisers highlighted that "The new vision for sustainable development that will emerge from the Rio+20 Earth Summit must recognize the significance of agriculture in economic growth, food security, poverty reduction and long-term environmental sustainability."

Catchment protection is an important component of the overall management of water resources. Impacts related to catchment protection in the Irati, Gikigie and Maragua catchments are considered to be manageable issues with no negative impacts. Major parts of the catchments of the proposed Northern Collector abstraction sites are included within the protected areas of the Aberdares, including the Aberdare National Park and neighbouring Aberdare Forest Reserve. Significant parts of the catchments are therefore considered to be under a “high protection" status. Outside of the protected areas, land cover of managed land is predominantly tea plantation. The deep roots and ground cover provided by tea results in relatively good soil and water conservation. Downstream of the intake weirs, it is also recommended that regular land management and control measures will be required for catchment protection, in particular in order to reduce the risks of soil erosion. Where possible this should be combined with local on-farm water harvesting measures and agricultural practices such as Conservation Tillage.

The Maragua, Gikigie and Irati Rivers each provide riparian vegetation along their length. Over this stretch of river no specific important ecosystems are identified with the exception of this riparian vegetation that provides an important natural corridor. Reduced flows will have an overall negative impact on the riparian vegetation cover, with expected long-term effects including reduced habitats, degraded stream bank stability, and potential changes in the depth of the water table. Combined with expected increase in clearance for agricultural activities, the long-term changes to riparian vegetation are expected to have a negative impact on the species diversity and populations of many birds, small mammal and other wildlife species using these resources. As a result, population numbers of some bird species are expected to decline downstream of the intake structures. Impacts are expected to reduce in intensity further downstream as other tributaries merge with the main rivers and the effective catchment area increases, providing some seasonal hydrological changes, including small floods and large floods.

Impacts from Construction

Potential negative impacts that can be expected from construction of the proposed intakes at Irati, Gikigie and Maragua, together with the construction of the Northern Collector Phase I Tunnel include:

i. Land acquisition and loss of cultivated areas, especially smallholder tea, in areas adjacent to the Intake Sites.

ii. Soil erosion resulting from site preparation and construction activities, including the construction of weirs, tunnels and pipelines.

iii. Change in local topography during site preparation/grading.

iv. Pollution from machinery and construction activities.

v. Construction of access roads, temporary settlement and workmen's camps, and permanent offices and settlement required to maintain and run each of the weirs.

vi. Disposal of rock and other material excavated from the Northern Collector Tunnel and access shafts.

vii. Pollution from machinery and construction activities, including accidental spillage.

viii. Possible impacts on hydrogeology as a result of tunnelling.

Disposal of Spoil

Construction activities for Northern Collector Phase 1 will result in significant volumes of spoil derived from the rock excavated from the tunnels (up to approximately 243,600 tonnes or about 216,000 m^3 of spoil). No areas for spoil dumps have been clearly identified. Disposal of the material from the tunnel in spoil dumps will have inevitable negative impacts whilst on-site storage is both impractical and likely to be dangerous due to the steep slopes of the terrain.

It is strongly suggested that instead of considering the excavated material as spoil, requiring disposal, it should be used as raw material for a range of activities such as road repair and construction, and for use as building material, including for example the making of blocks/bricks for buildings. Where no alternative uses are possible, excavated material should be transported to safe and secure sites such as abandoned quarries.

Pipelines

An extensive network of pipelines is planned. The routes and extent of pipelines will ultimately depend on the development strategies that are finally adopted. The installation of the necessary transmission and distribution pipelines will result in potential disturbance to natural habitats, to agricultural land and to communities along the pipeline routes. Habitat restoration and maintenance will be required after pipeline construction is completed. Impacts on local flora and fauna will be long-term if habitat restoration is not carried out. Most of the pipelines will be in settled areas that are already environmentally altered and land will need to be acquired.

Positive impacts from pipeline construction include the creation of job opportunities, as well as the potential for improved habitats for local wildlife species along the wayleave if this strip of land is managed appropriately. Compensatory plantation of trees and other vegetation should be carried out at the rate of a minimum of five trees planted for every tree cut.

Compensation of affected land and property assets lost should be provided. There may also be a requirement for provision of new or modified infrastructure to compensate for loss or impacts to existing facilities (including roads, schools, health facilities, market areas etc.). Consideration

should also be given to ensure that rural communities traversed by the pipelines are fully provided with piped water supplies.

12.4.3 Summary of Impacts and Mitigation Measures

Potential impacts due to construction and operation of the intake weirs and associated structures along the Northern Collector Phase 1 are listed in Table 9.40 and Table 9.41. Further details are given in the report of Preliminary EIA for the Selected Scenario: Nairobi Water Sources, Phases 1 & 2 (2011). Similar impacts can be expected for those areas downstream of the intakes on the proposed Northern Collector Phase 2.

Mitigation measures are required to be set and managed in order to eliminate, offset, or reduce adverse environmental and social impacts. These mitigation measures may have a number of different actions or objectives, including:

- Avoidance: Avoiding activities that could result in adverse impacts; avoiding certain resources or areas considered to be environmentally or socially sensitive.
- Prevention: Measures aimed at preventing the occurrence of negative environmental impacts and/or preventing activities that are likely to have harmful environmental and social impacts.
- Preservation: Preventing any future actions that might adversely affect an environmental resource. This may for example be achieved by extending legal protection to selected resources.
- Minimisation: Limiting or reducing the degree, extent, magnitude or duration of adverse impacts. This can for example be achieved by scaling down, relocating, or redesigning individual elements.
- Restoration: Restoring affected resources to an earlier (and possibly more stable and productive) state, typically a 'pristine' condition.
- Compensation: Creation, enhancement, or protection of resources at an alternative suitable and acceptable location, or compensating for lost resources. The sustainability of compensation measures should be considered, e.g. the loss of future household income due to the loss of productive agricultural land may not be sustainable from a one-off compensation payment but could be offset by activities designed to provide long-term and improved sources of household income.

Table 9.40: Impacts Due to Construction of weirs, intake structures and tunnels (Northern Collector Phase 1)

Issues	Nature of Impacts	Mitigation Measures
Loss of land	Land will be acquired to enable construction of and provision of adequate buffer zones round weirs, treatment works, pipeline wayleave, workmen's camps and working areas. Loss of smallholder tea plantation in particular will lead to long-term changes in household incomes.	• Compensation for loss of land • Compensation for loss of household income

Issues	Nature of Impacts	Mitigation Measures
Change in land use	Change in land use from one dominated by natural riparian vegetation with adjacent tea plantation, to cleared area with intake structures and associated infrastructure. Clearance of riparian vegetation will disrupt natural wildlife corridors.	• Minimize clearance of natural vegetation • Creation of wildlife corridors
Access roads	Access roads will be required to enable construction, as well as for subsequent system operation. Maragua and Gikigie can largely use existing access, but new access tracks will be required for Irati, tunnel outfall and adits.	• Compensation for loss of land
Soil erosion and Siltation	Combined with the steep terrain, exposed earthworks required for site preparation and construction are likely to result in increased soil erosion. Siltation created during construction will pass downstream, with potential negative impacts on the environment and on water quality.	• Erosion control measures • Due diligence during construction
Pollution	Construction activities will create air, dust and noise pollution. Contamination from wastes and oil/fuel spills may occur. Contamination from dust, and from oil/fuel spills, may spread to adjacent agricultural land, e.g. tea, thereby significantly reducing its value.	• Pollution control measures • Due diligence during construction
Solid waste disposal	Construction activities will result in significant volumes of excavated material, especially from tunnels. Disposal of this material may have a negative impact unless carefully planned, or used for other activities such as road construction, or building materials. Instead of being classified as “spoil” it should be seen as a potentially useful raw material.	• Planning of disposal of excavated material • Use excavated material for road repair & construction and as raw material for other construction
Workmen’s camps and Settlements	Camps required for construction workers may overburden local services. Surface waters may be contaminated by sewage, with associated dangers to public health. Induced settlement is likely to occur as a result of construction. This may be beneficial to local communities, but will also stress local resources, including water supplies and household fuel. There may also be health risks and increased requirements for health services. The construction phase may also provide local employment opportunities, but these must be scheduled to avoid peak tea picking activities.	• Careful planning and location of campsites • Provision of adequate sewage and waste disposal facilities • Provision of adequate services • Provide local employment
Hydrogeology	Tunnelling may result in changes to underground drainage as a result of underground fractures.	• Detailed investigation during construction
All issues	A technical committee should be established to assess potential impacts before and during construction activities, as well as to evaluate damage caused and assess required compensation. The technical committee should include environmental assessment experts.	

Table 9.41: Impacts Due to Operation of Weirs

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Change in downstream flow in Irati, Gikigie and Maragua Rivers. Including Cumulative Impacts from the combined changes in downstream flow of all three rivers.	Change from a natural flow to a flow similar to a permanent low flow, extreme low flow or drought condition as a result of: a) diversion of water at weirs, and b) retention of this water in Thika Reservoir Loss of downstream water resources, and reduced ecosystem services in the impacted rivers. Loss of vegetation and wildlife dependant on these water resources. Potential for extinction of aquatic fish species that depend on migration upstream for breeding during wet season. Reduced potential for settlement and agricultural development downstream. Changes in the water table as a result of reduced flows in the rivers. Reduced water quality as a result of downstream flows being similar to extreme low flows.	• Long-term. Permanent. • High impact without adequate Environmental Flow Release (EFR) • Low impact if good quality Reserve Flows are adopted and managed • Release Reserve Flow adequate to sustain all required downstream water resources • Establishment of a comprehensive monitoring programme and technical committee • Install mini-hydro power facility at tunnel outlet
Diversion of flow from Irati, Gikigie and Maragua Rivers to Thika reservoir	A dam safety assessment may be required.	• Conduct dam safety assessment
Reduced flows available for use by households	Reserve flows include Compensation flows and there will be a need for a complete inventory of required compensation flows, together with a need for ensuring that all households are included in rural water supply schemes.	• Inventory of all needs • Release of adequate Compensation Flows • Household water supply schemes for all
Periods with very low or zero flow in downstream areas	Some periods with zero flow and very low flow are predicted to occur further downstream. Reserve Flows will need to be monitored and adjusted accordingly on a regular basis.	• Release Reserve Flow adequate to sustain all required downstream water resources
Change or loss of habitat downstream as a result of changed hydrological regime. Including cumulative downstream impacts.	Loss of riparian vegetation. • Reduced stability of stream banks due to fewer roots and less vegetation binding the soil. • Potential increase of pollution in the rivers.	• Long-term impact • High impact without EFR. Low impact if a good EFR regime is put in place and well managed.

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Effects of reducing the flow of nutrients downstream	Reduced nutrient availability in downstream areas may result in a reduction in productivity of downstream systems, including cultivation in alluvial areas downstream.	• Long-term. Permanent • Mitigation possible through EFR and sediment transport enabled by flood events
Trapping of sediments	Nutrients captured in Thika Reservoir, especially those that tend to bind with fine sediments, will no longer be available to downstream systems and may result in increased eutrophication in the reservoir.	• Incorporate sediment release capabilities in weirs. • Incorporate sediment release capability in Thika Reservoir.
Sedimentation at interface between inflowing stream and the reservoir	Unless sediments are filtered out before entering the Northern Collector tunnel, increased sediment deposits will form at reservoir entrance.	• Long term. Low impact. • No mitigation other than removal of accumulated sediments.
Change in aquatic environments and reduced potential for fish migration, and movement of other aquatic species	The potential for passage of fish upstream will need to be assessed in detail at the detailed design stage of each structure, to ensure survival of fish species, including endemics and potentially threatened species.	• Designs for fish ladders need to be reviewed and fully incorporated in all proposed Intake weirs.
Power lines	The presence of power lines creates a potential hazard to larger bird species.	• Mitigation thorough appropriate design of power lines and transmission towers.
Access roads	Improvements to existing access roads and development of new access tracks open up new areas to development and if carefully planned with inputs from local communities can provide local benefits. Material excavated from the tunnel can be used for road maintenance or rehabilitation.	• Low impact if mitigation measures are adopted. • Mitigation through careful routing of access roads.
Settlement resulting from project operation	In addition to operational staff, induced settlement is likely to occur in the surrounding area, creating potential stress on local resources and facilities, including fuelwood, as well as health facilities.	• Planning of settlements and provision of fuel resources. • Improved health facilities or clinics

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Impact from presence of pipelines	Long-term access to the pipelines will be required for routine checking and maintenance. Assuming that most of the pipeline length is buried with limited surface structures, the overall impacts will be relatively low.	• Careful management and location of pipelines.
Leakage from pipelines and contamination of supply lines	Leaks are highly likely to occur along transmission and distribution pipelines, and possibly at treatment works. Contamination of supply pipes may also occur at these sites. Leakage may result in health risks, e.g. Malaria, Cholera and other water-related diseases.	• Regular monitoring and maintenance is essential. • Early detection of leaks reduces the possibility of public health risks.
Public health risks	Reduced water quality as a result of reduced flows will result in increased health risks for downstream communities or households dependant on untreated river water. A change in faecal bacterial concentrations and waterborne pathogens as a result reduced flows and from inflow of contaminants from upstream is likely and needs to be monitored.	• A programme for regular monitoring of pathogens, and assessment of risks from waterborne diseases.
Inflow of effluents and pollutants from upstream sources	Inflow of dissolved effluents and pollutants will have an impact on water quality with potential impacts on human health. Inflow of solid wastes and pollutants are likely to have a negative impact on the natural environment. Reduced flows will result in increased concentrations of pollutants.	• Regular water quality monitoring. • Active management and clearance of solid wastes may be necessary. • Sewage and effluent collection and treatment facilities for all habitation within catchment areas.
Effects from changes in groundwater levels	Changes in local groundwater regime are possible as a result of reduced downstream flows.	• Long-term. • Uncertain impact.
Impacts due to proposed treatment works	Use of hazardous chemicals, including chlorine (gas and/or Hypochlorite solution). Agricultural chemicals resulting from agricultural activities in catchment areas may also require additional or special treatment of water before distribution.	• Proper procedures for use and disposal of chemicals. • Catchment management.

Issues	Nature of Impacts	Type of Impact and Mitigation Measures
Risks from Seismic Activity	The proposed Northern Collector Tunnel is in an area with recorded seismic activity. Data are recorded at the seismic station at Kilima Mbogo. Seismic activity could have an impact on tunnels, as well as the existing Thika Reservoir. Annual, or more frequent, inspections of the Northern Collector tunnel should be conducted, and there should be a contingency plan to be followed in the case of earthquakes.	• Risks will need to be fully assessed as part of detailed design. • The tunnel should be issued with an annual compliance certificate that it is seismically sound.

12.5 Scoping of Potential Impacts post 2017

Proposed future water sources for the Nairobi City Area served by Nairobi City Water and Sewerage Co. (NCWSC) include the Phase 1 and 2 developments discussed above. Post year 2017, further planned developments include the following proposed water sources, depending on the chosen long term development strategy:

Long-term development strategy, and potential water supply options	Ultimate Capacity m^3/s	Ultimate Capacity m^3/d
1. Independent Water Supply Option:		
• S. Mathioya Transfer to Thika Dam + Maragua 4 Dam ($30Mm^3$)	1.53	132,192
• Northern Collector Tunnel Phase 2 to Thika Dam	1.39	120,096
• Ndarugu 1 Dam ($300Mm^3$) with Natural Inflow	2.50	216,000
2. Strategic Water Supply Option		
• Ruabura Dam ($19Mm^3$)	0.38	32,746
• Karimenu 2 Dam ($14Mm^3$)	1.16	100,000
• Ruiru 2 Dam ($30Mm^3$) with Ndurire Transfer	0.69	60,000
• S. Mathioya Transfer to Thika Dam + Maragua 4 Dam ($30Mm^3$)	1.53	132,192
• Northern Collector Tunnel Phase 2 to Thika Dam	1.39	120,096
• Thiririka Dam ($7Mm^3$)	0.31	26,698
• Ndarugu 1 Dam ($300Mm^3$) with Natural Inflow	2.50	216,000
• Chania-Komu Transfer to Ndarugu 1 Dam	2.10	181,440
3. Mixed Water Supply Option		
• S. Mathioya Transfer to Thika Dam + Maragua 4 Dam ($30Mm^3$)	1.53	132,192
• Northern Collector Tunnel Phase 2 to Thika Dam	1.39	120,096

Long-term development strategy, and potential water supply options	Ultimate Capacity	
	m^3/s	m^3/d
• Ndarugu 1 Dam (300Mm^3) with Natural Inflow	2.50	216,000
• Chania-Komu Transfer to Ndarugu 1 Dam	2.10	181,440

Under the Strategic Water Supply option there is the proposed construction of a series of smaller dams on the Ruabura, Karimenu, Ruiru, and Thiririka Rivers. These are largely required for water supplies for the satellite towns and are included in Section 12.5.3 below.

12.5.1 Northern Collector Phase 2

Common to all three of the long-term development strategies is the development of the Northern Collector Tunnel Phase 2, connecting to the Phase 1 tunnel at the Maragua River. The Northern Collector Phase 2 tunnel will connect weirs abstracting water from the South Mathioya, Hembe, Githugi and North Mathioya Rivers. It is assumed that the Downstream Reserve Flows (Compensation Flows plus Environmental Flows) below the abstractions along the Northern Collector Phase 2 will follow the same rules as currently proposed for the Northern Collector Phase 1 and will therefore be set at the release of Q95 flows, augmented by any high flows, or flood flows, that exceed the tunnel capacity. Downstream environmental and social impacts will therefore be similar to those expected for abstraction along the Northern Collector Phase 1.

The main environmental and socioeconomic impacts resulting from the operation of the Northern Collector Tunnel Phase 2 will be related to the diversion of water, and the resulting significant reduction in downstream flows in these rivers. This will require an assessment of the required downstream Reserve Flows, including both Environmental Flows and Compensation Flows, prior to the construction of the tunnel and intake weirs. Impacts related to reduced downstream flows are expected to be long-term. Additional impacts are related to the construction of the facilities themselves. However, assuming appropriate mitigation measures are carried out prior to and during construction, these are expected to be local-level and relatively short-term impacts.

Impacts and recommended operational procedures are expected to be similar to those outlined above for the Northern Collector Tunnel Phase 1, including impacts from reduced downstream flows, and from construction, disposal of spoil, and construction of pipelines.

Abstraction and diversion of water to the Northern Collector Tunnel Phase 2 will also result in a reduced water resource available for use by the downstream hydropower facilities, e.g. at Masinga Dam, and all the additional downstream dams including the proposed Grand Falls dam. A detailed assessment of the diverted flows and the remaining downstream flows in these rivers will need to be carried out in order to determine the cumulative impacts on hydropower production.

12.5.2 Maragua 4 and Ndarugu 1 Dams

The long-term development strategy includes proposals for the construction of additional dams to create a number of storage reservoirs. Of these, Maragua 4 Dam and Ndaragu 1 Dam are common to all three of the potential long-term development strategies. Depending on the adopted development strategy, a series of ten or smaller storage reservoirs are possible to

provide water supplies to satellite towns. Scoping of potential impacts of these is considered below.

Maragua 4 Dam

The construction of Maragua 4 Dam is proposed, together with the transfer of water from the South Mathioya River to both Thika Dam and Maragua 4 Dam, providing water supplies by the year 2020. The construction of Maragua 4 Dam will provide additional buffering to the diverted flows from South Mathioya, Githugi, Hembe and North Mathioya Rivers. It is proposed to provide additional storage in Maragua 4 Dam midway of the implementation of the Northern Collector Tunnel (Phase 2), specifically after the diversion of the South Mathioya River. At this stage, the buffering capacity of Thika Reservoir will already be reduced by half and significant loss of water through overflow is expected at Thika Dam due to the additional inflow. The mode of operation of the Northern Collector tunnel will be such that when Thika Dam is spilling, diversion from Maragua River is stopped or reduced and available flows are released to Maragua 4 Dam. Scoping of potential impacts includes:

- Significant reduction in downstream flows in the Magarua River, and also in South Mathioya, Githugi, Hembe and North Mathioya Rivers.
- Less flow available for rural household water supplies. Especially critical for those households that depend on collection of water directly from rivers (recorded as 49.5% and 38.3% of households Muranga North and Muranga South Districts in 2008).
- Less flow available for downstream abstraction for agricultural, industrial and other activities, e.g. coffee factories and tea processing plants. Similarly, a reduction in flow available for important activities such as sewage processing plants in downstream areas.
- Reduced flow to Masinga Reservoir, and reduced potential for hydropower production.
- Loss of land due to construction of Maragua 4 Dam and flooding of the reservoir, and transformation of a land and river environment into lacustrine conditions.
- Loss of smallholder tea plantation in those areas impacted by construction of the Northern Collector Tunnel and by the flooding of Maragua Reservoir.
- Reduced potential for agricultural development in all areas downstream on these Dams, as a result of reduced water flowing in the rivers.
- Change or loss of riparian habitats downstream as a result of changed hydrological regime in the South Mathioya, Githugi, Hembe and North Mathioya Rivers.
- Creation of barriers to the movement of aquatic species, including fish, upstream and downstream in this area.
- There will be a requirement for design of flow release structures and sediment release facilities from Maragua 4 and Ndarugu 1 Dams to release downstream Reserve Flows (Compensation Flows plus Environmental Flows) in order to satisfy downstream demand.
- Based on the storage capacity of the proposed Maragua Reservoir, with inflows from South Mathioya, Githugi, Hembe and North Mathioya Rivers, there will be some potential for release of improved downstream Reserve Flows in the Maragua

River. This contribution is likely to be most important during periods of extreme low flow.

- Maragua Reservoir could be used as a source for development of additional rural water supply schemes.

The Maragua Reservoir would be constructed at or shortly below the junction of the Maragua and Gikigie Rivers. Maragua Reservoir will therefore capture and store all flows released by the Northern Collector intake weirs on these two rivers. Previous impact assessment reported in the Preliminary Design and Feasibility Study (2012) assumed that the chosen scenario was without the construction of Maragua 4 Dam. However, the potential storage of all flows released by the weirs, including high flow pulses, small floods and large floods, will ensure that these important hydrological events are not released to downstream areas in the Maragua River, unless the flows are actively released by management of the dam. Long-term impacts from Maragua Reservoir will therefore include a greater reduction in the downstream flows, with consequent impacts on the flows to Masinga Reservoir and greater reduction in hydropower generating capacity.

Movement of fish will be blocked by the proposed dams, leading to possible reduction in breeding, reduced populations and, combined with the construction of other proposed dams, the possible extinction of some migratory species. Fish ladders or fish passes will be required as a mandatory component of the dam design. Two *Labeo* species found in the Tana, namely *Labeo cylindricus* and *L. gregorii* both migrate into upstream tributaries at the time of the first floods. Reduction in flows and the resulting hydrological alteration will have inevitable long-term negative impacts on such species.

A potentially important positive social impact is the potential for the development of rural water supply schemes based on the storage capacity of Maragua Reservoir, and designed to provide water for all rural households. .

Ndarugu 1 Dam

Ndarugu 1 Dam would impound the main Athi drainage at the junction of the Athi, Komu and Ndarugu Rivers. Utilisation of these water sources would require pumping to higher levels in Nairobi. The Strategic and Mixed water supply options also include a proposed transfer of water from the Chania to the Komu River, thereby diverting some of the water resource from the Thika drainage to the Athi drainage, and flowing into Ndarugu Reservoir.

Storage of water in the proposed Ndarugu Reservoir will have an inevitable impact on the downstream flows in the Athi River. These reduced flows will impact all downstream communities relying on the Athi River for approximately 300 kilometres until the Athi River flows into the Indian Ocean as the Galana, north of Malindi. Those areas adjacent to the Athi River will also be impacted by reduced flows. Of major concern should be the maintenance of adequate dry season flows in the Athi River flowing through Tsavo National Park. Urbanisation in the headwaters of the Athi River Basin has led to reduced infiltration of rainfall, causing rapid, but short-lived, high flows and reduced base flows. Increased upstream abstraction and use of this water, combined with the storage of water in the proposed Ndarugu Reservoir, will result in reduced high flows and in further reductions in the base flows downstream.

A detailed examination of the long-term impacts on downstream flows in the Athi River will be required. In particular, it is considered critically important that the flows required in the Athi River within Tsavo National Park during the dry season are maintained, in order to preserve wildlife populations and to maintain Kenya's national tourist industry. Similarly, the release of adequate

dry season flows from Ndaragu Reservoir will be critical in order to provide water sources for all downstream communities relying on this water source.

12.5.3 Scoping of Potential Impacts: Water Sources for Satellite Towns

The proposed additional water sources for satellite towns include: storage reservoirs, groundwater, and additional river intakes (Table 9.42). The potential impacts from development of groundwater sources are expected to be similar to those outlined above when considering impacts of Phase 1 development of groundwater sources in Kiunyu and Ruiru areas.

The construction of dams and the resulting creation of storage reservoirs have significant effects in that a land and river environment is transformed into a new environment with lacustrine conditions. Under these new conditions, important long-term impacts include socio-economic impacts, ecological impacts, impacts on groundwater resources, and changes to water quality, as well as potential geological impacts. Whilst a series of storage reservoirs are proposed, depending on the final adopted long-term development strategy, the final design details of these dams and reservoirs are currently unknown. Detailed environmental and social impact assessments will be required to be carried out for each of these dams. At the current stage, a scoping of potential impacts is possible and assists with the development of a preliminary environmental and social management plan.

The environmental impact of reservoirs is of increasing importance as the demand for water and the number, and size, of reservoirs increases. Worldwide, a variety of adverse environmental and sociological impacts have been identified during and after many reservoir constructions. Impacts related to construction can be mitigated and controlled through careful planning and through provision of adequate compensation. The flooding of natural habitats that existed before the dam's construction is also likely to require mitigation through the provision and setting aside of alternative areas in order to compensate for habitat loss, and loss of productive agricultural land used by local communities.

Impacts from the construction and operation of reservoirs for water supplies for Satellite Towns are expected to include:

- Reduced downstream water availability. The major impacts related to the operation of storage reservoirs are related to the reduced downstream flows that are the inevitable result of water storage. The combined impacts of storage of water resources in all of these proposed reservoirs is likely to have negative impacts on both downstream communities and downstream environments, resulting in reduced high flows as well as reduced base flows.
- The initial filling of a reservoir floods the existing plant material, leading to death and decomposition of carbon-rich plants. The resulting rotting of organic matter releases carbon dioxide to the atmosphere. The decaying plant matter settles to the non-oxygenated bottom of the reservoir, produces and will eventually release dissolved methane. However, these processes can be mitigated by the clearance of all of this material from the reservoir area before flooding.
- Reduced release of sediment to downstream riverine areas. The construction of a dam blocks the flow of sediment downstream, leading to downstream erosion, for example of river banks. Sedimentation of reservoirs will result in diminished storage capacity.
- Movement of fish will be blocked by the proposed dams, leading to possible reduction in breeding, reduced populations and possible extinction of some migratory species. Fish ladders or fish passes will be required as a mandatory component of the dam design.

- Reservoir sedimentation is also a process that must be considered and catered for by appropriate design and management of reservoir structures, and by appropriate land management in the watersheds.
- Dams and the creation of reservoirs also require relocation of human populations if they are constructed close to residential areas.
- The combination of urbanization and dam construction can spread water-related diseases by creating new environments for infectious agents. This includes the health impacts associated with the provision of breeding areas for disease vectors, including mosquitoes as vectors of Malaria, and snails as vectors of Schistosomiasis, as well as other water related diseases. Another health impact of poor water quality caused by dams is Cyanobacteria. These can cause a range of gastrointestinal and allergenic illnesses in humans. Some Cyanobacteria can also promote liver cancer during chronic low exposure.
- Downstream impacts on flood-dependent ecosystems and agriculture.

Table 9.42. Proposed Future Water Sources for Satellite Towns, including options 1, 2 & 3: Independent, Strategic, & Mixed

Satellite Town	Potential New Water Sources: New Dams / Reservoirs	New or expansion of existing River Intakes	Groundwater Sources
Kikuyu	Kamiti 1 Dam (16.4Mm^3) Ndarugu 3 Dam (11.2Mm3)		New boreholes
Kiambu	Ruiru 2 Dam (36 Mm^3) with Ndurire Transfer (For Kiambu, Karuri & Ruiru-Juja) Riara Dam (7 Mm^3) Komothai 2 Dam (4.9 Mm^3)		
Karuri	Ruiru 2 Dam		
Ruiru-Juja	Ruiru 2 Dam (36 Mm^3) Karimenu 2 Dam (14.2 Mm^3) Gatamayu 2 Dam (7.1 Mm^3) Thiririka Dam (14.7 Mm^3)	New Water Supply - Intake in Ruiru River (under construction) Augmentation of Juja Water Supply, Ndarugu River (under construction)	
Mavoko Municipality	Stony Athi Dam (21 Mm^3) Mbagathi Dam (45 Mm^3)		
Ngong, Ongata Rongai & Kiserian	Kiserian Dam (1.2M Mm^3) (under construction) Ruabura Dam (19 Mm^3)		New boreholes
Limuru Town			New boreholes
Githunguri Town			New boreholes
Gatundu Town			Increased extraction from existing boreholes

Satellite Town	Potential New Water Sources: New Dams / Reservoirs	New or expansion of existing River Intakes	Groundwater Sources
Thika Town	Thika 3A Dam (13 Mm^3)	Thika River Intake – Existing	
Tala-Kangundo Towns			New boreholes

***Note**: The potential Mbagathi Dam is downstream of Kiserian Dam which is under construction. Remaining flows are unlikely to make Mbagathi dam a viable proposition. Mbagathi Dam is not considered suitable due to its low yield, high capital costs, pollution risks, environmental concerns, and concerns from Kenya Airports Authority[5&6]. Flow data indicated an effective zero flow for almost 70% of the time, and the overall unit cost of the dam is considered high compared to its yield.*

12.6 Preliminary Environmental and Social Management Plan

12.6.1 Objectives of the Environmental Monitoring Plan

The environmental and social monitoring plan must be viewed as a long-term plan with regular continuing commitment to monitor and report on environmental and social development or changes, including both beneficial and negative changes.

In order to fully achieve mitigation of potential impacts, it is necessary to monitor actual impacts and the mitigation measures that are incorporated, and to adapt management strategies based on the results of monitoring. The Environmental Monitoring Plan (EMP) will need to be developed in detail alongside the detailed designs for each of the individual components of the programme.

The objectives of the Environmental Monitoring Plan include:

- Place the proposed activities within the context of the local and regional environment, at the same time ensuring compliance with relevant regulatory authority requirements and guidelines. These may be national and/or international.
- Identify the environmental issues and risks associated with the proposed activities, and ensure that the allocation of project resources and budget are sufficient so that the scale of EMP-related activities, e.g. requirements for mitigation and compensation, are consistent with the potential significance of impacts.
- Provide the basis of the long-term environment management program, ensuring that the environmental impacts resulting from the proposed activities, including cumulative impacts, can be acceptably managed.

[5] Tanathi Water Services Board (2010). Athi River – Mavoko Water Supply and Sanitation Project. Feasibility Study and Preliminary Design Report. Tanathi Water Services Board, Republic of Kenya.

[6] EPZA (2007) Independent Water Supply Project, Environmental Assessment. EPZA, Republic of Kenya.

- Recording of relevant baseline conditions, e.g. downstream river flows, existing abstraction or household use of river water sources (both licensed and unlicensed), surveys of aquatic and riverine fauna and flora, water quality, and land use.
- Verifying environmental performance through recording of information on impacts as they occur, and to report to the relevant authorities on emerging and outstanding environmental management issues, and provide advice on mitigation and control of environmental risks, including health and safety.
- Responding to changes in project implementation that may not have been considered earlier.
- Responding to unforeseen events, and changes in circumstances.
- Providing feedback for continual improvement in environmental performance.

The Environmental Monitoring Plan will need to include recommendations that the following be monitored:

- An extension of the river gauge network to include all impacted rivers, with 10 km intervals, or less, between gauges. Regular monitoring of flows upstream and downstream of all diversion structures and storage reservoirs. This will also include the monitoring and reporting of the volume of Reserve Flows, including both Environmental Flow and Compensation Flow components.
- Monitoring of sediment loads at intake weirs and downstream of intakes, and at sites upstream and downstream of proposed storage reservoirs.
- Periodic surveys of aquatic fauna upstream and downstream of all of the proposed intake weirs and proposed storage reservoirs, as well as in the existing Thika and Ruiru reservoirs. Surveys should also be carried out of bird populations and riparian vegetation in riparian areas downstream of proposed intakes and proposed storage reservoirs. These surveys should be designed to provide an up-to-date and comprehensive assessment of the aquatic and riparian communities, create a baseline, to monitor changes, and to allow for subsequent monitoring of impacts on these communities. Surveys should include both native and introduced species. It is recommended that surveys should be carried out either annually or twice each year (e.g. wet and dry seasons), with inputs from the National Museum and from Universities.
- Changes in demand for water downstream of the intakes. This should include household water supplies with changes in household numbers and population densities, as well as changes in demand related to increased demand for agricultural production (including small scale irrigation, commercial irrigation and livestock requirements).
- Changes in the quality and availability of water supplies from rivers and associated streams and impacts on public health, including those communities dependant on downstream flows. This should include regular testing for chemical pollution from agricultural inputs upstream of intake points, as well as monitoring of potential faecal-bacterial pollution and other communicable disease health risks (e.g. including Malaria, Schistosomiasis, Cyanobacteria).
- Upstream land use and land cover, including forest cover in the Aberdares catchment area, as well as agricultural activities in the catchment areas of the rivers associated with the Northern Collector phases 1 and 2, and within the catchments of proposed and existing storage reservoirs.
- Land use and land cover downstream of proposed intake weirs, and storage reservoirs, as well as land use adjacent to proposed groundwater well sites.

In order to achieve the above objectives, the Environmental Monitoring Plan should also include:

- Definition of the environmental management objectives to be followed in order to enhance benefits and minimise adverse impacts, including during construction and operational phases.
- Description of the actions needed to achieve these objectives, including by whom, and with what resources, as well as necessary monitoring or verification.
- Consideration should also be given to address possible changes in the project implementation, emergencies or unexpected events.

An assessment of Cumulative Impacts should be included in the overall Environmental Monitoring Plan.

Construction Phase

Separate EMPs should be prepared for Construction and Operational phases. Construction EMPs will be required to deliver a practical and achievable plan of management and to ensure that potential environmental impacts during the construction phases are minimised. Plans will need to be developed prior to construction, but can only be proposed once sites are finalised and full design and construction details are available. The following issues will need to be included:

- Physical setting, flora and fauna, ensuring minimal environmental impact and proposing mitigation measures, including the setting aside of alternative terrestrial and aquatic habitats for preservation to compensate for loss of habitats;
- Prevention of interruption to existing infrastructure installations and services, including the building of alternative access routes as required;
- Resettlement and land compensation, including compensation for potential loss of livelihoods;
- Ensure that noise and vibrations are kept to acceptable standards during all construction activities, including the impacts from blasting associated with construction activities for tunnels, and dam construction;
- Water quality management, dust and air quality, soil and groundwater contamination control;
- Waste management, land contamination, erosion and sediment control, and
- Environmental Performance Monitoring.

Operational Phase

Operational Environmental Management Plans will be required. These will need to focus on sound environmental management practices undertaken to minimise adverse impacts on the environment during normal operation of the intake sites, reservoirs, groundwater well sites, and water transmission tunnels and pipelines. The following issues will need to be included:

- Overall management strategy, including environmental performance monitoring and regular reporting. It is recommended that a scientific advisory committee be established to aid with long-term environmental monitoring.
- Maintenance of environmental integrity, including the provision of adequate downstream Reserve Flows:
    a) Provision, maintenance and monitoring of Environmental Flows,
    b) Preservation of those habitats that depend on these flows (if necessary by declaration of protected area status),
    c) Provision, maintenance and monitoring of Compensation Flows for downstream communities affected by reduced flows,

d) Provision, maintenance and monitoring of flows required for purposes of downstream agricultural production, including irrigation, livestock, and the needs of factories (e.g. tea and coffee), and

e) Preservation of water quality standards, including the minimization of potential impacts on public health resulting from reduced downstream flows.

- Minimization of leakages in transmission pipelines and in the distribution pipeline network.
- Disposal of wastes resulting from the water treatment process so as to ensure that there is no contamination of surface water and groundwater, or areas adjacent to the treatment works.
- Energy management, including measures to ensure minimizing greenhouse gas emissions.

Environmental Monitoring Plans may also be required for areas of specific ecological or social value, for example to ensure preservation of potentially important habitats or social amenities that may form part of the planned route for the proposed pipelines from the proposed storage reservoirs to the treatment works, or other pipeline routes.

12.6.2 Draft Environmental Management Plan

There are three main elements or phases to the environmental management plan. During the pre-construction phase important baseline information will need to be collected and this will form the basis for environmental monitoring during the subsequent construction and operational phases. The environmental management plan in the construction phase will require to focus on detailed monitoring of potential impacts and on mitigation and/or compensation for impacts.

Pre-Construction Phase

An important task in the pre-construction phase will be to set up a series of monitoring systems that will be capable of providing the important critical information required during the construction phase and also during the subsequent operational phase. Chief amongst these are the establishment of additional river gauges required to provide important information on the downstream flows so as to ensure adequate Reserve Flows, together with an up-to-date and complete listing of all abstractions of water from all downstream rivers sources, including both licensed and unlicensed abstractions. Regular daily monitoring of all flows will be required and a system for rapid reporting of these flows, perhaps by mobile phone systems, so that adequate downstream Reserve Flows can be maintained under all conditions – including both environmental flows and compensation flows.

In addition, there will need to be surveys of aquatic and riparian fauna upstream and downstream of the intake weirs along the Northern Collector Tunnel (Phases 1 and 2), as well as aquatic fauna in the existing Thika Reservoir, and in all other rivers impacted by proposed storage reservoirs. These surveys will provide up-to-date assessment of the aquatic and riparian communities, and will create a comprehensive baseline from which to monitor changes and potential impacts on these communities.

Surveys of aquatic fauna should include surveys of fish species present in all the impacted rivers flowing from the Aberdare mountain range in the Athi and Tana catchments, and in Thika Reservoir. Surveys of riparian fauna should include seasonal surveys of bird species to determine the numbers of species and population numbers. These data on bird assemblages (including migratory species) will subsequently be used as indicators of riparian condition and components of environmental monitoring during construction and operational phases.

The management of disposal of material excavated from the Northern Collector Tunnel (Phases 1 and 2) will need to commence during the pre-construction phase. It is recommended that no permanent "spoil dumps" are used. Instead of considering the excavated material as "spoil" requiring disposal, it should be used as raw material for a range of activities such as road repair and construction, and for use as building material, including the making of bricks for buildings. It is therefore recommended that on-site storage of excavated material should be minimized and that only temporary storage sites should be constructed within reach of each of the access sites. It is also recommended that the excavated material is transported away from the sites at a rate similar to the rate of extraction. The emphasis should be for the material to be transported for either temporary or permanent storage at suitable sites elsewhere.

Table 9-43: Pre-Construction Phase Information Requirements

Information Requirements		**Actions, Surveys or Data Recording**
Monitoring of water resources	Adaptive water management needs reliable and comprehensive data on which to base decision making. These data should cover not just daily hydrological characteristics, but also indicators of water use and abstraction.	Upgrade existing and establish new river gauges for monitoring flows. River flow gauges are required to be spaced at not more than 10 km intervals (a) downstream of the intake weirs, and (b) upstream and downstream of all proposed storage reservoirs. Establish systems for daily reporting of these data to a central system, and for collation and reporting of these data to those responsible for daily management of water source infrastructure, e.g. abstraction at intake sites.
Monitoring of water use and abstraction, including both existing abstraction and future requirements.	Monitoring of downstream water use by communities and industries is required. 1. Household use 2. Agricultural use 3. Industrial/commercial use	Up-to-date information on all abstractions from the rivers, including both licensed and unlicensed abstractions for all uses. Obtain data on volumes of water required as well as monthly or seasonal changes in requirements, and methods of abstraction.

Information Requirements		**Actions, Surveys or Data Recording**
Rural Water Supplies	Collection of up-to-date information on the status of rural water supplies to households as well as the numbers of households connected and not connected to rural water supplies.	Develop proposals for development of rural water supplies to ensure that as many as possible of the rural households in those areas downstream of intakes and storage reservoirs are connected.
	Consideration should be given to ensure that all communities traversed by the pipelines, and those adjacent to proposed storage reservoirs, are fully provided with piped water supplies, as a priority.	Provide adequate local, rural and urban water supplies along pipeline routes
Data for monitoring aquatic and riparian fauna	Monitoring for the EMP requires a set of accurate and comprehensive baseline data on which to base subsequent surveys, compare changes, and determine required actions. It is recommended that surveys should include involvement of personnel from the National Museum.	Surveys of aquatic fauna, including fish species in all of the impacted rivers and in the existing reservoirs (Thika Reservoir and Ruiru Reservoir). Development of detailed plans and designs for fish passes or fish ladders as integral components of each of the intake weirs. Development of detailed plans and designs for fish passes or fish ladders as integral components of all proposed storage reservoirs. Surveys in the riparian zone of bird species and population numbers.
Resettlement Action Plan	The installation of the pipelines may result in displacement of households.	A Resettlement Action Plan should be prepared. Involuntary displacement should be avoided.
Data on land use / land cover	Detailed information on the land use and land cover will be required as part of the EMP for all areas adjacent to the intake sites, outfall and other access sites for: 1. Northern Collector tunnel 2. Storage Reservoirs 3. Borehole sites 4. Pipeline routes	Detailed land use and land cover surveys. These will form a baseline for environmental and social monitoring components of the Environmental Management Plan.

Information Requirements		Actions, Surveys or Data Recording
Disposal of excavated material	Instead of considering the excavated material from the Northern Collector Tunnel (Phases 1 and 2) as "spoil", requiring disposal, it should be used as raw material for a range of activities such as road repair and construction, and for use as building material.	Selection of suitable sites for long-term storage of excavated material. It is suggested that disused quarries should be used for storage of excavated material. It is also recommended that disposal of excavated material is integrated with the regeneration and rehabilitation of disused quarries.
Storage areas for excavated material	Construction of temporary on-site storage of material excavated from the Northern Collector tunnels will be required. Storage will need to be within fully bunded structures so as to prevent erosion and siltation in rivers.	Selection of suitable sites for temporary storage of excavated material. Purchase of the land and compensation of households for loss of future earnings from these areas. Storage sites will need to be constructed with at least 40 m buffer zone between the bunded storage area and the edge of the river.
Ambient air quality	Active sampling methods to determine air quality will be required.	Baseline sampling to determine ambient air quality will be carried out prior to the commencement of construction activities.
Baseline noise levels	Noise level measurements will be need to be carried out as per ISO standards.	Baseline sampling to determine noise levels will be carried out prior to the commencement of construction activities.
Technical committee	A technical committee, including environmental assessment personnel, needs to be established with the remit to assess any damage caused and assess required compensation or mitigation measures during construction and operational phases.	Establish technical committee and review the collection of baseline monitoring data. Ensure that contracts for the construction phase include reference to supervision by the technical committee. Ensure that all local communities are fully aware of the details of upcoming activities.

Information Requirements		Actions, Surveys or Data Recording
Payment for Environmental Services (PES)	There is a need for improvement in water resources management, including water quality. This can be accomplished by development of market-based mechanism where land owners are rewarded by service beneficiaries.	Develop PES mechanisms within the watersheds in order to improve water quality and to provide improved ecosystem services for both existing water sources and proposed water sources for the satellite towns, including proposed storage reservoirs.

Construction Phase

Where the household property or productive assets (e.g. plantation tea) adjacent to the construction or operational sites are to be infringed upon or otherwise impacted, owners and workers should be sufficiently and promptly compensated. Similarly, where property or productive assets are impacted by trucks or other transport associated with construction and excavation activities, sufficient compensation should be given. National guidelines for compensation rates should be followed as minimum compensation, including rates provided by the Ministry of Agriculture for the value of crops and trees. The value of tea and coffee plantations should also take account of the long term value of these crops to household incomes in this area.

During the construction phase, the role of the contractor is critical. With specific reference to the Environmental Management Plan (EMP), the role of the Contractor will be to:

- Implement, manage and maintain the construction elements of the EMP for the duration of the contract;
- Designate, appoint and/or assign tasks to personnel who will be responsible for managing the relevant components of the construction EMP, and assign appropriate authority, accountability and necessary equipment and facilities for these personnel to carry out their duties;
- Ensure that all sub-contractors and other workers appointed by the Contractor are aware of their environmental responsibilities while on site or during the provision of their services off site, and ensure that they comply with and implement the construction EMP during the duration of their specific contracts;
- Provide appropriate resources, including budgets, equipment, personnel and training, for effective control and management of all environmental risks associated with the construction phase.

Table 9-44: Environmental, Safety and Health Issues during Construction Phase

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Technical committee	Continue the technical committee and review the collection of baseline monitoring data. Ensure that the technical committee is able to review information from continued environmental monitoring activities as well as all ongoing construction activities.	All involved Authorities and Construction management
River flows	Continued daily monitoring of flows upstream and downstream of all diversion structures and storage reservoir sites on a daily basis, including at all new river gauge sites installed during pre-construction phase. Monitoring of sediment transport at all river gauges.	Data collection
Water Quality	Monitoring of water quality, including tests for biological contamination that may be related to potential human health issues. Monitoring to be carried out at all river gauge sites.	Data collection, Health & Safety
Loss of land and changes in land cover	Monitor changes in land use and land cover, including: • Extent of the riparian vegetation. • Forest and woodland, and individual trees. • Tea and Coffee plantations. • Other agricultural areas, and areas that are suitable for and used by grazing livestock (e.g. sheep and cattle owned by the communities). • Household land and adjacent community areas. • Roads and tracks, including footpaths used by the community. • Loss of access to land as a result of pipeline wayleave. • Change in vegetation cover and land use along pipeline routes. • Change in vegetation cover and land use in and adjacent to proposed Ngorongo Water Treatment Works.	Data collection
Establishment of Buffer Zones	Ensure that all construction activities are confined to within defined buffer zones.	Administrative
Awareness	Ensure that all construction personnel and supervision personnel are aware of the environmental requirements and are equipped to deal with these requirements. This should include relevant health and safety requirements.	Administrative

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Site management	All areas should be securely fenced at least 3 m from the edge of operational areas using chain link fencing of at least 1.5 m high. Warning notices / signs erected at all entrances. All roads and tracks to be safely accessible. All footpaths and access to tea plantation lands to be safely accessible by local communities and landowners.	Administrative
Workmen's camps and Settlements	Ensure careful planning and location of both temporary campsites, and more permanent workmen's camps. Provide local employment. Provision of adequate sewage and waste disposal facilities, and adequate resources, including water supplies and household fuel. There may also be health risks and increased requirements for health services, including both first aid facilities and medical centres.	Construction management Administrative, Health & Safety
Health and Safety	Relevant protective gear and equipment should be used by all construction personnel, including: • Protective helmets • Gloves • Protective footwear • Safety goggles • Dust masks • Overalls/dust coats Blasting materials and all other potentially dangerous materials to be acquired, stored and used subject to relevant permits.	Administrative, Health & Safety
Safety Training	Operators to be trained on safety, health and environmental issues. Each construction site should have a person in charge of safety, and Safety, Health and Environment Committees should be established at each construction site. These should report to the Technical Committee.	Administrative, Health & Safety
Waste Disposal	Waste collection and disposal pathways and sites will be identified for all major waste types expected from construction activities. Mineral construction waste will be separated from general refuse, organic, liquid and chemical wastes by onsite-sorting and stored in appropriate containers. There will be no open burning of waste materials at the sites.	Administrative, Health & Safety

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Welfare	Adequate welfare facilities to be provided at all sites, including clean water and sanitation, first aid kit with trained first aiders.	Administrative
Access Roads to NC tunnel access sites, and Dam construction sites	Road maintenance to be carried out on a regular basis to ensure continued access for all local services. Road maintenance should make maximum use of material excavated from the tunnel.	Administrative
Pipelines and Access Roads	Impacts may occur where transmission pipelines cross roads. These impacts should be prepared for and included in detailed designs. Required mitigation measures should be incorporated in designs and action plans.	Construction management
Pipeline Access for Maintenance	Long-term access to the pipelines will be required for routine checking and maintenance. Careful location of pipelines will be required, and access incorporated in detailed designs.	Construction management
Noise Levels	Regular monitoring of noise levels. Reporting of unacceptable noise levels.	Data collection
Air Quality	Regular monitoring of air quality, including monitoring of dust levels near all excavated material storage sites, and reporting of unacceptable air quality levels so that appropriate actions can be taken by construction management.	Data collection
Habitat Restoration Required as a result of Clearance of Vegetation	Minimize clearance of natural vegetation. Ensure a buffer zone of a minimum of 30 metres between all construction sites or related activities and the riparian zone along the rivers. The only exception to this will be the construction of the intake weirs and associated structures. For every tree cut or felled, ensure that a minimum of five trees are planted and maintained elsewhere in suitable sites nearby along the rivers, either upstream or downstream of the intake sites, or adjacent to storage reservoirs. Creation of wildlife corridors to replace all areas where removal of trees or other vegetation has resulted in disruption to existing wildlife corridors. Habitat restoration in areas impacted by clearance of vegetation along the transmission pipeline routes.	Construction management

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Monitoring of Habitat Restoration	All areas impacted by clearance of vegetation will require habitat restoration. This restoration should be monitored to ensure success and feedback of these findings must be provided to construction management to enable improvements where necessary.	Data collection and Construction management
Erosion	Monitor erosion and ensure adequate erosion control measures are in place	Data collection and Construction management
Pollution	Monitoring of pollution, including dust and noise pollution. Contamination from wastes and oil/fuel spills may also occur. All sites where oil or fuel may be stored should be protected by fully bunded structures to contain all potential spills. Such sites will require to be constructed with a buffer zone of at least 40 m between the fuel storage area and the edge of the river.	Construction management
Excavated Material	Finalise the construction of temporary on-site storage facilities for material excavated from the tunnels. Storage will need to be within fully bunded structures so as to prevent erosion and siltation in rivers.	Construction management
Storage of Excavated Material	On-site storage of excavated material will require the construction of fully bunded structures to contain all of the excavated material so as to prevent erosion and siltation in the rivers, constructed with a buffer zone of at least 40 m between the bunded storage area and the edge of the river. Storage areas should avoid areas being close to tea plantations due to the potential problems related to contamination of tea with dust from excavations. Storage areas should avoid being located on steep slopes due to the potential problems of erosion.	Construction management
Transport of Excavated Material	Ensure that there is sufficient transport to enable transfer of excavated material from temporary on-site storage areas to permanent facilities that have been prepared elsewhere.	Construction management

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
Hydrogeology	Tunnelling may result in changes to underground drainage as a result of underground fractures. This will require detailed investigation during construction. Storage reservoirs may also result in changes to underground drainage. The wider impacts of changes in underground drainage on groundwater resources will also need to be investigated, and suitable mitigation measures developed and implemented.	Data collection and Construction management

Operational Phase

Impacts that can be expected from operation of the intake weirs for the Northern Collector Phase 1 are listed in Table 9.41. Similar impacts can be expected for the Northern Collector Phase 2. Primary environmental impacts resulting from operation of the intake weirs are related to the significant change in downstream hydrology. These will result from changes to water flow patterns, changes in quantity (in particular reduction in flood events), and also from a deterioration in water quality. Changes in water quality are themselves a direct response to the changes in flow. In addition, the normal or base flows will, after installation of the intake weirs and abstraction of water, change to the flows similar to those currently classified as “extreme low flows”, or to the lower range of flows classified as low flows, or base flows. Similarly, flows released below all proposed storage reservoirs are expected to be equivalent to extreme low flows.

The provision of adequate downstream environmental flows, as a component of Reserve Flows, is considered to be essential for all rivers. Similarly, provision of adequate compensation flows is viewed as being critically important for all downstream communities.

An important consideration will be the cumulative impact arising from the combined operation and release of downstream Reserve Flows from all intake weirs, as well as from proposed storage reservoirs. Cumulative impacts are likely to include the following factors:

- Less flow available for rural household water supplies, especially for those households that depend on collection of water from rivers;
- Less flow available for use in current and future agricultural activities, especially for use during dry seasons, in order to provide food required by the increasing population of Nairobi;
- Reduction in the flow reaching Masinga Reservoir;
- Short periods with zero flow, preceded and/or followed by further periods with extreme low flow.
- Reduction in flow available for use by the Yatta irrigation scheme.

Up-to-date information on all downstream abstractions from the rivers, including both licensed and unlicensed abstractions for all uses (including: household, agricultural, irrigation, industrial uses, and methods of abstraction) should continue to be obtained, following on from the

collection of this information as part of the EMP during pre-construction phase. These data will need to be monitored and updated on a regular basis and the requirements for downstream Reserve Flows modified accordingly.

Monitoring surveys initiated as part of the EMP during the pre-construction phase should continue to be conducted on a regular basis. These include surveys to determine changes that may occur within aquatic and riparian habitats. Where such changes are related to reduced downstream flows, it may be necessary to either adjust the levels and timing of environmental flows accordingly, e.g. though the provision of high flow pulses, or to carry out alternative mitigation or preservation measures.

Where there are a number of different relevant Authorities for management or control of specific issues raised by the Environmental Monitoring and Management Plan, it will be necessary to establish Technical Committees and Working Parties with representatives from each of the different authorities. Examples may include monitoring of downstream flows and the setting of or modifying Reserve Flows (Environmental Flows and Compensation Flows). Different Authorities may be responsible for the monitoring and recording of daily flows, for Nairobi water supplies, for the licensing of abstractions, for the use of water for irrigation of smallholder and/or commercial agriculture, household and rural water supplies, and for environmental flow requirements, as well as for downstream hydropower use at Masinga Dam or mini-hydro schemes and other downstream needs.

Table 9-45: Environmental Issues during Operational Phase

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
River Flows	Continued daily monitoring of flows upstream and downstream of all diversion structures, and all storage reservoirs, on a daily basis. Monitoring of sediment transport at all river gauges.	Data collection
Reserve Flow Requirements	Continued assessment of the abstractions by downstream water users (both licensed and unlicensed) will be required on a regular basis, including monthly or seasonal abstraction requirements. Changes in requirements, as well as trends in future needs, need to be monitored and assessed in order to maintain up-to-date and adequate levels for Reserve Flows.	Data collection and analysis
Rural Water Supplies	Ensure that all abstraction sites for rural water supply systems are supplied with adequate flows. Future changes in requirements for downstream rural water supplies need to be incorporated within the overall management of downstream Reserve Flows.	Management of Intake Sites
Irrigation Requirements	Ensure that downstream irrigation requirements are supplied with adequate flows. This needs to incorporate the future needs for irrigation	Management of Intake Sites

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
	and water supplies that will be required in order to supply the agricultural products (including both crops and livestock).	
Groundwater Levels	As a result of reduced downstream flows there may be a reduction of recharge to groundwater from impacted rivers. Changes in groundwater levels may also occur as a result of extraction of water from the proposed well fields. It will be necessary to install an increased network of river gauges and recording stations in order to cover the potentially impacted areas. Existing springs and dug water supply wells in the areas within the geological strata affected by the proposed groundwater well fields will need to be identified and mapped. The yields from these sources will need to be recorded and monitored. Alternatively, piped water supplies will need to be provided in those cases where these water sources are impacted by reduced groundwater levels resulting from abstraction	Data collection
Provision of Downstream Reserve Flows	Based on the assessment of downstream water use requirements, adjust the provision of Reserve Flows to ensure adequate provision of water resources for all downstream users, whilst at the same time maintaining adequate environmental flows. Ensure that there are no periods with unacceptable low flows or zero flows in downstream reaches of the rivers. At such times, increased release of flows at intake sites (largely derived from forested areas of the Aberdares) is likely to correct these potential problems. In some cases it may be necessary to restrict abstractions by selected users in order to ensure maximum provision of water resources to all downstream communities.	Management of the Intake Sites
Water Quality	Monitoring of water quality, including tests for pollutants and biological contamination that may be related to potential human health issues. Monitoring to be carried out at all river gauge sites on a regular monthly basis (or more frequently).	Data collection, Health & Safety
	Detailed monitoring of water quality should also be carried out at the proposed Ngorongo Water Treatment Works.	Data collection, Health & Safety

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
	Reduced nutrient availability in downstream areas, resulting from the reduction in downstream flows, may result in a reduction in productivity of downstream systems, including cultivation in alluvial and other riparian areas downstream. In such cases it may be necessary to carry out mitigation or corrective measures, for example through the release of high flow pulses or flood events to induce sediment transport.	Data collection. Actions to be taken by Relevant Authorities.
	Reduced water quality as a result of reduced flows may result in increased health risks for downstream communities especially for those households dependant on untreated river water. A change in faecal bacterial concentrations and waterborne pathogens as a result of reduced flows and from inflow of contaminants from upstream is likely and needs to be monitored. There may also be increased risks from malaria, schistosomiasis, and cyanobacteria.	Monitoring of diarrheal and other diseases in rural households. Actions by Relevant Authorities.
	Untreated sewage waste runoff from surrounding communities, and contamination from agricultural chemicals, accumulating in proposed storage reservoirs.	Actions by Relevant Authorities.
	Carry out baseline survey on water-borne diseases at the health centres.	Relevant Authorities
Water Quality (continued)	All water quality data to be analysed and made available on a regular basis to all authorities involved with the management of the water resources and related issues.	Relevant Authorities
	Develop Payment for Environmental Services (PES) mechanisms within the watersheds of proposed storage reservoirs in order to improve water quality and to provide improved ecosystem services for both existing water sources and proposed future water sources for the satellite towns.	Relevant Authorities
Changes to Aquatic and Riparian Habitats	It will be necessary to continue regular monitoring of riparian habitats, and surveys of aquatic fauna and bird populations in riparian zones. Results of these surveys will provide indication of potential changes or loss of habitat downstream as a result of changed hydrological regimes, including cumulative downstream impacts. Depending on the nature and specific locations of observed changes, those management authorities concerned with the maintenance of riparian zones will	Data collection Actions to be taken by Relevant Authorities

Environmental and Social Issues	Environment Monitoring and Management Requirements and Mitigation Measures	Type of Action or Authority
	need to propose and carry out mitigation or corrective measures. These may for example include release of environmental flows that include high flow pulses, and/or the release of higher flow volumes during the dry seasons.	
Increased Settlement	Increased permanent settlement is likely to result from activities during the operational phase. In addition to operational staff, induced settlement is likely to occur in the surrounding area, creating potential stress on local resources and facilities, including fuelwood.	Intake Site Management Authorities
Impact from presence of pipelines	Long-term access to the pipelines will be required for routine checking and maintenance. Assuming that most of the pipeline length is buried with limited surface structures, the overall impacts can be expected to be relatively low. However, leaks are highly likely to occur along transmission and distribution pipelines, and possibly at treatment works. Contamination of supply pipes may also occur at these sites. Leakages may result in health risks, e.g. Malaria, Cholera, Typhoid, Dysentery, Diarrhoea and other water-borne or water-related diseases. All leaks should be monitored and controlled accordingly. Regular monitoring and maintenance is considered essential. Early detection of leaks reduces the possibility of public health risks.	Pipeline Management Authorities.
Pipeline leakage	Leakage from distribution pipelines is likely to account for an unacceptable loss, both of water and potential revenue to the system. Regular identification and repair of all leakages will contribute towards an unnecessary loss of water resources.	Relevant Authorities

13 Multicriteria Analysis of Satellite Towns

13.1 Principles

Three water supply Options (Independent, Strategic and Mixed Supply) have been considered and investigated to meet the water sources development strategy for the 13 satellite towns until 2035. A Multicriteria Analysis has been carried out to compare and rank the different options against the objectives of the development strategy. The criteria have been selected to assess the impact of each option against the following six key sustainability issues:

- **Natural Resources Criteria**: essentially these are mandatory water quantity indicators on: the impact on downstream environmental flows and competition with alternative

downstream/upstream uses; the security of the water resource and the diversity/ reliability of the resource to meet the water demand of the satellite towns.

- **Economic Sustainability**: options are compared through their respective indicators of least cost analysis: *Average Incremental Economic Cost of water (AIEC),*the present value of the total capital and O&M costs of an option divided by the present value of water outputs for that option over the period 2012-2037. *Present Value of Economic Costs (PVEC**),*** an indicator of the scale of the capital investment costs and O&M costs*; Present Value of Operation and Maintenance Costs (PVO&M)*, a measure of the relative cost of operating the system over its life.
- **Technical Aspects**: Options are rated on the flexibility of the new infrastructure to allow for further development of the resources and flexibility in supply to adjust to changes in population and future demand, and the complexity of the scheme in the number of new resources that have to be developed.
- **Operation and Management**: Five aspects of Operation and Management are considered: the complexity and number of management entities involved; susceptibility to prioritisation and conflict in water allocation in times of scarcity; multiplicity of water treatment works, conformity to national water supply policy; and the degree of variability in water tariffs/ potential for a standardised tariff.
- **Environment Sustainability**: Options are compared against their downstream impacts of water quantity releases on the environment; the impact they have on water quality issues for upstream land use; and potential environmental impacts on downstream ecosystems during the construction and operational stages.
- **Social Sustainability:** Options are compared against their potential impact on resettlement, land losses and compensation through the development of the infrastructure.

13.2 Weighting Criteria

All criteria do not have the same importance for the ranking and are given a weighting according to their importance to the assessment. The table below presents the adopted weights for each of the criteria factors. Overall, the natural resources aspects are accorded 15%, economic aspects 35%, technical aspects 10%, operation and management 25%, environment 10% and social 5%. Table 9.46 presents the matrix used for the Multicriteria Analysis showing the weighting given to each factor.

Table 9-46: Multi-criteria Analysis Matrix –Weighting of Criterion

Sustainability Issue		Headline Criteria	Sub-criteria	Weighting %	
A. Natural Resources					
A-1	Resources	Water Quantity	Environmental & Downstream Water Demands	5%	
A-2	"	"	Security of the Resource	5%	
A-3	"	"	Diversity of the Resource	5%	15%
B. Economic					
B-1	Economic	New Infrastructure	Average Incremental Economic Cost (AIEC)	15%	
B-2	"	"	Present Value of Economic Costs (PVEC)	10%	
B-3	"	Operation	Present Value of O&M costs (PVO&M)	10%	35%
C. Technical					
C-1	Technical	New Infrastructure	Flexibility in Further Development/ Allocation	7.5%	
C-2	"	"	Number New Additional Independent Water Sources	2.5%	10%
D. Operation and Management					
D-1	Management	New Infrastructure	Institutional and Managerial Complexity	8%	
D-2	Operation	"	Risk of Bulk Supply Prioritization Conflict	5%	
D-3	"	"	Treatment Facilities Complexity & Operational Reliability	4%	
D-4	Management	"	Institutional Policy Conformity	4%	
D-5	"	"	Variation of Tariffs	4%	25%
E. Environment					
E-1	Environment	Water Quantity & Quality	Downstream Impacts	5%	
E-2	"	"	Upstream Impacts	2%	
E-3	"	New Infrastructure	Construction Impacts	2%	
E-4	"	"	Operational Impacts	1%	10%
F. Social					
F-1	Social	Amenity	Resettlement / Compensation/ Land-loss Issues	5%	5%
			TOTAL	**100%**	

13.3 Multicriteria Analysis Steps

The analysis is carried out in three steps:

First Step – Mandatory Criteria: Meeting Projected Water Demand and Security on the Resource.

As all three options are designed to meet the quantity of water supply required to meet the projected 2035 demand for the Satellite Towns, they are all considered to meet this mandatory precondition, and therefore a criteria for this aspect is not required to be assessed.

The other criteria in this section: (i) ensuring sufficient security on the water sources for downstream environmental flows and other water demands, (ii) the security of the resources, and (iii) diversity of the resources have been considered as mandatory criteria. The three aspects are scored as either poor, medium or good, and judged whether they meet the mandatory criteria.

Second Step: Economic Least Cost Analysis.

The costs of developing each option are compared through the least cost analysis applying the three criteria mentioned above: AIEC, PVEC and PVO&M, calculated over the 2013-2035 period.

Third Step: Multicriteria Analysis on Other Criteria.

The scenarios are then compared though a multicriteria analysis against the other secondary indicators comprising the four main sustainability issues which include technical aspects, operation and maintenance issues, environmental considerations, and social aspects.

13.4 Results of Multicriteria Analysis

The three Options for developing water supply for the Satellite Towns have been assessed against the multicriteria matrix above. The main points about the assessment are discussed below, with the results of the weighting criteria shown in Table 9-47 while Table 9-48 presents the final weighted score and ranking of the three options.

A. Natural Resources (Mandatory) Criteria (First step)

- ✓ **Downstream Water Demands**

All three Options are considered to score equally (satisfactory/good) for allowing sufficient water for downstream environmental flows and to meet anticipated future urban and rural water demands. This aspect was part of the design standard for water abstraction so maintaining minimum flows were allowed for in the design.

- ✓ **Security of the Water Resource:**

Security of water supply is considered for both the security on the water sources and the reliability of water supply routes.

The Independent Option is considered to have greater security as it has run-of the river sources fully supported by more storage dams while the Strategic Option scores lower because the storage component is lower (fewer dams). The Mixed Option ranks in the middle as it is a combination of the other Options.

- ✓ **Diversity of the Water Resource**:

This relates to the risk of the supply to long term or extended change through dry years and climate change. This risk is higher for scenarios which rely mostly on run-off river abstraction, without developing new dams with storage reservoirs. Other alternative complementary sources such as groundwater, rainwater collection etc., are also considered.

Of the three Options, the Independent Option has more dams and storage and so is judged to have greater diversity and resource resilience. The Strategic Option has less diversity and scores lower. None of the options have comprehensive plans to develop roof collection of recycled water and the ground water exploitation is similar for all three options, especially for the four towns that rely exclusively on ground water for meeting the projected demand.

B. Economic Least Cost Analysis (Second step)

Details of the economic least cost analysis is presented in the preceding Section 8, while a summary of the Average Incremental Economic Cost of water per m^3 AIEC for the three options is presented in Table 9-38. Of the three Options, the Mixed Supply Option scores clearly the best as its AIEC of US\$0.72/m^3 is 27% less compared with the other two Options (US\$0.99/m^3 and US\$0.92/m^3 for Independent and Strategic respectively).

The present value of economic costs PVEC (which includes the initial capital investment costs, annual fixed and annual variable operation and maintenance costs) shows that the Mixed Option also ranks the highest with the lowest PVEC, as a result of having capital costs 28% less than Independent supply, the most expensive option.

The present value of O&M costs, included to allow for the importance of the future pumping costs which affects financial sustainability and the magnitude of water tariffs, shows that the Mixed Supply Option ranks highest as it has the lowest PV of O&M costs.

Third Step - Multicriteria Analysis of other Criteria

The assessment of the four remaining aspects completes the Multicriteria Analysis. Pertinent comments are included below.

- **Technical aspects.** Two criteria are considered: flexibility in further development, and the number of new water sources to be developed.
    - **Flexibility in further development.** The three Options are assessed whether the development plan allows for further development of the resource share and scored "poor" if it does not allow, "medium" if it partially allows; and "good" if the option fully allows. The Independent Option is scored medium on account of the largely self contained water resources to be developed, Strategic Option is scored good as it has greater flexibility, while the Mixed Option scores midway between.
    - **Number of new water resources to be developed.** An option is considered poor against this criterion when there are many sources to be developed adding to complexity through to good for few new sources. The Strategic Option is scored good on account of the fewer number of dams and sources, while the Independent Option scores poor, with the Mixed Option scoring medium to good.
- **Operation and Management aspects.** Five criteria are used to compare the different development options relating to operation and management:
    - **Operation and management**: relating to the institutional and management capacity required to manage the water supply operation according to the number of institutions or entities involved. The Independent Option is judged to score poor on account of the greater number of water supply providers that would be involved to manage each town's water supply system, more or less autonomously, while the Strategic Option which would involve a larger centralised bulk-water provider scores good as this entity could be expected to have a critical mass to recruit and retain the more competent water management personnel and to operate on a more commercially viable manner. The Mixed Option is assessed as medium.
    - **Prioritisation of water demands:** this aspect relates to the susceptibility to prioritization and inequitable water supply allocation in times of shortage. The Independent Option scores the highest as it will have most control over the extraction and allocation of its water resources and not be subject to the allocation of scarce resources to competing demands by a central bulk provider in time of shortages. Conversely, the Strategic Option will have the highest chance of prioritization and so is rated least favourable while the Mixed Option will be between the two extremes.
    - **Treatment facilities:** relating to the number of water treatment facilities and their operational complexity with options having fewer facilities rating higher. The Strategic Option is judged to score the highest as it has fewer WTWs, while the Independent Option ranks poorest with the Mixed Option ranked midway.
    - **Institutional policy:** the options are assessed on their conformity to the national institutional policy for providing water supply services, which is understood to favour a centralised system rather than a number of independent water service providers. The Strategic Option is given a higher score on this account as being more in line with the current policy.

- **Tariff regime:** relating to the potential (and need) for variation in the tariff structure between the Towns. The Option with the potential to have more uniform tariffs is preferred and scores higher than a situation with the likelihood of having a range of tariffs. The Strategic Supply Option receives the highest score for the reason that one main central bulk water provider a universal tariff could be applied for bulk water delivered to all the Satellite Towns. This simplifies the tariff setting procedures and minimises the administrative burden and the potential for conflict. The Independent Option scores poor as there is likely to be a wide variation in tariffs under this Option.

- **Environment considerations:** the four selected criteria include water quantity, water quality and construction and operation impacts.
  - **Downstream impact (water quantity and quality):** impact of water quantity downstream on the environment: water flow patterns and water and land use. The Strategic and Mixed Supply Options are assessed as having some impact, while the Independent Option is likely to have less impact and so scores higher.
  - **Upstream impact (water quality and quantity)**: impact on upstream land use, water quality, erosion, nutrients, pesticides, and runoff. The Strategic and Mixed Options are assessed as having manageable issues and score midway, while the Independent Option is assessed as potentially having significant issues on account of having more dams, and consequently scores lower.
  - **Construction and operational impacts**: Impact on and appropriate management of downstream ecosystems during the construction and operational stages. All three options are assessed as having minimal impact and are ranked the same.

- **Social Criteria:** the criteria applies to resettlement and compensation issues and land lost for dam storage, pipelines, WTWs etc.
  - **Resettlement/land losses:** The Strategic and Mixed Supply Options are assessed as having manageable issues and are scored mid range, while the Independent Option is rated as having a greater risk of potential significant issues because of the greater number of dams to be constructed and associated land loss necessitating resettlement and compensation. .

13.5 Results of the Analysis

The following tables present the results of the Multicriteria Analysis. Table 9-47 shows the weighting criteria and the allocation of weightings, while Table 9-48 presents the final weighted score and the ranking of the six scenarios.

Comparison of the three Options shows that overall Mixed Option with a score of 71% ranks higher by 12% than Strategic supply at 59%, with the Independent Option ranking the lowest against the combined criteria with 46%.

13.6 Discussion of Results

The Multi-Criteria Analysis clearly shows that the Mixed Supply Option has the highest ranking and is the preferred Option. The main reason for this is because its capital investment costs of US$871 million are lower, by 20% or US$225 million, compared with the Strategic Supply Option, which is estimated to cost US$ 1.1 billion, the next best least cost option. As a result, the Mixed Option scores higher for the economic criteria, which as this factor contributes 35% to the weighting; provides an overwhelming advantage in the overall weighting.

In terms of the other criteria, the Mixed Option is mostly assessed as being mid-way between the other two Options – Independent Supply and Strategic Supply. The Strategic Supply Option scores best for the technical aspects concerning flexibility in further development and the number of new water sources that have to be developed, and has advantage in terms of institutional and management complexity, conformity to institutional policy and uniform tariff setting. The only other criteria where the Mixed Option is assessed as scoring better than Strategic Option is the risk of prioritisation conflict in the allocation of water resources in time of shortage. Generally apart from the economic least cost analysis which clearly favours Mixed Supply, the Strategic Supply Option scores highest, while the Independent Option scores the least

The Mixed Option does have an advantage that the development of the infrastructure could be developed on a more piecemeal or pragmatic manner compared with the Strategic Supply Option which requires that the four new dams be constructed by 2018 to provide the necessary supply. The Strategic Supply Option will require a large tranche of finance to implement this, which may be more difficult to secure than a number of less costly components that might be more attractive to a mix of funding agencies. If funding is not secured and the development of the infrastructure is delayed then towns that are relying on bulk supply to meet their growing demand will be left high and dry. Under the Mixed Option they will have the Option of developing their own water resources, perhaps using a mix of funding sources.

An important difference between the Mixed Supply and Strategic Supply Options is the role of a centralised bulk water provider and the integration of the Satellite Town system with the Nairobi City. The centralised bulk supply will allow interregional transfers that may be more flexible in accommodating changes in the future demand without the need for developing localised infrastructure. Conversely, if the projected demand does not materialise for a specific location or town, bulk supply can provide according to demand avoiding the under utilisation of capital investment in local infrastructure, such as an independent dam or well field.

The growth in water demand within the Satellite Towns (and within Nairobi City) is dynamic affected by many factors such as the development of new arterial roads, infrastructure, housing estates, industrial development projects etc. that may result in the future actual demands being much different to that which has been projected.

Table 9-47: Multi-criteria Analysis - Weighting Criterion/ Allocation of Weightings

Sustainability issue		Headline Criteria	Sub-criteria	Description	(0) Poor	(0.5) Medium	(1) Good	Independent	Strategic	Mixed
A. Natural Resources (Mandatory Criteria)										
A-1	Natural Resources	Water Quantity	Downstream Water Demands	Water left for downstream Environmental flows and to meet Downstream Rural and Urban water demands	Not Enough	Satisfactory (70%)	Good (96% of minimum flow)	**0.75**	**0.75**	**0.75**
A-2	Natural Resources	Water Quantity	Security of the Resource	Risk of water supply option to long term or extended changes in dry years, climate change etc	Run-of the river source	Run-of the river source with some storage	Run-of the river source fully supported by storage	**1.00**	**0.50**	**0.75**
A-3	Natural Resources	Water Quantity	Diversity of the Resource	Share of alternative water sources e.g. groundwater, roof catchment, wastewater recycling etc. to surface water sources	Below 5% of year 2035 total water demand	Between 5 to 10% of year 2035 total water demand	More than 10% of year 2035 total water demand	**1.00**	**0.50**	**0.75**
							Average Score - Mandatory Criteria	**0.92**	**0.58**	**0.75**
							Course Screening	**Consider**	**Consider**	**Consider**
B. Economic (Least Cost Analysis (5% discount rate))										
B-1	Economic	New Infrastructure	Average Incremental Economic Cost (AIEC)	Normalised discounted Average Economic Cost / m3 (Capex and O&M) of the proposed scenario over the projected life of the infrastructure	AIEC > 0.90 USD/m3	0.80 USD/m3 < AIEC < 0.90 USD/m3	AIEC < 0.80USD/m3	**0.25**	**0.25**	**1.00**
B-2	Economic	New Infrastructure	Present Value of Economic Costs (PVEC)	Total Present Value of Capital Costs and Operation and Maintenance Costs	PVEC > 700 MUSD	500 MUSD < PVEC < 70 MUSD	PVEC < 500 MUSD	**0.30**	**0.40**	**0.75**
B-3	Economic	Operation & Maintenance	Present Value of O&M cost (PVO&M)	Net Present Value of Operation and Maintenance Costs over the projected life of the infrastructure	PVO&M > 150 MUSD	100 MUSD < PVO&M < 150 MUSD	PVO&M < 100 MUSD	**0.40**	**0.40**	**0.75**
C. Technical Aspects										
C-1	Technical	New Infrastructure	Flexibility in Further Development	Allows for further development of the sources and flexibility in supply	Does not allow	Partially allows	Fully allows	**0.50**	**1.00**	**0.75**
C-2	Technical	New Infrastructure	Number of New Water Sources	Number of new water sources to be developed - dams, run-of-river, ground water	Many sources	Average number	Few sources	**0.25**	**1.00**	**0.75**
D. Operation and Management										
D-1	Management	Operation & Maintenance	Operational aspects	Institutional and management capacity required for water supply operation	High number of institutions	Average number of institutions	Low number/ centralised management	**0.25**	**1.00**	**0.50**
D-2	Operation	Infrastructure	Prioritization of Demands	Susceptibility to Prioritization in water supply allocation in times of shortage	Likely to Prioritization	Minimal Prioritization	Not likely to Prioritization	**1.00**	**0.25**	**0.50**
D-3	Operation	New Infrastructure	Treatment Facilities/ Operation	Multiplicity of water treatment facilities & operational complexity	Many treatment facilities	Average number of treatment facilities	Few treatment facilities	**0.25**	**0.75**	**0.50**
D-4	Management	Infrastructure	Institutional Policy	Planning in line with National water supply policy	Not Consistent	Fairly Consistent	Adequately Consistent	**0.25**	**1.00**	**0.75**
D-5	Management	Infrastructure	Variation of Tariffs	Potential for variation of water tariffs from one scheme to another	High variations	Moderate variations	Minimal variations	**0.25**	**1.00**	**0.75**
E. Environmental Considerations										
E-1	Environment	Water Quantity and Quality	Downstream Impacts	Impacts on Environments Downstream; water flow patterns, downstream water and land use from reduced environmental flows	Significant Impacts	Some Impacts	No change	**0.75**	**0.50**	**0.50**
E-2	Environment	Water Quantity and Quality	Upstream Impacts	Impacts on Upstream Land Use on water quality; runoff & erosion, nutrients/pesticides runoff, change in wood cover and land use.	Significant Issues	Manageable Issues	No Issues	**0.25**	**0.50**	**0.50**
E-3	Environment	New Infrastructure	Construction Impacts	Environmental impacts from construction, including Diversion Weirs, Dams, Water Treatment works and Transmission Systems	Significant Impacts	Some Impacts	Minimal Impacts	**0.25**	**0.75**	**0.50**
E-4	Environment	New Infrastructure	Operational Impacts	Environmental impacts from operation, including management of intake sites, aquatic fauna and riverine ecosystems, incl impacts on protected areas and vulnerable species.	Significant Impacts	Some Impacts	Minimal Impacts	**1.00**	**1.00**	**1.00**
F. Social Aspects										
F-1	Social	Amenity	Resettlement / Land losses	Resettlement, compensation and land loss issues for dam storage reservoirs, pipelines, WTW, etc.	Significant issues	Manageable issues	No major issues	**0.25**	**0.50**	**0.50**
							Average Score - Other Criteria	**0.41**	**0.69**	**0.67**

Table 9-48: Multi-criteria Analysis - Weighting of Criteria and Ranking of Options

Sustainability Issue		Headline Criteria	Sub-criteria	Weighting		Independent	Strategic	Mixed
				%				
A. Natural Resources								
A-1	Natural Resources	Water Quantity	Environmental & Downstream Water Demands	5%		0.04	0.04	0.04
A-2	"	"	Security of the Resource	5%		0.05	0.03	0.04
A-3	"	"	Diversity of the Resource	5%	15%	0.05	0.03	0.04
B. Economic (Least Cost Analysis (5% discount rate))						***0.14***	***0.09***	***0.11***
B-1	Economic	New Infrastructure	Average Incremental Economic Cost (AIEC)	15%		0.04	0.04	0.15
B-2	"	"	Present Value of Economic Costs (PVEC)	10%		0.03	0.04	0.08
B-3	"	Operation	Present Value of O&M costs (PVO&M)	10%	35%	0.04	0.04	0.08
C. Technical Aspects						***0.11***	***0.12***	***0.30***
C-1	Technical	New Infrastructure	Flexibility in Further Development/ Allocation	7.5%		0.04	0.08	0.06
C-2	"	"	Number New Additional Independent Water Sources	2.5%	10%	0.01	0.03	0.02
D. Operation and Management						***0.04***	***0.10***	***0.08***
D-1	Management	New Infrastructure	Institutional and Managerial Complexity	8%		0.02	0.08	0.04
D-2	Operation	"	Risk of Bulk Supply Prioritization Conflict	5%		0.05	0.01	0.03
D-3	"	"	Treatment Facilities Complexity & Operational Reliability	4%		0.01	0.03	0.02
D-4	Management	"	Institutional Policy Conformity	4%		0.01	0.04	0.03
D-5	"	"	Variation of Tariffs	4%	25%	0.01	0.04	0.03
E. Environmental Considerations						***0.10***	***0.20***	***0.15***
E-1	Environment	Water Quantity & Quality	Downstream Impacts	5%		0.04	0.03	0.03
E-2	"	"	Upstream Impacts	2%		0.01	0.01	0.01
E-3	"	New Infrastructure	Construction Impacts	2%		0.01	0.02	0.01
E-4	"	"	Operational Impacts	1%	10%	0.01	0.01	0.01
F. Social Aspects						***0.06***	***0.06***	***0.06***
F-1	Social	Amenity	Resettlement / Compensation/ Land-loss Issues	5%	5%	0.01	0.03	0.03
						0.01	***0.03***	***0.03***
TOTAL				**100%**		**46%**	**59%**	**71%**

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Chapter 10 - Assets Management Plan

1 Introduction to Asset Management Planning

This Chapter describes the purpose and requirements of an Asset Management Plan for a Water Services Provider based on current international best practice that is applicable to AWSB and NCWSC.

Asset Management is described as:

"*The combination of management, financial, economic, engineering and other practices, applied to physical assets with the objective of providing the required level of service in the most cost effective manner*".

It can also be described as: "maintaining a desired level of service provided by assets at the lowest life cycle cost." Lowest lifecycle cost refers to the best appropriate cost for rehabilitating, repairing or replacing an asset. Asset Management is implemented through an asset management programme that usually includes a written Asset Management Plan that is a living document. In summary an AMP indentifies the assets that owned by the entity, it identifies the whole of life cost of managing those assets to a specified level of service and allows the entity to more effectively meet its objectives.

The challenges faced by a water services provider can be listed as follows:

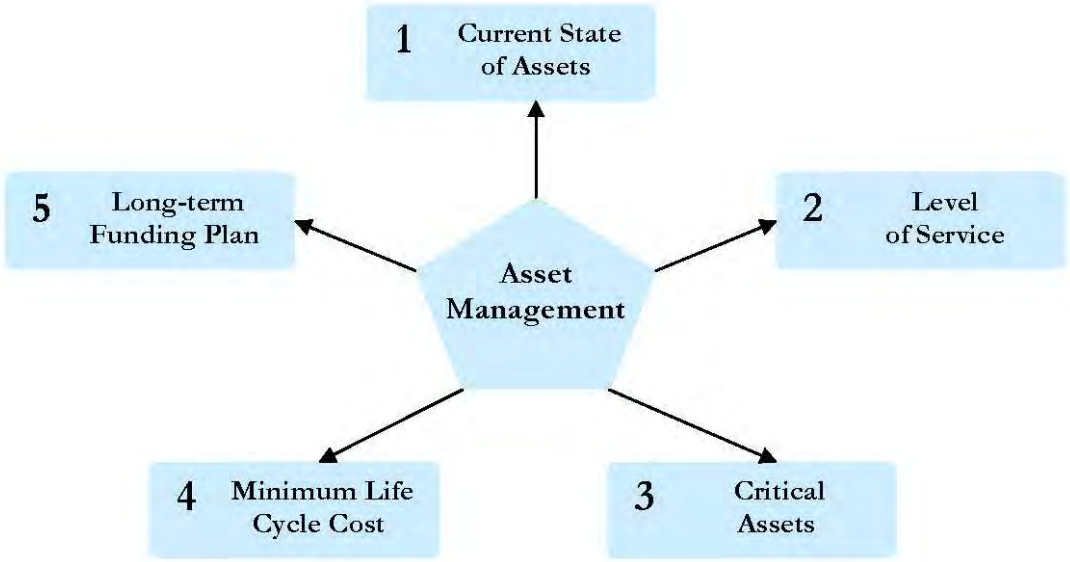
- Determining the best (or optimal) time to rehabilitate / repair aging assets.
- Increasing demand for services
- Overcoming resistance to increasing tariffs
- Diminishing resources
- Rising expectations of customers/ consumers
- Increasingly stringent regulatory requirements
- Responding to emergencies as a result of asset failures
- Protecting assets

The benefits of asset management can be stated as:

- Prolonging asset life and aiding in the rehabilitation/ replacement decisions through efficient, focussed and planned operation and maintenance
- Meeting consumer demands with a focus on system sustainability.
- Setting tariff rates based on sound operational and financial planning
- Budgeting focused on activities critical to sustained performance
- Meeting service expectations and regulatory requirements
- Improving response to emergencies
- Improving security and safety of assets

There are five core aspects that need to be considered in implementing asset management, as shown in the following diagram. This framework covers all the major activities associated with asset management and can be implemented with a level of sophistication applicable to any given water supply system and situation. These five core framework questions provide the foundation for asset management.

Figure 10-1: The Five Core Questions of Asset Management Framework



2 Asset inventory

The first step in asset management is having an inventory of assets, knowing their current state and remaining useful life. Asset inventories need to be regularly updated to allow for assets that are rehabilitated, repaired, added or removed from service. An asset inventory should include information on: ownership, location, age/ condition, useful life and value (original cost, depreciated value and replacement value) with assets grouped and subdivided into components and elements with similar base lives. Each component or element should be allocated its unique ID.

International best practices include:

- Recording the details and physical location of each asset in an asset database that is categorised by type, location, condition etc, which can be easily searched and manipulated.
- Mapping the system with spatial data stored in a GIS with multiple levels and layers showing the different components,
- Developing a condition assessment and rating system for all assets,
- Assessing the remaining useful life of assets through projected useful life tables and asset decay curves, and determining asset values and replacement costs.

3 Levels of Service

Knowing the required level of “sustainable” service helps in the implementation of an asset management programme and to communicate with stakeholders its objectives. It is a defined service standard against which service performance can be measured, which is driven by legislation and regulation and customer expectations. Quality, quantity, reliability and environmental standards are all elements that can define the level of service and associated

performance goals for a water supply system, both short-term and long- term. Defining level of service requirements can use information about customer demand, utility commissions and boards, and information from other stakeholders to help develop the level of service requirements.

The sustainable level of service needs can be updated periodically to account for changes due to future growth in supply and demand, regulatory requirements and technology improvements.

Questions that need to be answered in determining the level of service cover:

- What level do stakeholders and customers demand?
- What are the regulatory needs of the water regulatory agency?
- What is the actual system performance?
- What are the physical capabilities of the assets?

Best practices include:

- Analysing current and anticipated customer demand and satisfaction with the system;
- Allowing for the current and anticipated regulatory requirements;
- Writing and communicating to the public a level of service “Agreement” that sets out the systems performance; and
- Using level of service standards to track system performance over time.

4 Critical Assets

It is necessary to determine which assets are critical to the sustainable performance of the system. Because assets fail, how are the consequences of failure best managed? Not every asset presents the same risk of failure, or is equally critical to the water delivery system’s performance. Critical assets are those that are classified as having a high risk of failing (through being old, in poor condition etc) and which have major consequences if they do fail (major expense, system failure, safety concerns etc.). Many water supply systems have already been through this type of analysis in vulnerability assessments.

Aspects for determining critical assets cover:

- How can assets fail
- How do assets fail
- What are the likelihoods (probabilities) and consequences of asset failure
- What is the cost of repair or replacement
- What are the other costs (social, environmental etc.) associated with asset failure.

Best practices include.

- Listing assets in the inventory according to how crucial they are to system operations.
- Conducting a failure analysis root cause analysis, failure mode analysis.
- Analysing failure risk and consequences
- Using asset decay curves to determine their economic life
- Reviewing and updating the systems vulnerability assessment

5 Asset Life Cycle Costs

Asset management enables a system to determine the lowest cost options for providing the highest level of service over time. Typically for water supply providers expenses for operation and maintenance, personnel and capital budget make up around 85% of annual expenses. An appropriate asset management programme helps to make risk-based decisions for choosing the priority projects according to a time schedule and sound reasons.

Important issues to be addressed include:

- What alternative strategies exist for managing O&M, personnel and capital budget accounts?
- What strategies are most feasible?
- What are the costs of rehabilitation, repair and replacement for critical assets?

Best practices include:

- Applying predictive maintenance rather than reactive maintenance
- Knowing the costs and benefits of rehabilitation compared to replacement
- Applying lifecycle cost analysis, especially for critical assets
- Allocating resources based on asset conditions
- Analysing the cause of asset failure to develop specific response plans

Lifecycle Asset Management focuses on management and strategies considering all relevant economic and physical consequences from initial planning through to disposal, as are depicted in Figure 10-2 below.

Figure 10-2: Life Cycle Asset Management

6 Long-Term Funding and Classifying Expenditure

Sound financial decisions and developing an effective long-term funding strategy are critical to the implementation of an AMP. Knowing the full financial costs and revenues generated by the water supply system enables managers to produce reliable forecasts and budgets, which helps to decide changes needed for the long-term funding strategy to meet the AMP. The funding plan shows the relative magnitude of the different expenditure categories, which are usually broadly divided into operating and capital expenditure.

Annual expenditure can be classified into four categories: operational, maintenance, capital renewal and capital development.

6.1 Operational Expenditure

This is expenditure associated with the day to day running of the assets. They are those that generally consume resources such as manpower, energy and materials.

6.2 Maintenance Expenditure

This is expenditure required for maintaining an asset so as to achieve its design life. Maintenance expenditure can be planned (proactive/predictive) or unplanned (reactive). This cost excludes asset rehabilitation or renewal. The application of regular and timely maintenance can have a significant effect on the performance and life of the asset.

6.2.1 Renewal Expenditure

Expenditure associated with work to rehabilitate or replace existing assets with those of equivalent capacity or performance. Providing for this type of expenditure is often overlooked with newer facilities, resulting on significant expenditure in 5 – 10 years time after construction when the assets require replacement.

Deterioration curves or asset decay curves are used to calculate the life of an asset and to help decide when it is time to renew the asset instead of spending increasing amounts on annual maintenance and repair.

6.2.2 Capital Expenditure

Expenditure used to create new assets, or to increase the capacity of existing assets beyond their original design capacity or service is classified as capital expenditure.

6.2.3 Funding Plan

The preparation of accurate budgets and forecasts in a funding plan show whether the entity has sufficient finding to maintain the assets to the required level of service, and ultimately are the tariffs sufficient to meet the long term needs.

Strategies to consider to meet this objective include:

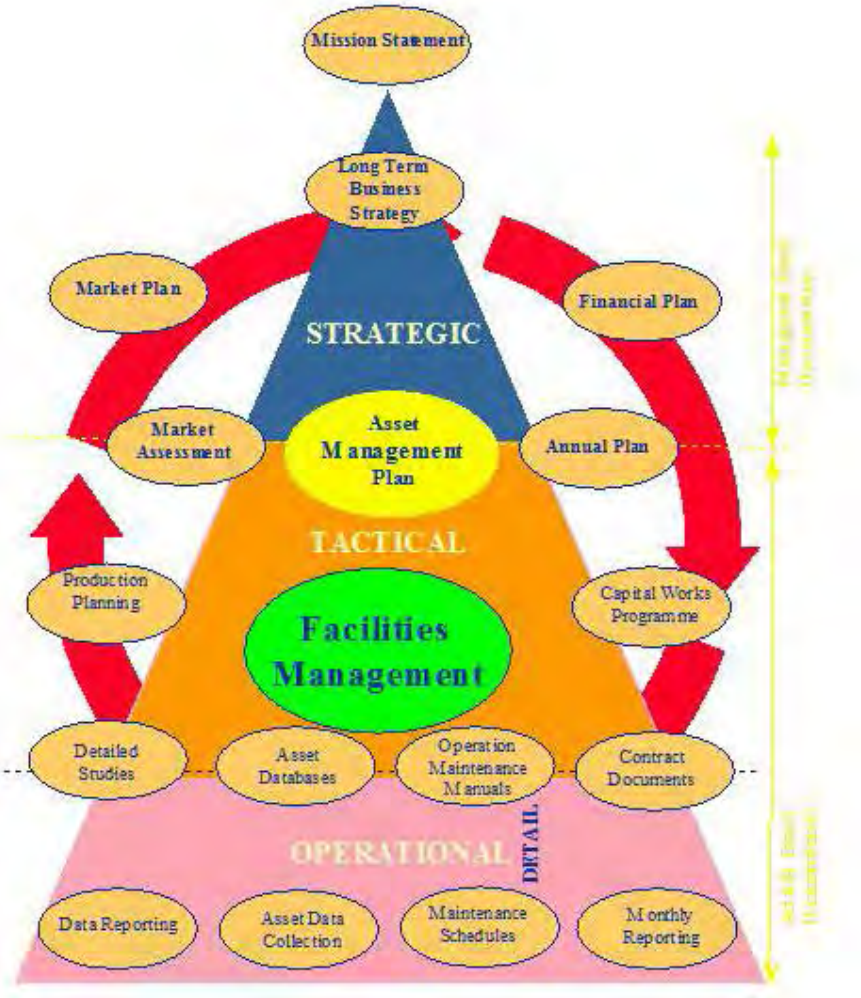
- Revising the tariff structure.
- Funding a dedicated asset renewal reserve fund from current revenue to provide for future needs (creating an asset annuity)
- Financing asset rehabilitation, repair and replacement through borrowing or other financial assistance.

6.3 Asset management plan implementation

An AMP is a “living document” that constantly requires updating and revision by managers to accommodate changes to the asset inventory through rehabilitation, replacement and addition as new information becomes available. Deficiencies in AMP can be detailed in the improvement programme through its updates.

Where AMP fits into the operational, faculties’ management and strategic sectors of the entity is as shown in the **Figure 10-3** on **Page 10-6**.

Figure 10-3: Where the AMP Fits In



6.4 AWSB Asset Management Plan Situation

Currently AWSB or NCWSC does not have a comprehensive asset management plan in place along the lines of the AMP structure described above. However a major valuation of assets exercise was conducted in 2007 with World Bank finding.[1] This study had the overall objective to determine the total net asset value of all fixed water and wastewater assets relating to Nairobi City belonging to the former Nairobi City Council, and those recently developed by AWSB. It resulted in an inventory of assets, which as well as estimating the value of the assets, provided an assessment of the condition and performance of the assets, the estimated useful remaining life and the replacement cost value. The study also compiled estimates of the future capital expenditure required to replace the existing operational fixed assets, by five-yearly periods for each system component for the above and below ground water supply and

[1] Study prepared by a consortium consisting of WS Atkins International Ltd., Pricewaterhouse Coopers, Howard Humphreys (East Africa) Ltd and CB Richard Ellis Ltd, appointed by Athi Water Services Board to undertake a World Bank-funded project entitled "Valuation of Assets for Provision of Water and Wastewater Services in Nairobi City."

wastewater system components. This information could be used as the basis for compiling an inventory of critical assets for an AMP.

Inventory Database

The inventory was classified according to individual assets including their constituent components and stored in a bespoke Asset Inventory Database in Microsoft "Access" that allows the easy manipulation, sorting and dissection of the data base to produce sub-sets of data according to "parent-child" relationships to meet all requirements.

The asset inventory database was constructed to allow AWSB to use its own asset numbering system to uniquely identify each asset, which they had planned to develop at the completion of the assignment.

Asset Condition

The condition of each component was assessed through a subjective scoring system rating the asset on a score of between one to five.

As assessment of the performance of the different components of the system was prepared based on historical records of water main failures and breakdowns within the system, with the objective to identify trouble spots within the system which had a greater share of maintenance demands and grade the condition of the distribution mains.

Useful Asset Life

The study also compiled an assessment of the useful asset life for water and wastewater assets based on the age and actual performance of the assets in the system. For most assets this showed a longer asset life that the useful asset life stipulated in the Design Manual for Water Supplies in Kenya.

Asset Replacement Investment Needs

The information from the inventory compilation and the condition assessment was used to assess the Gross Modern Equivalent Asset value based on an assumed future replacement cost in 2006 values. The result of this exercise was a future estimate of the five-yearly capital expenditure required to replace the existing operational and non-operational fixed assets for each system component (including site works and non-operational buildings). For the period 2007 to 2026 this amounted to KES52,500 million in 2006 values.

6.4.1 Update 2007 Asset Valuation Report

AWSB has recently prepared terms of reference for consultancy services to update the 2007 Asset Valuation Report as described above and the development of an Asset Management Register. The assignment is part of the Water and Sanitation Improvement Project (WaSSIP).

Changes brought about by the adoption of The Constitution of Kenya 2010 and changes in the area of supply of AWSB, additional investment, the revised national water policy, etc. necessitate updating of the asset valuation reports and the asset inventory database prepared in 2007. The proposed Water Act 2012, which provides a clear distinction between cross-county water service providers (WSPs) and the systems which are under the operation of the WSPs will also affect the governance and management of the sector.

The objective of the updated valuation study is to develop a clear delinked asset register which will include the proposed cross-county systems, county WSP systems, distribution systems and sewerage systems.

The scope of work will cover the following aspects:

- Update the 2007 Asset Valuation Report and provide a report of the Way Leaves and ownership status
- Facilitate the registration of land to AWSB for water supply and sewerage infrastructure
- Develop an asset inventory database incorporating GIS plans and diagrams
- Design an asset management information system structure
- Develop an asset register including: asset data, costs, asset life. Condition grades, performance grades and the criticality of the assets
- Delineate the assets register to be in compliance with the county structure of local government, providing for cross-county systems and systems that serve WSPs wholly

6.4.2 Preparation of an Asset Management Plan

The proposed update of the asset inventory to be carried out in 2012/13 could serve as the basis for the development of an AMP for AWSB and other WSPs responsible for providing water and sanitation services.

The valuation of asset components is a fundamental part of the asset management cycle. It provides the critical link between asset management and financial management.

It is recommended that the scope of the asset revaluation study should be broadened to include the development of an AMP relevant to their needs.

The additional aspects that will need to be addressed to develop the AMP are to;

- Define sustainable levels of service to customers
- More specifically determine critical assets and asset life cycle costs
- Define O&M, asset rehabilitation and renewal costs with a long-term funding strategy for the AMP
- Define the resources needed for implementing the AMP in terms of manpower, equipment, spare parts, training, outsourcing, etc.
- Define the process of incorporating the AMP into the business plan and operational procedures of AWSB and WSPs and procedures for the regular updating and modification of the AMP in the future as needs and infrastructure changes.

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Chapter 11 - Water Resources Management

1 Introduction

This Chapter discusses the following items:

- Existing/Planned Institutional Arrangements for Water Resources Management
- Existing Institutional Capacity for Water Resources Management
- Suggestions for Enhancing Water Resources Management Capacity.

This Chapter focuses on governance arrangements for Water Resources Management. Governance is exercised through the formulation and implementation of policies, laws and regulations; the establishment of institutions with properly-defined functions and mandates; and by ensuring that those institutions are adequately resourced and have proper knowledge, and financial and technical capacity.

Kenya's Policy, Legislation and Institutions for the Management of Water Resources deal more broadly also with natural resources, and with land use and physical planning. This report therefore discusses National Policies on Water Resources Management, Environmental Management and Land Use Planning, in order to provide a complete picture of the arrangements for Water Resources Management. The overall conclusion is that the policy, legal and institutional frameworks that exist are somewhat deficient if viewed from the perspective of capacity for implementation and enforcement.

This section is organised around the following components: –

- Policy
- Legislation and Regulations
- Institutions
- Rights and Responsibilities
- Knowledge and Capacity
- Financing
- Suggested Reforms for Enhancement of Management Arrangements
- The Constitution of Kenya 2010
- Threats, Actions Needed and Responsibility
- Water Resources Management of Existing and Future Water Sources for Nairobi and Satellite Towns

2 Policy

The following policy documents have been reviewed for the purpose of ascertaining the policy provisions on Water Resources Management: –

- National Policy on Water Resources Management and Development;
- National Land Policy;
- Policy on Environment and Development;
- Report on Groundwater Governance; and
- Integrated Urban Water Management in Africa.

2.1 National Policy on Water Resources Management and Development

Sessional Paper No. 1 of 1999, National Policy on Water Resource Management, and Development (GoK 1999a) is the principal policy framework for the governance of Kenya's water sector. The National Water Policy sets out four policy objectives: –

1) To preserve, conserve and protect available water resources and allocate it in a sustainable, rational and economic way;
2) To supply water of good quality and in sufficient quantities to meet the various water needs, including poverty alleviation, while ensuring safe disposal of wastewater and environmental protection;
3) To establish an efficient and effective institutional framework to achieve a systematic development and management of the water sector; and
4) To develop a sound and sustainable system for effective water resources management, water supply and sanitation development.

The policy recognises that surface and groundwater resources are unevenly distributed both in space and time, due to rainfall variability and diverse climatic and geographical conditions. As a result the flow regimes of rivers and streams as well as groundwater vary considerably.

The policy notes that water resources are vulnerable to human and land use activities. It states that intensifying human activities, particularly in water catchment areas, has resulted in the deterioration and loss of areas under forest and constitutes a threat to the country's water resources, not only in respect of siltation, but also with regards to run-off, the water balance and groundwater recharge. The effect has been the diminution of renewable water resources. It identifies the solution to these problems to be the conservation and development of national water resources.

On institutional frameworks, the policy identified the problems existing in water resource organisations to include: –

> *"over-centralised decision making processes, inappropriate and run-down monitoring network, inadequate database, discontinuous assessment programmes, uncoordinated source development, non-operative water rights, absence of special courts to arbitrate on water use conflicts and a generally weak institutional set up." [para 2.2.1]*

One of the consequences of institutional weakness is a poor database. The policy states that information flow in the water sector is characterised by data gaps due to discontinuous water resource assessment programmes, weak monitoring systems and an inadequate user database. It notes that the solution to these problems lies in setting up mechanisms for the continuous assessment of water resources, which includes strengthening the institutional

capacity of the agencies responsible for the collection, storage and analysis of water resources data. This should be followed by the establishment of a fully-fledged hydrological, hydrogeological, water quality, water permit and socio-economic database at all water resource management levels [para 2.7.4].

The policy makes the point that inadequate financial resources for water management generally occurs because water has been perceived as a free commodity to be supplied freely and has not been regarded as a major source of revenue. Water revenue has been inadequate due to limited revenue base, ineffective revenue collection mechanisms and low water tariffs. The policy therefore states that abstraction of water in its natural form will be charged a fee commensurate with the amount of water abstracted and the funds so generated will be used for assessing, monitoring conservation and management of water resources.

The policy also deals with Integrated Water Resources Management (IWRM) and proposes that a National Standing Committee to deal with cross-sectoral issues will be established with representatives from all main water and related sector actors under the guidance of the Ministry in charge of water affairs. This Committee will spearhead the formulation of a policy on land, water and forests [para 2.3.3].

The Committee has not been set up. Instead of developing a joint policy on land, water and forests, each of the sectors has developed its own policy. The Ministry in charge of land has developed its own policy, just as the forest sector has its own policy. Whereas they call for cross sectoral linkages none of these policies provides any concrete mechanisms for fostering such linkages, with the consequence that the management of water resources has continued to be carried on in isolation from the management of land and other land based resources.

Para 2.6 deals with water quality issues and states that pollution of surface and groundwater resources has become a major problem due to human activities; however, all the solutions proposed relate to surface water. They include strict stream effluent discharge standards, a process of water quality monitoring and prior authorisation of discharge of undesirable substances into the water system.

Significantly, the Policy Paper does not make provision for Water Resources Management Plans. The policy recognises the potential for pollution of water resources as a result of waste discharge. It makes provision for water quality control to address this.

The policy does not make any reference to the impacts of climate change on water resources availability and management. This could be explained by the fact that the issue of climate change had not, at the time the policy was formulated, become a key national policy issue. More recently a strategy on climate change has been formulated.

The water policy recognises local water resources management arrangements and stakeholder participation. However, focus seems to be given to local water supply. Para 4.1.4 states that the Government will support private sector participation and community management of services backed by measures to strengthen local institutions in sustaining water and sanitation programmes. In practice, the role of the private sector together with that of non-governmental organisations has been confined principally to that of constructing boreholes, rather than involvement in the management and conservation of water resources.

Although the National Water Policy recognises that Kenya has shared water resources, no specific proposals for the management of shared water resources are included in the policy objectives. This weakness covers surface water, in regard to which there are no provisions for cooperative management with neighbouring countries either. More recently, in 2009, the Ministry formulated a draft policy paper on shared water resources (MoWI 2009d). However the draft policy paper has not finalised into a formal policy paper.

2.2 National Land Policy

Water use and water resources management and protection is affected to a great extent by land use and land use change. Kenya does not have a national land use policy at present, but the law provides for the formation of regional and local physical development plans, which in effect provide the framework for land use planning in areas where these have been formulated. However, there is in place a land policy, which is a precursor to the formulation of a national land use policy. A number of its policy objectives are pertinent to groundwater management, particularly in areas of institutional frameworks.

Key institutional weaknesses include the absence of a coordinating framework for cross-sectoral issues, the lack of effective land use planning and limited management and technical skills for natural resources management. It calls for putting in place the necessary mechanisms for effective coordination across sectors. Notably, however, no concrete steps have been taken to put in place such coordinating mechanisms, and therefore the policy statements remain mere aspirations, Ref. Annex 1 on National Land Policy.

2.3 Policy on Environment and Development

Another important Policy Paper for Water Resources Management is the Environmental Management Policy (GoK 1999c).

The national policy on environment and development has as its overall goal the integration of environmental concerns into national planning and management processes. Its objectives include conserving and managing Kenya's natural resources. Specific mention is made of the protection of water catchments and wetlands as objectives. Water Resources Management underlies the discussion on land degradation, drought and desertification (para 4.2.6). Therefore the management and protection of water resources as an aspect of the policy on environment and development can be implied from the mention made of natural resources generally.

Among the principles for environmental conservation which it outlines is that sustainable development and a higher quality of life can be achieved by reducing or eliminating unsustainable production and consumption practices.

Under land and land-based resources (discussed in Chapter 6.1.5), the policy states that an integrated and coherent approach to planning and management of land resources is essential to sustainable resource utilization. This is a point that has been made repeatedly in policy papers and yet no meaningful progress towards putting it into effect has been made.

In summary, the policy framework recognises water resources as an important land based resource. This theme has been carried forward into the Constitution of 2010.

3 Legislation and Regulations

3.1 Water Rights and Water Permits

Legislation (including the 2010 Constitution) has vested ownership of all water resources, including groundwater, in the state. The current position under legislation is that water rights may only be acquired through a permit" Section 27 makes it an offence to construct or use works to abstract water without a permit. Section 26 of the Act gives three exceptions to the permit requirement, one of which relates specifically to the use of groundwater.

So, statutory law deals with groundwater in a way that is markedly different from surface water, notwithstanding that the ownership of both groundwater and surface water is vested in the State. But unlike in cases of surface water use, the use of groundwater does not ordinarily require a permit. A permit will only be required in the specific instances, including in a groundwater protection area.

Rights of access to groundwater are obtained through a permit or authorisation issued under the Water Act, 2002 and the Water Resources Management Regulations, 2007.

The permit is for a defined period of time limited to five years although it may be renewed at the request of the holder [see regulations 39 and 44]. The permit holder is required to maintain a record of the water abstracted and give the date, time, quality, quantity and purpose for which the water was used. The conditions subject to which the permit is issued will specify the quantity of water to be abstracted and the purpose for which it may be abstracted. The nature of the access therefore is fixed quantity and time based access.

In practice many water users do not install measuring devices, such as water meters for measuring the abstraction of groundwater. The result is that many have no accurate record of abstraction volume; at least one study shows that many abstractors abstract far more than is permitted, and use the water abstracted for purposes other than permitted, where the authorisation was for domestic use (Groundwater Governance, WRMA).

The potential environmental impacts of the abstraction of water resources require to be considered as part of the permit process. Under section 29(4) of the Rules, which deals with the procedure for obtaining a water use permit, an application for a permit shall be subject, where applicable, to an environmental impact assessment in accordance with the requirement of the Environmental Management and Coordination Act, 1999 (EMCA: GoK 1999b). This requires a prospective developer to carry out an assessment of the potential impacts of the development on the environment, and to apply for an Environmental Impact Assessment (EIA) license from the National Environment Management Authority (NEMA).

Wastewater licensing is dealt with under both the Water Resources Management Rules 2007, and the Environmental Management and Coordination (Waste Management) Regulations.

Part V of the Rules give the WRMA power to control the pollution of water, impose a requirement for an effluent discharge permit and stipulate that effluent may only be discharged into a water resource if it meets prescribed standards. The subsequent rules impose requirements for effluent discharge records to be maintained and for an effluent discharge control plan to be developed to support an application for an effluent discharge permit. These provisions can be used to regulate discharges of waste water which potentially could threaten the quality of water resources.

Under The Environmental Management and Coordination (Water Quality) Regulations, 2006 (GoK 2006), NEMA has imposed wide-ranging controls on water pollution which mirror the water pollution control powers exercised by the WRMA. Rule 6 prohibits the discharge of effluent from sewage treatment works, industry or other point source pollution without a valid effluent discharge licence issued in accordance with the provisions of EMCA. Rule 11 prohibits discharge into the aquatic environment unless such discharge complies with [set] standards. These rules similarly can be used to regulate potentially polluting discharges of wastewater which can threaten the quality of water resources.

The Environmental Management and Coordination (Waste Management) Regulations L.N No 212 of 2006 imposes requirements for the sound management of hazardous waste. Regulation 19 requires every person who generates hazardous waste to dispose of leachate in accordance with conditions set out in the licence or in accordance with guidelines in the licence. The

Regulations require operators of waste disposal sites to operate the sites in an environmentally sound manner and to comply with licence conditions.

3.2 Controls on Development in Recharge / Discharge Zones and Pollution

The protection of recharge and discharge zones of groundwater from pollution could also be achieved under the powers given to water service boards (WSBs) by section 73 of the Water Act, 2002 to make regulations, for among other things, for the purpose of protecting against degradation, any water, whether on the surface or underground, which belongs to the WSB or which for the time being the WSB authorized to take. The regulations would define the area within which the WSB deems it necessary to exercise control; prohibiting or regulating the doing, within that area, of any act prescribed by such regulations; and prescribing penalties.

Regulations made by a WSB may empower it to require the owner or occupier of any land or premises within a prescribed area within the WSB's limit of supply to execute and keep in good repair such works or take such other action as it considers necessary for preventing the degradation of such water. Section 73 (7) provides that the WSB shall pay compensation on just terms to the owner or occupier of any premises within the prescribed area in respect of any curtailment of or injury to his legal rights by restrictions imposed by such regulations; and any expenses incurred by him in complying with a requirement to construct and maintain any works, take other action, which would not, but for the provisions of the Water Act, lawfully have been required.

However if a person has not appealed against the requirement and the time for appeal has lapsed or the appeal has been dismissed but he nevertheless fails to comply with the requirement, the WSB may execute and keep in good repair the works and recover its expenses (other than expenses in respect of works the construction of which could not lawfully have been required otherwise than upon payment of compensation) as a debt from the person concerned.

Under section 75 a WSB may, on land belonging to him, or over or in which he has acquired an easement or right, construct and maintain drains, sewers and other works for intercepting or disposing of any foul water arising or flowing upon such land or otherwise for preventing water belonging to it or which he is for the time being authorized to take, from being polluted.

Although these regulations are appropriate for protecting water resources which are used as source works for water for domestic consumption from pollution, no WSB has gazetted any regulations to protect the water resources from which they abstract water for public water supply. This is the case even in vulnerable aquifers which are critical public water supply sources. Making regulations by a WSB under section 73 would be an appropriate way to protect sources of water for public water supply.

3.3 Water Management Plans and Land Use Planning

Land use planning is undertaken under three different pieces of legislation, all of which operate independently of each other, thus highlighting the point made earlier about a lack of coordinating mechanisms. These are: –

- the Water Act, 2002;
- the Physical Planning Act, 1996 and
- the Environmental Management and Coordination Act, 1999

The Water Act, 2002 creates mechanisms for planning. Section 11 of the Water Act, 2002 provides that the Minister shall formulate a national water resources management strategy in accordance with which water resources of Kenya shall be managed, protected, used, developed, conserved and controlled. Additionally, the strategy shall provide for: –

a) determining the reserve;

b) classifying water resources; and

c) identifying areas which should be designated protected areas and groundwater conservation areas.

The determination of the reserve and the classification of water resources are mechanisms which could apply to surface water as well as to groundwater. However, not surprisingly, these concepts and tools have not so far, been applied to groundwater and there is an underlying assumption that they apply principally to surface water.

Thus the WRMA has the mandate to formulate a catchment management strategy for the management, use, development, conservation, protection and control of water resources within each catchment area. Among other issues, the strategy shall:

a) Contain water allocation plans which set out principles for allocating water; and

b) Provide mechanisms and facilities for enabling the public and communities to participate in managing the water resources within each catchment area.

A catchment area plan ought to contain plans for the use, allocation and management of water resources in the area. Legislation provides for the formulation of water resources management plans, which are referred to as catchment management strategies (CMS) and sub-catchment management plans (SCMPs).

The Water Act and the rules made under it also provide a framework for planning in regard to development of water resources. Section 44 provides that where the WRMA is satisfied that, in any area, special measures for the conservation of groundwater are necessary in the public interest for the protection of public water supplies or water supplies used for industry, agriculture, or other private purposes, it may, following public consultations, by order published in the Gazette, declare the area to be a Groundwater Conservation Area. The WRMA may impose such requirements and regulate or prohibit such conduct or activities in or in relation to a Groundwater Conservation Area as it may think necessary to impose, regulate or prohibit for the protection of the area and its groundwater.

Another important legislation that addresses land use planning is the Physical Planning Act, Chapter 286 (provisions of which are to be transferred to the Urban Areas and Cities Act, 2011 and the Devolved Governments Bill, 2012) which mandates the Director of Physical Planning, an officer in the Ministry of Lands, to: –

a) formulate national, regional and local physical development policies, guidelines and strategies; and

b) be responsible for the preparation of all regional and local physical development plans.

Among the matters set out in the First Schedule which may be dealt with in a regional physical development plan are “natural resource endowments” of the area. Among the matters set out in the Second Schedule which may be dealt with in a local physical development plan is the conservation of the natural beauty of the area, including lakes and other inland waters, banks of

rivers, foreshores of harbours, and other parts of the sea, hill slopes and summits and valleys. In both respects, these matters concern water resources management.

EMCA also gives a mandate for environmental planning. Section 37 of EMCA establishes a National Environmental Action Plan Committee to prepare a national environmental action plan for consideration and adoption by the National Assembly. Similarly Provincial and District Action Plans are to be prepared by the respective committees every five years. It is these which are to be collated into the National Environmental Action Plan.

As this review of legislation and regulations shows, the Water Act and the Water Resources Management Rules together with other sectoral legislation, such as the Physical Planning Act, include specific water resources management provisions. The Water Act has dealt with water resources as a public resource vested in the State and subject to control by the Minister, as is the case with surface water. There are rules regulating waste water discharges insofar as it affects groundwater and groundwater pollution. These provisions form a sound basis for managing water resources.

There are however significant weaknesses in the implementation and enforcement of the legal provisions and the rules. In a number of cases the rules duplicate each other, particularly those rules made under the Water Act and the ones made under the Environmental Management and Coordination Act. Each of the organisations lacks the institutional capacity to discharge its statutory mandate adequately. At the same time there are limited inter-sectoral coordination mechanisms, which undermine cooperation between the various implementing agencies.

3.4 Stakeholder Participation

The Water Act, 2002 provides for public consultation over key decisions (including decisions on issuing abstraction permits) as one of the mechanisms for involving stakeholders in water resources management. Section 107 of the Act and Part II of the Water Resources Management Rules make provision for involving stakeholders in decision making.

Regulation 28 requires that the WRUA give comments on an application for a water use activity. Therefore the WRMA shall submit a copy of every relevant application to the WRUA for comment. Additionally, the Authority shall cause to be published in a national newspaper a list of permit applications that fall into categories C and D. The Authority shall also display a notice of all applications received at the offices of the district commissioner, the district officer and the chief and at its own regional office.

A person may raise an objection to the application within thirty days of the public notification. Where an objection has been received then the Authority may hold a public meeting at the site with the relevant stakeholders and the WRUA to consider it.

A third way in which users and stakeholders are involved in water use decisions is that the Authority is required to maintain a register of authorisations and permits, which shall be open to the public. One may obtain a copy on payment of a prescribed fee.

The Water Act also provides for the establishment and operation of Water Resources Users Associations (WRUAs), and envisages that where the water resource in question is a groundwater resource, the WRUA would be formed in regard to the management of that particular groundwater resource.

WRUAs are not traditional organisations. They are associations set up specifically to bring together users of a given water resource. They could certainly be based on traditional arrangements, but as water resources are allocated by means of abstraction permits rather than on traditional rights of access, WRUAs tend not to revolve around traditional use rights.

4 Strengths and Weaknesses of Current Legislation

There is a comprehensive legal framework for the management of water resources. Water resources are vested in the State, and its control is vested in the Minister in charge of water. There is an express provision requiring authorisations and permits to be obtained for the abstraction and use of water resources. Furthermore, the law recognises the value of water resources and imposes a charge for its abstraction and use.

However, the legislation has weaknesses; enforcement has been weak, and many of the provisions have not been implemented. By way of example, despite there being provision for the designation of groundwater conservation zones, none has been declared since the Water Act 2002 came into effect. Furthermore, many water abstractors do not have permits and do not pay water charges for the water abstracted. Weak implementation is due to a perception that water is an inexhaustible resource, because of poor knowledge on water resources, weak institutional capacity, poor funding and weak political commitment at senior policy-making level. The result is that over-abstraction and poor management has continued. In this sense the statement made in the National Water Policy remains substantially true in regard to water resources management.

4.1 Recommendations for Possible Future Changes

Addressing the problems affecting water resources management and conservation does not require additional or new legislation, except in respect of alignment to the Constitution of 2010. The principal requirement is action on key recommendations and policy objectives which have been made in policy statements over the years, the lack of attainment of which has been known for a considerable number of years.

Key among these is the development of a functioning mechanism for coordination of actions relating to water resources across diverse sectors which affect the sustainable management of water resources, including land, environment, and water resources.

Secondly, it will be necessary to give priority to water resources management in the activities and programmes of water sector management institutions. This requires providing them with resources – human, technical and administrative – necessary to discharge their mandates effectively.

Third, action to enforce the rules regarding the requirement for authorisations, permits and water charges, and to improve compliance needs to be taken. Such action would need to target influential individuals and strategic public sector institutions. Success depends, therefore, principally on political will and commitment, since the legal framework which is in place has the basic elements required to manage water resources sustainably. If the political will is present, the institutions mandated to manage water resources would be provided with the technical and managerial capacity they require to successfully manage the resources.

5 Institutions (Administrative / Technical Capacities at National and Basin Levels)

Table 11-1 shows institutional roles and responsibilities.

Table 11-1: Institutional Roles and Responsibilities

Institution		Roles and Responsibilities
1.	Ministry of Water and Irrigation (MoWI)	• Development of legislation, policy formulation, sector coordination and guidance, and monitoring and evaluation.
2.	Water Resources Management Authority (WRMA)	• Planning, management, protection and conservation of water resources. • Planning, allocation, apportionment, assessment and monitoring of water resources. • Issuance of water permits. • Water rights and enforcement of permit conditions. • Regulation of conservation and abstraction structures. • Catchment and water quality management. • Regulation and control of water use. • Coordination of the IWRM Plan.
3.	Catchments Area Advisory Committees (CAACs)	• Advising WRMA on water resources issues at catchment level.
4.	Water Resource Users Associations (WRUAs)	• Involvement in decision making process to identify and register water user. • Collaboration in water allocation and catchments management. • Assisting in water monitoring and information gathering. • Conflict resolution and co-operative management of water resources
5.	Water Services Regulatory Board (WSRB)	• Regulation and monitoring of Water Services Boards. • Issuance of licenses to Water Services Boards. • Setting standards for provision of water services. • Developing guidelines for water tariffs.
6.	Water Services Boards (WSBs)	• Responsible for efficient and economical provision of water services. • Developing water facilities. • Applying regulations on water services and tariffs. • Procuring and leasing water and sewerage facilities. • Contracting Water Service Providers (WSPs).
7.	Water Service Providers (WSPs)	• Provision of water and sewerage services
8.	Water Services Trust Fund (WSTF)	• Financing provision of water and sanitation to disadvantaged groups.
9.	The Water Appeals Board (WAB)	• Arbitration of water related disputes and conflicts.
10.	National Water Conservation and Pipeline Corporation (NWCPC)	• Construction of dams and drilling of boreholes
11.	Kenya Water Institute (KEWI)	• Training and Research
12.	National Irrigation Board (NIB)	• Development of Irrigation Infrastructure

Figure 11-1 shows the relations between and hierarchy among the different Sector Organisations.

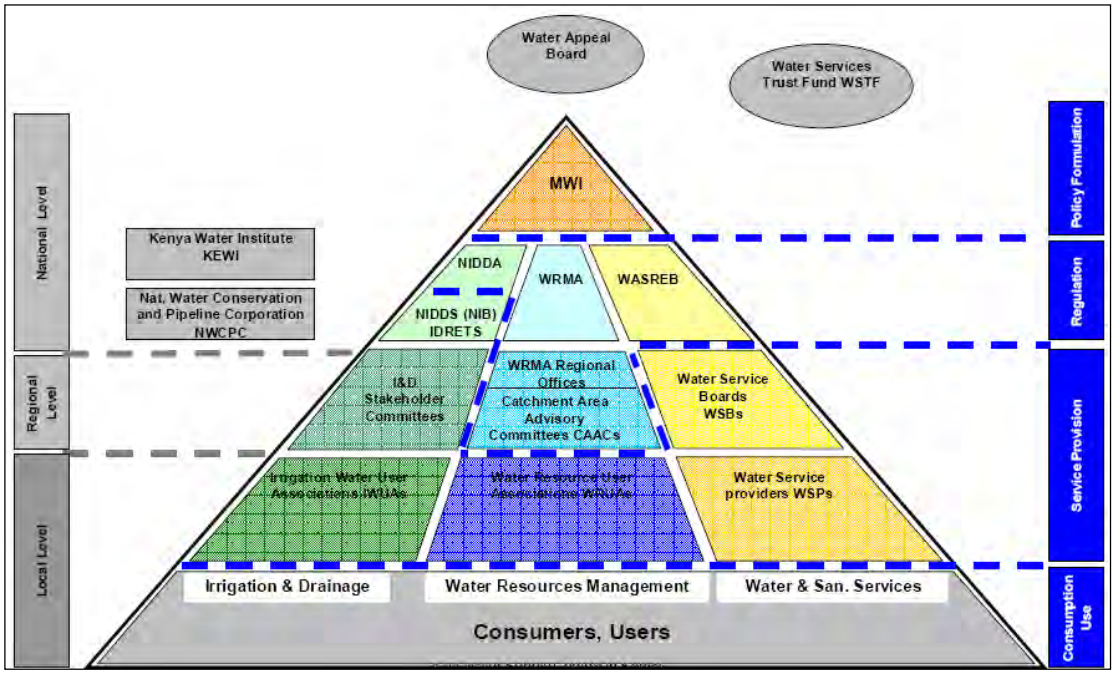

Figure 11-1: Relations Between & Hierarchy Among Different Sector Organisations

5.1 Devolution to Regional Institutions

Section 7 of the Water Act 2002 establishes the Water Resources Management Authority. Its functions are set out in section 6. Under section 14 of the Water Act, 2002, WRMA may designate a defined area from which rainwater flows into a watercourse to be a catchment area for purposes of the Act; Section 10 requires WRMA to establish regional offices in or near catchment areas.

Kenya has five hydrological basins. However, the WRMA has defined six catchment areas out of these five basins by dividing one of these, Lake Victoria, into two catchment areas, Lake Victoria South and Lake Victoria North. The other catchment areas are Athi, Rift Valley, Tana and Ewaso Ngiro North. All of these institutions were set up during 2005 (following the commencement of the Water Act, 2002) and have been operational for a period of six years now. Each catchment area is headed by a Regional Manager. For the purposes of groundwater management, WRMA has deployed to each regional office one hydrogeologist, with the exception of Athi region (within which the Nairobi aquifer is located) where there are three.

There are no catchment areas or other institutional arrangements for managing trans-boundary water resources. These require the development of cooperative framework between the countries with which Kenya shares a water resource. Currently, there are efforts to develop cooperative frameworks for the Mara River Basin between Kenya and Tanzania (including the establishment of a transboundary water resources users association) and for the Sio-Malaba-Malakisi River Basin between Kenya and Uganda. In both these cases the catchment area has been defined on the basis of surface water catchment areas.

The WRMA has presence at the regional (RO) and sub-regional (SRO) office levels, but is not as effective as it might be due to institutional, human resource, technical capacity and finance limitations.

CAACs were established under the Water Act, to advise WRMA regional managers on water resources management issues in the catchment. The CAAC has a statutory membership of fifteen persons drawn from stakeholders including sectoral institutions in government, the private sector and civil society which are relevant to water resources management. Members may be drawn from the ministries responsible for lands, forests, mines, agriculture and others. Non-governmental organisations working in the area of water supply, many of whom construct boreholes, could also be represented.

A common complaint emanating from CAACs is that, being advisory in nature, they have limited influence on decision making; WRMA Regional Officers are not obliged to heed advice tendered by their CAACs, and are not accountable to the CAACs for their actions. This could be enhanced if greater attention was given to the need for enhancing the effectiveness of coordinating mechanisms.

The environmental management committees at provincial and district levels also bring together a wide range of stakeholders, including government representatives, non-governmental organisations and the private sector that have a role in environmental management. This institution could also facilitate coordination in managing water resources. The key constraint faced by environmental committees, from the perspective of water management, is that the potential scope of their mandate is so overarching that their ability to focus on a specialized issue like water resources and its interconnection to environmental management is limited.

Physical planning liaison committees also have a membership that represents a diverse stakeholder group from within and outside government. However this institution is not a standing body; the law states that it is to be convened as and when the need arises. It has therefore rarely been functional and its impact has been limited.

In summary, the capacities of the CAACs have not been made full use of, and because they have no powers, they are not always able to influence decision making in WRMA. Consequently, their effectiveness in respect of water resources management has been limited.

5.2 Capacity for Water Resources Management

WRMA inherited the majority of its staff from the MoWI, many of whom joined WRMA on secondment. Subsequently, WRMA gave contracts to the staff, who are now employed as WRMA staff, and have been delinked from the Ministry. Nevertheless, the Ministry retains some water resources management staff.

The staff complement at WRMA headquarters and in the regional and sub-regional offices is set out below.

Table 11-2: WRMA Staff Complement, 2010

Regions	Staff Permanent (No.)
WRMA HQ	40
Lake Victoria North Catchment Area	56
Lake Victoria South Catchment Area	45
Rift Valley Catchment Area	73
Athi Catchment Area	70
Tana Catchment Area	82
Ewaso Ngiro North Catchment Area	55
Total	**421**

As is clear, given the size of task of water resources management country wide the capacity of WRMA to effectively manage water resources is limited. Additionally, there is limited water resources management capacity in the private sector, which employs a number of hydrologists, EIA experts and other water resources management experts as consultants. Occasionally, on specific assignments, these consultants are engaged on undertaking studies and other assignments on water resources management issues on behalf of WRMA. It is clear that understaffing in the water resources sub-sector within WRMA is a significant problem.

Whereas no workload analysis was available, given the geographical scope of the catchment areas it is a logical supposition that there is significant understaffing within WRMA in regard to the management of water resources.

EIAs in respect of water resources are regulated by the NEMA. NEMA has District and Provincial Environmental Officers at district and provincial levels respectively. These officers act as secretaries to the District and Provincial Environment Committees. EIAs are discussed by these committees, although the decisions are made at headquarters. Consequently, NEMA's capacity to deal with EIA applications in respect to the development affecting water resources from across the country and to monitor compliance is limited since there is only one officer at the district and one other at the provincial level.

The institutional arrangements for physical planning and development control are contained in the Physical Planning Act, Chapter 286. Section 4 establishes the office of the Director of Physical Planning which is responsible for formulating national, regional and local physical development plans. Part III establishes physical planning liaison committees at national, provincial and district levels. These bodies are set up as appeal and advisory bodies over physical planning matters. The development control function is vested in local authorities, within which the physical planning department is responsible for technical evaluation of applications for planning permission. Water resources issues would be considered in the context of planning permission applications. However, the local authorities retain physical planners and not hydrologists. Therefore their capacity in regard to addressing water resources issues is non-existent.

Apart from staff size the other issue relates to the technical capacity of the staff to manage water resources. The water resources sub-sector suffers from a lack of technical equipment and logistic support; the ability of staff to generate scenarios is constrained more by lack of data and operating platforms than a lack of ability.

There is limited understanding of the need to manage water resources, at both the strategic (national water security) and local levels. This is partly due to more attention being paid to day-to-day regulatory functions than to maintaining a strategic outlook. So, the capacity of technical staff within the public water sector is not as developed as is desirable, and insufficient staff are available to meet water resources management needs within the country.

Within the sector, a number of shortfalls in water sector capacity have been identified; these include the following among them inadequate laboratory facilities and capacity and inadequate data analysis and management capacity.

In summary, while the technical capacity generally exists in terms of skill-sets, inadequate staff numbers and limited resources, allied to a lack of strategic focus, means that water resources management at the national and Catchment area level is ineffective. Although there is training capacity and academic research capacity in Kenya, research is not coordinated, and planning and additional human and financial resources are needed to coordinate and implement a more focused water sector research programme.

6 Stakeholder Involvement in Water Resources Management

6.1 Community-Based Organisations

Under section 15 of the Act, WRMA is required to formulate a catchment management strategy for each catchment and, under section 16, it shall appoint a Catchment Area Advisory Committee for each catchment area. The catchment area management strategy shall among other things, provide mechanisms and facilities for enabling the public and communities to participate in managing water resources within each catchment area. Section 15(5) deals more specifically with the institutional arrangements for community participation and states that "the catchment area management strategy shall encourage and facilitate the establishment and operation of water resources users associations [WRUAs] as fora for conflict resolution and cooperative management of water resources in each catchment area".

For a WRUA to be considered for registration by the Authority, it should be legally registered as a society, have a constitution conducive to the collaborative management of the water resources of a particular resource and which promotes public participation, conflict mitigation, gender mainstreaming and environmental sustainability [Regulation 10].

A number of WRUAs have proved to be effective in resolving water use conflicts, particularly in those catchments which are prone to water use conflicts. However, WRUAs are voluntary associations and therefore they are not uniformly spread across the country.

As indicated, the Water Act enables water users (organised as WRUAs) to participate in water resources management. Additionally, the general public may participate in water resources management decisions, particularly as regards water use (i.e. abstraction etc.) by lodging objections and comments when an application for a water use is made. These mechanisms enable the pubic generally and interested stakeholders, particularly the WRUAs to be involved in decision making.

The key weakness of these mechanisms is that they depend on pro-activity by members of the public, and have tended to be used largely by professional persons rather than members of the public per se. Registers of WRUAs are in many cases not established, notwithstanding the clear legal provisions. The WRUAs that have been set up have set out to deal with conflicts and management of water resources mainly in those areas that are prone to water use conflict.

6.2 Level of Authority Accorded to Representative Groups

CAACs are groups that represent catchment level interests. However, there has been a complaint by many CAAC members that they are not effectively involved in decision making, and that their advice is often not taken account of. Some members of CAACs have expressed the desire to become fully autonomous boards as a way of enhancing their influence.

The level of authority accorded to WRUAs has been less than is provided for in the Rules, in particular regulations 7 and 8. These state that the Authority may enter into an MOU with a WRUA for purposes of collaborative management of water resources. This MOU may provide for the role of the WRUA including data collection, collection of levies and monitoring of water use. WRUAs have indicated that they would like to have an enhanced role in water resources management, going beyond the activities which WRMA has been engaging them in to date. Overall WRMA has not made use of the full potential of WRUAs to manage water resources – and equally, water users and other stakeholders have not grasped the opportunities offered by WRUAs.

6.2.1 Water Resources Data Storage and Use

In Kenya, water resources and allocation data of all kinds are theoretically available for purchase, at costs described in the Rules (GoK 2007). However, in reality these data are often difficult or impossible to obtain; some are held by the Ministry of Water and Irrigation, some by the WRMA and some by the WSBs/WSPs. There is no centralised repository of data, nor is there anywhere a detailed listing of which agency has what data (and at what cost). This means that water allocation decisions may be based on incomplete data or no data at all.

7 Financing

Section 8 (g) provides that WRMA may determine charges to be imposed for the use of water from a water resource. Section 79 provides that the Authority may, with the approval of the Treasury, retain some or all of the revenue from water use charges payable under a permit to be applied in meeting the costs of performing its functions. Such charges include charges for abstraction of groundwater, although WRMA does not segregate the charges it collects from groundwater and surface water.

Part VIII of the Rules deals with water use charges. Regulation 104 stipulates that any person in possession of a valid permit or who is required to have a valid permit shall be required to pay water use charges. Regulation 108 provides that an additional five percent shall be added to the water use charge for any water abstraction or diversion within a GCA to cover the cost of the greater management needs of such areas.

WRMA may review water use charges taking account of: –

a) Inflation rate;

b) Cost of managing the water resources and water catchment areas;

c) The use of water charges as a tool for water demand management; and

d) The use of water as a social and economic good.

The Rules are designed on the basis of self-assessment. Under Regulation 106 the water user shall make a fair assessment of the quantity of water used with respect to each permit and shall submit the assessment together with supporting records and calculations to WRMA. Where the user does not make a fair assessment WRMA shall make a fair assessment of the quantity of water used. Water use charges may be paid directly to WRMA or to an appointed revenue collection agent. Failure to pay water use charges is a breach of the conditions of a permit and may be a basis of revocation of the permit.

WRMA has experienced a serious shortfall in financial resources ever since it was established. WRMA's policy is 50% of the revenue collected from water users (applications for water permits; permit fees; and water use charges) is retained by the Sub-region, and 50% is returned to Headquarters towards the costs of its management.

Despite attempts to reform the water sector, together with the development of an integrated water resources management strategy and water efficiency plan, there remains an inadequacy in water resources management.

WRMA needs enhanced capacity to properly manage the water resources. At present the Authority does not have the staff, technical or financial resources to manage water resources properly.

8 Suggested Reforms for Enhancement of Management Arrangements

This section summarises the measures required for enhancing water resources management arrangements and capacity.

8.1 Amending and Streamlining Sectoral and Cross-Sectoral Policies

Generally, policies currently in place are not an impediment to improving water resources management, but they do require harmonisation and implementation to effectively capture cross-sectoral involvement. However: there is no cross-sectoral water resources management protection policy, a deficiency that should be remedied as swiftly as possible. In our view the laws do not require much amendment. Neither are new laws required, as those in place provide a suitable basis for water resources management.

But grey areas exist in the mandates of the environment and water sectors, particularly in wastewater management. Mandates must be clarified to eliminate the confusion and double-charging that exists. Coordination also needs to be enhanced to minimise overlap and duplication in mandates, which is wasteful of the minimal resources available for water resources management.

8.2 Rights and Responsibilities

Many water users do not have water permits or pay water charges. This is not out of ignorance, but out of apathy or lack of interest. WRMA is unable to enforce the WRM Rules with these entities, principally because of limited support by the Government in terms of provision of required resources. WRMA's resources and capacity ought to match the task at hand. Additionally, WSBs ought also to take up their responsibilities by introducing the required regulations to protect the sources from which they draw water supplies. As stated, the provision for such regulations exists but no WSB has moved to make the required regulations.

8.3 Knowledge and Capacity

- The availability of water resources management professionals in the public sector is imbalanced, with many more in the Ministry (legislation, policy, coordination and M&E), than in the WRMA (water resources management).
- The technical capacity of WRUAs needs to be enhanced; and the CAACs need to be empowered through capacity building for a more active role in water resources management decisions.
- Technical equipment required for water resources management is inadequate to provide the WRMA with the tools it needs to manage water resources and these need to be enhanced.
- The existing water resources monitoring networks are inadequate to support water resources management; the WRMA's efforts to expand these must be resourced adequately.

9 The Constitution of Kenya 2010

The need to realign the policy, legal and institutional framework for water resources management to the Constitution of Kenya 2010 provides an opportunity to streamline the water resources management framework. This section puts forward some proposals on how this can be done.

9.1 WRMA's Mandate Under the Water Act 2002

Section 7 of the Water Act, 2002 establishes the Water Resources Management Authority (WRMA). Section 8 defines its mandate to be to:

a) Develop principles, guidelines and procedures for the allocation of water resources;

b) Monitor, and from time to time, reassess the national water resources management strategy;

c) Receive and determine applications for permits for water use;

d) Monitor and enforce conditions attached to permits for water use;

e) Regulate and protect water resources quality from adverse impacts;

f) Manage and protect water catchments;

g) In accordance with guidelines in the national water resources management strategy, determine charges to be imposed for the use of water from a water resource;

h) Gather and maintain information on water resources and from time to time publish forecasts, projections and information on water resources;

i) Liaise with other bodies for the better regulation and management of water resources;

j) Advise the Minister concerning any matter in connection with water resources.

As can be seen one of WRMA's functions is to protect and manage water catchments. In exercise of this mandate WRMA has been actively engaging water resources users associations (WRUAs) in preparation and implementation of sub-catchments management plans, which mainly comprise soil and water conservation measures to be implemented on the land by the land owners and occupiers. The discharge by WRMA's of its mandate of managing and protecting water catchments has to be looked at carefully in light of the promulgation of the Constitution of Kenya 2010.

9.1.1 Water Resources Management in the Constitution of Kenya 2010

Article 260 of the 2010 Constitution defines land to include:

a) any body of water on or under the surface;

b) marine waters in the territorial sea and exclusive economic zone; and

c) natural resources completely contained on or under the surface.

The same Article defines natural resources as including "**surface and groundwater**" thus the definition of land encompasses water and water resources.

Article 62 defines public land to include:

a) all minerals and mineral oils as defined by law;

b) Government forests, government game reserves, **water catchment areas**, national parks, government animal sanctuaries, and specially protected areas.

c) all roads and thoroughfares provided for by an Act of Parliament

d) all rivers, lakes and other water bodies as defined by an Act of Parliament

e) the territorial sea, the exclusive economic zone and the sea bed

f) the continental shelf

g) all land between the high and low water marks.

Public land falling under these classifications shall vest in and be held by the national government in trust for the people of Kenya **and shall be administered on their behalf by the National Land Commission**. The effect of these provisions is that rivers, lakes and other water bodies shall vest in the national government **and shall be administered and managed by the National Land Commission**.

Additionally, the Fourth Schedule at item 11 includes among the mandates of county governments that of implementation of specific national government policies on natural resources and environmental conservation, **including soil and water conservation**.

It is important to ensure that WRMA's future mandate does not duplicate and overlap with the mandate which the Constitution has assigned to the National Land Commission over water resources. A preliminary review of the allocation of functions by the Constitution suggests that catchment management and protection activities have been assigned to the National Land Commission together with county governments while regulation of the use of water resources has been left to be carried out by a national state organ, for which WRMA is the ideal candidate given its present mandate under the Water Act, 2002.

Notably the Constitution, the National Lands Commission Act, 2012 and the Water Act, 2002 all do not clearly define the terms "management" and "regulation" of use of water resources. A clear definition of these terms is necessary in order to allocate mandates properly between the National Land Commission and county governments on the one hand and WRMA on the other.

9.2 Identifying WRMA's Role in the New Constitutional Dispensation

In accordance with Article 62(3) ownership of rivers, lakes and other water bodies shall vest in the national government and shall be administered and managed by the National Land Commission.

In its ordinary meaning the term "manage" means "to control or be in charge of…" "Manager" is the person in charge of running an activity. Arising from this the National Land Commission as the manager of rivers, lakes and other water bodies will be in charge of water bodies and be the national state organ responsible for the activities to be carried out in respect to the rivers, lakes and water bodies, including soil and water conservation activities. The National Land Commission stands in the same position as the owner or occupier of private land who has responsibilities of management of private land.

County governments have a role in regard to water resources management that is akin to that of the National Land Commission, that of **soil and water conservation** at county level.

The Constitution deals with the use of water bodies as an aspect of use of public land but also as an aspect of the use of natural resources. Article 62(4) stipulates that "public land shall not be disposed of **or otherwise used** except in terms of an Act of Parliament specifying the nature and terms of that disposal or use." Thus the Constitution leaves it to an Act of Parliament to set out the terms under which rivers, lakes and other water bodies may be used.

Further, Article 260 states that natural resources include "surface and groundwater." The Fourth Schedule assigns to the national government the function of 'the use of international waters and water resources." Thus the national government is vested with the ownership of water encompassed within rivers, lakes and other water bodies and also has the function of the use of water resources.

The Constitution also deals with **the regulation of use** of natural resources. Article 66 stipulates that the "state may regulate the use of any land, or any interest in or right over any land in the interest of defence, public safety, public order, public morality, public health or land use planning.

The word "regulate" means "to control by means of rules while "regulator" is the person or organization that officially controls an activity to makes sure that it is operating in accordance with set rules. Under Article 66 the mandate of regulating the use of land is vested in the state (**but not in the National Land Commission or County Governments**).

It is clear that the Constitution of 2010 separates responsibility for "**management**" of water resources from responsibility for **use and the regulation of use** of water resources. These two functions are vested in different organs of the State. This means that, ideally, the legislation on water resources management and the regulation of water use ought to provide that the institutions which will be mandated to regulate the use of water resources will be separate, distinct and autonomous from those institutions charged with the mandate of managing water resources. This is also clear from a study of the provisions of the Land Act, 2012.

The Constitution has provided that management of water resources shall be a function of the National Land Commission and county governments. Therefore, the regulation of the use of water resources must be vested in a different state organ, a function for which WRMA is ideally suited. WRMA's mandate ought to be restricted to regulating the use of water resources. Among its key functions will be to:

- Apportion water resources among various water users;
- Institute a system for issuing permits for water use;
- Impose conditions for use of water and monitoring the enforcing of the conditions;
- Secure sufficient residual water (in line with the Fourth Schedule of the Constitution);
- Set and enforce national standards for the protection and conservation of water resources to be implemented by county governments; and
- Collect and manage data on water resources demand, management and use.

This means that future legislation should realign WRMA's mandate away from the mandate **to manage and protect water catchments**. This mandate should be left to the National Land Commission and county governments. In fact the rules imposed by WRMA as the water resources regulator will be directed at, and must be complied with by, all users of water, including the National Land Commission and county governments, and private and community land owners who use water resources.

It is recommended that future water resources management legislation should enhance the arrangements for water resources management by streamlining them in line with the Constitution of 2010.

10 Threats, Actions Needed and Responsibility

Required Action	Threats	Responsible Party	Applicable Laws / Regs
Protection of Sources of public water supply for Nairobi City	Pollution from wastewater discharge; Siltation; Non-point source pollution from run-off etc.	Water Service Boards; Water Service Provider, WRMA, NEMA, Public Health Officer	Section 73, Water Act, 2012; Water Resources Management Rules, 2007, Environmental Impact Assessment & Audit Regulations, 2003, Environmental Management and Coordination (Waste Management) Regulations, 2007, Public Health Act section 129.
Protection of downstream competing uses	Over abstraction, diversion of water from watercourse, impoundment and obstruction through creation of reservoirs	WRMA, NEMA	Sections 26 to 44 of the Water Act, 2002; Part II Water Resources Management Rules, 2007, Part VI EMCA,
Catchment protection	Reduced run-off especially low flows, increased pollution, erosion and sediments, wildfires, etc.	WRMA, NEMA, Ministry of Agriculture, Kenya Forest Service, local authorities, county governments, National Land Commission, Water Resources Users Association	Section 17 (protected areas); Part IX Water Resources Management Rules; Physical Planning Act, Cap 286, Agriculture Act, Part IV (on preservation of the soil), Forest Act, 2005 and Chief's Act, Cap 128 section 13.
Groundwater protection	Over abstraction, climate change, pollution from diffuse and joint sources, urbanisation and large developments, agricultural activities and pesticides, etc.	WRMA, NEMA, WSB, WSP and Local authority in the area.	Section 44 Water Act, (groundwater conservation areas); Part XI Water Resources Management Rules, 2007, Physical Planning Act, Cap 286.
Environmental Impact Assessment for proposed development	Potentially adverse impact on water resources and other water uses & proposed mitigation measures.	NEMA, developer (e.g. WSB or other entity undertaking the development	Environmental Impact Assessment and Audit Regulations, 2003, which deal also with strategic environmental assessment
Permit for siting of septic tanks and pit latrines	Contamination of water sources arising from seepage and soil contamination	Local authority, local provincial administration (e.g. chief)	Chief's Act, section 201 Local Government Act, Cap 265 (Local Government (Adoptive By Laws) Order, Part IX Public Health Act, Cap 242 (on sanitation and housing)
Stakeholder participation and conflict resolution	Tension arising from misconceptions about proposed development	WSB, WRMA, NEMA, WRUAs, CAACs and provincial administration	Water Act, section 15, Water Resources Management Rules 2007 Part rule 28.

Required Action	Threats	Responsible Party	Applicable Laws / Regs
Effluent discharge licensing	Contamination or pollution of water sources from discharge of pollutants	NEMA, WRMA, local authority, public health officer and WSB.	Part V Water Resources Management Rules, 2007, Water Act, 2002, EMCA, and Environmental Management and Coordination (Water Quality) Regulations, 2006, local authority by-laws, EIA Regulations, Environmental Management and Coordination (Waste Management) Regulations
Establishment & management of a database	Poor decision making due to limited information or absence of appropriate data	WRMA, Ministry of Water & Irrigation, NEMA, Regional Development Authority, WSB, WSP, Meteorology Department, Director of Physical Planning	Section 8(1)(h) Water Act, 2002, section 9(2)(h) EMCA, 1999 and Physical Planning Act, Cap 286.

11 Management of Existing and Future Water Sources for Nairobi and Satellite Towns

11.1 Introduction

The study area for the Feasibility Study and Master Plan for Developing New Water Sources for Nairobi and Satellite Towns falls within the Athi Catchment except for Thika Town which falls within the boundary of Athi and Tana Catchments. The major water sources which presently supply the study area originate from Tana Catchment on the Northern side of the study area. This implies that the present water supply system comprises of Inter-basin Transfer from Tana to Athi Catchment thus reducing runoff in the Tana Catchment and increasing runoff in the Athi Catchment through wastewater discharges.

Therefore it is imperative that proper Water Resource Management be developed to treat water systems in a holistic and integrated manner. This is to ensure equitable distribution of the resource from the areas of surplus to the areas of deficit while ensuring minimal impacts to the downstream users.

An Integrated Water Resource Management plan is intended to overcome the many problems that can arise in a watershed area as a result of the uncoordinated use and abuse of increasingly scarce water resources.

Better management of upstream water resources can be important to achieving sustainable urban water systems, but this will not necessarily improve access to water or sanitation among deprived communities, let alone bring the sort of health improvements that better water and sanitation provision allows. Avoiding urban water wastage and water demand management is important, but if these policies focus narrowly on saving water, the water that is saved is unlikely to find its way to the urban residents who need it most. Thus proper coordination through and integrated development and utilisation of the available water resources in the study area is required.

At present, water and sewerage services are provided within the wider study area by a number of Water Service Providers (WSPs) all of whom face rapidly increasing demands for water supply. Presently, the degree of coordination in the development of resources has been limited. Only rarely have attempts been made when undertaking water resource development studies to consider the needs of other water service providers or the possibility of utilising one scheme to provide water to a number of WSPs.

This unstructured method of developing water resources can only be tolerated in a situation where water availability far exceeds the demand for water. However, as the demands made upon the finite water resources of the wider study area continue to increase, so does the need to control and coordinate the overall development of the available water resources.

The forecast demand for water presently has started to equate or exceed the economically available finite water resources. It is therefore essential to integrate the development and hence use water over the whole of the study area or even the catchment areas of the Tana and Athi Rivers rather than water development for individual WSPs. The proposed Long Term Development Strategy (Mixed Water Supply Option) has been developed with this in mind, through the following three guiding principles:

- Water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.
- Water has an economic value in all its competing uses and should be recognised as an economic good.

These principles are based on the three sustainable dimensions of sustainability: ecological sustainability, social equity and economic efficiency.

11.2 Management of Existing Sources

Table 11-3 shows the existing water sources which supply Nairobi and the 13 Satellite Towns. The table shows that more than 80% of the present water sources for Nairobi and Satellite Towns originate from the Tana Catchment area.

The sources are located at the upper side of the catchment and are fed mainly by runoff from the Aberdares Forest Reserve.

Table 11-3: Existing Water Sources – Nairobi and Satellite Towns

Town	Water Supply Scheme	Source	Source Catchment	Yield, m^3/d
Nairobi	Thika - Chania - Ngethu	Thika, Kiama, Kimakia and Chania Rivers	Tana	414,720
	Sasumua Dam	Sasumua-Chania River	Tana	56,000
	Ruiru Dam	Ruiru River	Athi	21,000
	Kikuyu Springs	Groundwater	Athi	4,000
	Boreholes	Groundwater	Athi	45,000
Kiambu	Boreholes	Groundwater	Athi	3,060
	NCWSC Bulk	Thika, Kiama, Kimakia and Chania Rivers	Tana	230
Kikuyu	Boreholes	Groundwater	Athi	4,202
Ruiru-Juja	Ruiru Water Supply	Ruiru River	Athi	1,500
	Ruiru Boreholes	Groundwater	Athi	480
	Juja Water Supply	Ndarugu River	Athi	2,000

Town	Water Supply Scheme	Source	Source Catchment	Yield, m^3/d
	NCWSC Bulk	Thika, Kiama, Kimakia and Chania Rivers	Tana	2,500
Ngong, Ongata Rongai & Kiserian	Boreholes & Springs	Groundwater	Athi	1,246
	Mbagathi	Mbagathi River	Athi	3,000
Karuri	Boreholes	Groundwater	Athi	1,667
	NCWSC Bulk	Sasumua-Chania River	Tana	1,100
Mavoko Municipality	NCWSC Bulk	Thika, Kiama, Kimakia and Chania Rivers	Tana	7,500
	Nol Turesh System	-	-	970
	Boreholes	Groundwater	Athi	700
Limuru	Boreholes	Groundwater	Athi	1,776
Githunguri	Boreholes	Groundwater	Athi	936
Gatundu	Ndarugu	Ndarugu River	Athi	3,000
	Boreholes	Groundwater	Athi	740
Thika	Chania	Chania River	Tana	26,000
	Thika	Thika River	Tana	
Tala - Kangundo	Boreholes	Groundwater	Athi	250

The rivers which serve Nairobi and Satellite Towns and which are located inside the Tana Catchment area also serve several local water supply schemes like the Kandara Water Supply Scheme and several intakes to the downstream side for irrigation and other water users.

Presently, limited monitoring systems have been put in place to ensure proper coordination of the different water users. Some of the existing hydrometric networks have already collapsed and an upgrade is required. Establishment of new river gauges is required to be spaced at not more than 10km at downstream of intake weirs and upstream and downstream of all storage reservoirs. Daily reporting of these data to central system is also required. Brief discussions on the various measures required on the existing components are given in the following sections.

11.2.1 Existing Run-of-River Abstractions

Field visits made on April 2011 to the Thika-Chania-Ngethu system showed that although there was ample run-of-river flow in the Chania River, transfers from the Thika Dam system were not required. However, water was still being drawn from the Kiama and Kimakia Rivers into the transmission tunnel. This is unnecessary, and such diversion of water will only exacerbate the impacts on riverine vegetation and aquatic fauna downstream of the Kiama and Kimakia intake due to deprivation of water for extended periods.

It is recommended that the intakes on the Kiama and Kimakia Rivers be closed when transfers to the Chania are not required in order to maintain the natural flow regimes of the rivers as far as is possible.

It was also observed that flow measurements of the diversions from each of the two rivers into the tunnel and the downstream flow were not being done. It is also recommended that mechanisms be established for measurements reporting to be carried out on a daily basis.

Regular flow measurements need to be also established on other run-of-river intakes like the Mbagathi, Ndarugu, Thika and Ruiru River intakes.

11.2.2 Existing Storage Dams

The main storage reservoirs which serve the study area are the Sasumua, Ruiru and Thika (Ndakaini) Dams. A decision support tool will be particularly useful for management of the three dams as recommended in the BRLi/Seureca (2010) Study. The following functions can be contemplated:

- Converting water levels to discharges by applying the rating curves,
- Water balance analysis at the reservoir and estimation of the inflow
- Statistical analysis
- Inflow forecasts for the coming months
- Determine flows to be released at short, medium and long terms, according to the dam control rules taking into account inflow forecasts and real water demands
- Simulation of management scenarios with the possibility of adjusting the demand and inflow assumptions
- Management of the hydrological database: calculation of ten-day, monthly and annual average flows, water balance at dams for different time steps, etc.

Currently the dam operators have some of the above tasks done manually, which is far from easy. A decision support system is useful for optimising the dam management in each of the following situations:

- “wet” situation: releases from dams to flush out sediments accumulating in reservoirs and intakes
- normal situation: adjusting the release to the real water demand
- “dry” situation: rationing of the water use to prevent catastrophic failure.

It will be possible to have an integrated system that incorporates hydrometric network supervision and decision-support tool.

It is recommended that specific training session on dam management be carried out and should include the following contents:

- Objective and challenge of the dam management
- Hydrological forecasting of inflows
- Principle of the optimisation for long term and short term operation
- Preparation of the dam control curves
- Simulation of management scenarios
- Operational management: decision-making procedure, etc.

The present dam operational and management rules for the Nairobi water supply reservoirs are based on the, "Nairobi Water Supply - Operating Philosophy" published by Howard Humphreys (1995). Considering the changes since, in particular the extension of Ngethu WTP and other works on the transfer system, the rules are obsolete and inappropriate for today's situation. These rules should be reviewed and updated in context of actual operational procedures which have been developed over the last decade of operations of the system.

Furthermore, when the Thika Dam management curves were drawn up in 1995, relatively high demands downstream of the dam were taken into account, corresponding to theoretical

estimates. The present demand, in particular for irrigation, is well below the 1995 estimates. Although the demand will change in the future, at short term, more realistic data needs to be taken into account.

For Sasumua and Ruiru Dams, the procedure for applying the rules will be very simple:

- Determine the Water Level Zone
- Determine the maximum flow to be released
- Release the maximum flow or the flow required by Sasumua WTP if lower
- Measure the flow actually released

For Thika Dam, the procedure is slightly more complex but the principles are the same:

- Determine the Water Level Zone
- Determine the maximum flow to be reached at Mwagu Intake from the management curves
- If the real demand at Ngethu WTP is lower than the maximum flow, take the demand flow as the target flow; if not take the maximum flow
- Calculate the difference between the real flow at Mwagu and the target flow
- Release the resulting amount of flow to supplement the flow at Mwagu
- Reassure the flow actually released

11.2.3 Pollution and Sedimentation Issues

Field visits were made to several Water Treatment Works like Ngethu, Thika, Mbagathi, Ruiru, Ndarugu (Juja) where it was reported that raw water has of late become increasingly silty and consequently harder and more expensive to treat. The increased turbidity requires the addition of higher concentrations of chemical coagulants to achieve the required quality standards. This was noted from anecdotal evidence to be due to deforestation, poor catchment management and urbanisation.

The Kabete and Sasumua Treatment Works seem to be functioning adequately. At both works, most of the sediment has had time to settle in the Ruiru and Sasumua Dams, respectively, before the raw water is transmitted to the treatment plants. Both dams have draw-off points at different levels so that if the water is very turbid, it can be drawn off the top.

The discharge of untreated alum sludge and other backwash wastes has been known to cause unnecessary local distress to the receiving waters at times of very low river flows, particularly at Ngethu. Normal and flood flows quickly dilute and dissipate the wastes.

Reports by WSPs indicate no significance level of chemical contamination on raw water sources emanating from agrochemical usage. However, as the population rises and the plot sizes decrease, increasing amounts of fertiliser and other agro-chemicals will be used so as maximise crop yields. This will then affect the water quality of the river, which may require specialised treatment to eliminate phosphates, nitrates and other chemicals in order to render the water potable.

Agricultural activities upstream of the proposed rivers and around the reservoir may accelerate sedimentation in the Thika Dam. Conservation of the catchment area is vital in this respect, and can only be done at regional level with collaboration between the various agencies such as the Ministry of Agriculture, Ministry of Environmental and Natural Resources, the Ministry of Water

and Irrigation, and non-government organisations, Water Resource Users Associations (WRUAs) and self-help groups involved in agro-forestry.

On sediment load monitoring, a Physiographical Baseline Survey for the Upper Tana Catchment Area carried out by Z&A - Antonaropoulos and Karavokyris (2011) concluded that future resources should not be spent on regular sediment load monitoring since this will rarely coincide with the timing of the peaking floods.

This was attributed to the difficulties of achieving the kind of continuous presence required in order to capture the right moment during a flood for optimal sediment load monitoring, and therefore it was recommended that future sediment monitoring efforts be directed towards conducting more frequent bathymetric surveys at the reservoirs. If sediment discharge monitoring is to be continued then it should be performed only during the wet periods, at safe locations (e.g. from bridges) and targeting specifically the flood events.

The Physiographical Study also found that annual sediment flows relate well with annual rainfall although generally the sediment response has a higher variability than the rainfall itself. Erosion rates are highest in the coffee zones and areas where maize and other cereals are cultivated. Intervening in particularly these areas is therefore considered optimal.

A scenario analysis carried out by the Physiographical Study showed that the highest basin-wide reduction on reservoir sediment inflow can be expected from the vegetative contour strips scenario. Especially, implementation of these practices together with the check dams at the coffee fields has the potential to reduce erosion dramatically.

The study also found that mulching has only little effect on the sediment budgets in the basin, as runoff is hardly reduced by this practice. Most of the impact of this scenario can be attributed to the effect of the check dams which reduce velocities in the concentrated flow areas.

The Physiographical Study found that tied ridges were not to be feasible for coffee and tea zones, so this practice was only studied for the fields where subsistence crops, maize and other cereals are cultivated. On these fields, erosion reductions can be obtained that are even larger than when vegetative contour strips are implemented. Maintenance of this practice however is more time-consuming and costly than the contour strips. Gully restoration and the construction of check dams to complement the farmers' practices was studied in all the scenarios and highly recommended to reduce peak flows and degradation of gullies and channels.

11.3 Management of Proposed Sources for Nairobi and Satellite Towns

The proposed water sources for supply to Nairobi and Satellite Towns based on the Mixed Water Supply Option which was found to be the most advantageous development plan for mobilising new water sources are given in Table 11-4.

Although the main water sources originate from the Tana Catchment area, a number of dams were identified close to the demands in the Athi Catchment for local supply to the Satellite Towns.

Table 11-4: Proposed Water Sources – Nairobi and Satellite Towns

Town	Water Supply Scheme	Source	Source Catchment	Yield, m^3/d
Nairobi (Bulk Sources)	Wellfields in Kiunyu and Ruiru	Groundwater	Athi	64,800
	Northern Collector Ph. I	Irati, Gikigie and Maragua Rivers	Tana	120,960
	Maragua 4 Dam with S. Mathioya Transfer	Maragua and S. Mathioya Rivers	Tana	132,192
	Northern Collector Ph. II	Hembe, Githugi and N. Mathioya Rivers	Tana	120,096

Town	Water Supply Scheme	Source	Source Catchment	Yield, m^3/d
	Ndarugu 1 Dam	Ndarugu River	Athi	216,000
	Chania-Komu Transfer	Chania River	Tana	181,440
Kikuyu	Boreholes	Groundwater	Athi	18,000
	Kamiti 1 Dam	Kamiti River	Athi	16,416
	NCWSC Bulk	NCWSC	-	20,000
	Ruiru 2 Dam	Ruiru River	Athi	21,000
Karuri	Ruiru 2 Dam	Ruiru River	Athi	30,000
Ruiru-Juja	New Ruiru Water Supply	Ruiru River	Athi	13,000
	Augmentation of Juja Water Supply	Ndarugu River	Athi	4,000
	Karimenu 2 Dam	Karimenu River	Tana	46,700
	Ndurire Transfer	Ndurire River	Athi	26,700
	NCWSC Bulk	NCWSC	-	38,000
Ngong, Ongata Rongai & Kiserian	Kiserian Dam	Kiserian River	Athi	15,000
	Boreholes	Groundwater	Athi	2,500
	NCWSC Bulk	NCWSC	-	33,000
Mavoko Municipality	Stony Athi Dam	Stony Athi River	Tana	60,480
	NCWSC Bulk	NCWSC	-	12,000
Limuru	Boreholes	Groundwater	Athi	8,000
Githunguri	Boreholes	Groundwater	Athi	4,000
Gatundu	Boreholes	Groundwater	Athi	740
Thika	Thika Intake	Thika River	Tana	10,368
	Thika 3A Dam	Thika River	Tana	40,000
Tala - Kangundo	Boreholes	Groundwater	Athi	3,600

The proposed development plan for the new water sources adopts an integrated water sources utilisation plan in which water sources are shared between Nairobi and the Satellite Towns. This has been shown to be the most gainful development plan.

11.4 Management of Proposed Surface Water Sources

11.4.1 Proposed Run-of-River Abstractions

According to WRMA (2009) Water Allocation Guidelines, a reserve flow (compensation flow) needs to be maintained in every water abstraction. The reserve flow is defined as that proportion of water resource that is set aside for ecological and basic human needs demands.

The guidelines state that the reserve quantity shall not be less than the flow value that is exceeded 95% of the time as measured by a naturalized flow duration curve at any point along the water course. Effectively this means that if the resource level drops to the level of the Reserve, then abstraction for domestic supplies would be curtailed to that of basic human needs. This eventually means that the WSPs must take account of the needs of the Reserve and therefore must take responsibility for any developments required to ensure reliability of supply. This principally involves the provision of storage.

The most significant impacts from the proposed abstractions are related to reduced flow levels in the rivers downstream of the points of abstraction. It is therefore imperative that river flows are regulated so that a minimum reserve flows in the rivers after abstraction in order that present users downstream and aquatic ecology are not affected. The downstream flows should be such that they also allow for adequate dilution of agro-chemicals and sediment loads.

With regard to the Northern Collector Tunnel, presently, the main water abstraction users that require significant off takes from the Irati, Gikigie and Maragua Rivers are for domestic use, irrigation, factories, power generation, posho mills and water supply. Water supply for Murang'a town comes from the Kayahwe River, a tributary of the Maragua River with a new intake on Irati River downstream of the tunnel off take under construction. Sewage and effluent from local industries in the town are discharged into the Maragua River. Hence the ability of the flow in the Maragua River to dilute sewage is important.

In the absence of data from the Water Resources Management Authority (WRMA), compensation flows have been determined here by taking- into consideration water requirements and uses of the respective rivers, while giving particular attention to the minimum recorded river flows. Although flow in the rivers is augmented by the various tributaries flowing into them, the flow calculation considers the contribution from these tributaries to be zero. Compensation flows have been calculated on the basis of the flow in the river at an intake weir, which is just sufficient to satisfy projected downstream demands. With the exclusion of hydroelectric power plants, compensation flows are set at the Q95 minimum level as required by WRMA.

Table 11-5 gives estimated compensation flows for the rivers from which water will be abstracted during Phase I and II of the Northern Collector.

Table 11-5: Consumptive Downstream Demands and Compensation Flows Allowed

River	Consumptive d/s Demands, m^3/s	Q95, m^3/s	Compensation flow allowed, m^3/s	Factor of Safety
Irati	0.401	0.340	0.481*	1.2
Gikigie	0.073	0.100	0.100	1.4
Maragua	0.482	0.645	0.645	1.3
S. Mathioya	0.270	0.625	0.625	2.3
Hembe	0.166	0.520	0.520	3.1
Githugi	0.073	0.435	0.435	5.9
N. Mathioya	0.169	1.170	1.170	6.9

**Compensation flow set to give a factor of safety of 1.2*

River abstraction should therefore only occur when river flows are above the estimated compensation levels. Intake weirs should be designed so that compensation flow levels are maintained. Strict adherence to compensation flow levels will be essential especially during low river flow conditions, as this will ensure that adverse downstream impacts are minimised. In particularly dry seasons, it may be necessary to ration the supply of water. In addition, when the dam is full, water should not be diverted into the intakes.

Water use downstream should be continuously monitored to determine any unexpected changes and trends which may trigger adverse impacts. Close collaboration with WRMA for monitoring of river levels will be necessary.

The setting of compensation flows which are determined by the downstream demands significantly dictates the yields to be obtained from the proposed scheme. Any significant changes to the demands not envisaged by the present study or the pattern of water use within the Murang'a County may affect the supply to Nairobi.

If the scheme is constructed as recommended, and increased demands are drawn by other users from the rivers upstream of the Northern Collector diversions, then the yield will be reduced. On the other hand the construction of the Northern Collector will limit the capacity of new intakes for other purposes constructed immediately downstream of the diversions.

Similar considerations have been made in other proposed run-of-river transfers. These transfers include:

- Chania to Komu River Transfer into Ndarugu 1 Dam
- Ndurire River Transfer into Ruiru 2 Dam

In the other proposed water supply schemes, the provision of storage has been considered to increase the abstraction volume while sustaining the downstream demands. The only run-of-river abstractions adopted are those under construction or existing intakes which can be utilised in future. These are:

- Ruiru Water Supply Intake on Ruiru River (Under Construction)
- Juja Water Supply Intake on Ndarugu River (Under Construction / Augmentation)
- Thika Water Supply Intake on Thika River (Existing)

11.4.2 Proposed Storage Dams

The WRMA guidelines require that the compensation flow for online storage structures such as dams across water courses be equal to or exceed the reserve flow plus downstream water allocations. For a dam whose total storage is a significant proportion (i.e. > 30%) of the mean annual volume, it is required that a detailed study be carried out to determine the flow compensation requirements, particularly during the initial impoundment period.

The construction of the Northern Collector Project will extensively alter the operating regime of Thika Reservoir. This will require the revision of the Reservoir operating rules to ensure its full yield can be realised safely and risks of total failure of the source are minimized. Rules will also need to be developed for abstractions at other reservoirs proposed for Nairobi and Satellite Towns water supply.

This is considered necessary to ensure that storage in the dams is conserved during times of drought due to unknown severity and duration of the event. Introduction of reservoir operating rules minimises the risks and severity of the failures, but the supply restrictions result to more frequent failures greater than once in every 10 years which is the design reliability.

Future sediment monitoring efforts need to be carried out particularly through conducting more frequent bathymetric surveys at the proposed reservoirs as recommended in the Z&A - Antonaropoulos and Karavokyris (2011) Study.

11.4.3 Pollution and Sedimentation Issues in the Proposed Sources

Monitoring of water quality, including tests for pollutants and biological contamination that may be related to potential human health issues will be necessary. Monitoring to be carried out at all river gauge sites on a regular monthly basis (or more frequently). Detailed monitoring of water quality should also be carried out at the proposed water treatment facilities.

Reduced nutrient availability in downstream areas, resulting from the reduction in downstream flows, may result in a reduction in productivity of downstream systems, including cultivation in alluvial and other riparian areas downstream. In such cases it may be necessary to carry out mitigation or corrective measures, for example through the release of high flow pulses or flood events to induce sediment transport.

Untreated sewage waste runoff from surrounding communities, and contamination from agricultural chemicals, accumulating in proposed storage reservoirs needs also to be monitored. Proper monitoring also needs to be carried out to ensure that wastewaters

generated from the proposed sources are well treated to acceptable levels before being discharged into water courses.

11.5 Management of Groundwater Sources

11.5.1 Groundwater Management Considerations for the Nairobi Envelop

This section considers measures for groundwater management within the existing City limits.

The Norken (2010) Preliminary Nairobi Water Allocation Plan (WAP) and the Groundwater Governance Study (2011) recognise the Nairobi Aquifer Suite as the most heavily used aquifer in Kenya. The effects of this has been decline in groundwater levels in certain 'hotspots' and deterioration of the water quality.

One of the biggest challenges for groundwater use management in the Nairobi Envelop is poor governance or lack of it. The Envelop is within an area that was declared a Groundwater Conservation Area (GCA), ratified in 1972 by the Government. However, the declaration apparently carried no conditions with it, as the number of boreholes continued to increase at an exponential rate (see Review of Groundwater Resources, BCEOM-MIBP, 2011).

The Preliminary Nairobi WAP was never implemented, yet one of the recommendations in the WAP is that – "it is strongly recommended that sound groundwater management be practiced and strictly adhered to".

Groundwater will remain under great pressure in the Nairobi Envelop due to the flexibility and spontaneity of use that it offers compared to mains water supply. This means that even those connected to mains supply find certain advantages in using boreholes that they have greater control over. Demand side management will therefore be a critical aspect of groundwater protection in this area. Water allocation plans that respond to these needs must be drawn and operationalized.

For example, areas where groundwater is already over-allocated or depleting should be considered to be served with more surface water so that there can be a corresponding reduction in the allocation of groundwater permits.

The plan should consider how deep the water table in Nairobi will be sustainably allowed to drop. The Upper Athi Series aquifer (UAS) is already depleted in some areas and pumping water levels are currently sustained above the Lower Athi Series. Should there be another episode of depletion, the pumping water levels will drop into the lower aquifer, yet the next aquifer layer may not be as productive as the first two. This means that pumping levels may drop to more than 250 metres below ground level. The question is whether such deep levels will be economical for private water users to pump small quantities from. If pumping water levels have to be maintained at the current 200 – 220m at the deepest, then a WAP must be drawn immediately and adhered to.

Another aspect that should be progressively studied is artificial recharge through artificial storage and recovery (ASR) from the wastewater treatment works. It is estimated that daily effluent form the Nairobi envelop will grow from the current net treated wastewater of 59,000 m^3/day to 294,000 m^3/ day in 2035. This subject should be approached with a view to the challenges of ensuring acceptable water quality for recharge and locating the right geological conditions.

11.5.2 Kiunyu Well Field Catchment Management

The Kiunyu site was selected because its upper catchment is still in good condition, being part of the Aberdare Forest. The wellfield is located at the base of the volcanic pile of basaltic lava

which is recharged on the southern Aberdares on which the Kikuyu Escarpment forest is located.

The catchment is approximately 300 square kilometres, of which 37% or roughly one-third is protected forest with a settlement density of 0 per square kilometre. This makes it an ideal location for recharge to the wellfield. The remaining two-thirds is densely settled, with populations of between 400 and 1500 per square kilometre.

Land is farmed for cash crops – mainly tea growing but also coffee. Farmers subsidize their tea crop with dairy and poultry farming. Food crops are planted in small strips of land - maize, beans, peas, bananas, arrow roots and potatoes being the main crops. Positively, most households plant small woodlots and other trees along farm boundaries.

a) Water Resources

Being a watershed, the catchment is endowed with numerous streams which provide sources of water that is in excess of local demand. As a result, there is very little need to exploit groundwater sources. Dug wells and boreholes are therefore scattered in the catchment. This state of water use makes it possible to scale up groundwater abstraction for public water supply transfer without the constraint of competing water use interests.

b) Water Use Priorities

With the dense population, domestic use takes precedence over other types of water demand. Other uses include light industrial applications in coffee pulping factories and milk cooling plants. In some, stock water is also required.

In the lower sections of the catchment where there is slightly less rainfall, some irrigation is practiced.

c) Threats to Water Quality

The combined anthropogenic factors of high population density and commercial and subsistence agriculture pose potential threats to water quality. Due to the pressure on land and its high value, farming activities are intensive: most lands cultivated for cash, food and animal fodder crops all year round. This intensive land use puts stress on its fertility; hence farmers take measures to ensure it remains productive all year round.

Fertilizer, pesticide, herbicide and acaricide use is therefore widespread. It is common to find advertisements for these products along the roads and at local trading centres. Being a recharge zone the potential for residual products to be introduced into the groundwater system is real. No systematic documentation of groundwater quality analyses can be cited, but comparing to a similar situation in the Kikuyu Springs catchment this caution is not without merit. In the latter case nitrate loading increases from zero at the head of the catchment to 4 ppm by the time groundwater exits the catchment. Following subsequent flow below Nairobi city, groundwater experiences nitrate increase to more than 12 ppm.

d) Threats to Aquifer Recharge and Water Reserves

Degradation of catchments could result from poor land husbandry in the densely populated zone, accompanied by soil erosion and increased runoff, thereby reducing infiltration. Although the Aberdare Forest is gazetted and fenced off, the status of this forest must be protected. Any attempt, legal or illegal, to hive off part of the forest for any other anthropogenic needs will reduce the percentage of catchment under forest while increasing the area of degraded land.

e) Proposed Management Measures

Catchment Protection: The pressure on land has led to the extension of farming activities into riparian land along streams and on to very steep slopes. Agricultural extension workers have done well in training farmers on soil conservation measures when farming steep slopes. Promotion of these activities should continue: better results will be achieved through coordination of efforts by the Ministry of Agriculture and the Ministry of Water and Irrigation through the Water Resources Management Authority (WRMA). The authority should facilitate water resource users associations (WRUA) in the Kiunyu wellfield catchment to engage in catchment conservation.

The WRUAs will also sensitise farmers who are their members on the need to protect riparian land along riverine areas. In coordination with the department of agriculture, crops that fix soil and do not use up too much water could be planted. This is a difficult area that must be handled with sustained effort and cooperation of all stakeholders. Dairy farmers for example could plant perennial fodder crops in these areas to minimise soil disturbance.

Along with these efforts, laws between the water and agriculture departments should be harmonised regarding riparian land. Ideally a certain freeboard should be left for the rise and fall of water level in the river and this does not have to be the 30m-rule. WRMA is in the process of preparing a Flood and Drought Disaster Management manual. One of the findings during research for the manual is that flood disasters sometimes happen when human activities encroach into river passages. If such reasonable freeboard was left undisturbed there would be less damage experienced. Ideally, WRUAs should make it one of their activities (similar to water allocation plans) to plan for this freeboard land along rivers within their sub-catchments. The distances will be variable according to the unique locations and may be as little as 10 metres from the river bank. This could make farmers more responsive to taking care of riparian areas with minimum policing from the authorities.

Minimising Pollution Vulnerability: Pollutant sources from agricultural chemicals will continue to put groundwater quality at risk. At this stage in the country's water resources management, what is advisable for now is to step up water quality monitoring, especially with regard to agricultural pollutants. This will again require WRMA coordination with WRUAs in its sampling programs. When farmers are sensitised that the chemicals pose a risk to the water that they also use, they have an opportunity to become more prudent in their application.

An aspect that has a more direct threat to groundwater is the storage and disposal of these agricultural chemicals. If poorly handled, they have a chance to be introduced in concentration directly into the ground. Coordinated efforts between the chemical manufacturers/distributors, agriculture, WRMA and WRUA to continuously sensitise farmers on handling of these products will reduce the risks of groundwater pollution.

Declaration of Groundwater Protection Area (GPA) around Wellfield: This proposal is apparently drastic, but in view of the wellfield being a source for public water supply this is a credible step. The radius of influence of most wells in the volcanic aquifers vary between 40 and 100 metres; for most wells, Standards for water quality require that a drinking water source should be located at a distance from potential sources of pollution. Depending on the local hydrogeological conditions, the distance should be such that it takes at least 50 days for flow from the potential contaminant source to reach the water supply source. Taking the minimum of 50 days, the desirable distance should be calculated based on the hydraulic characteristics of the aquifer and twice the radial distance of the area of influence of the well added. In most cases for this terrain this will be a total of about 150 metres.

This means that typically owners of land within 150 metres of the wellfield should be required to not do certain activities, including, but not limited to:-

- Installation of inorganic fuel depots;
- Location of agricultural chemical depots;
- Installation of large underground effluent treatment works;
- Location of landfills and garbage dumps, etc.

Such an area may require legislation into local county by-laws, not necessarily national gazettement. In the event such facilities already exist in the proposed wellfield area, provisions for commensurate/ reasonable compensation of owners should be made.

Managing Groundwater Abstraction: This applies to abstraction from within the wellfield, the surrounding area and downstream of the Kiunyu wellfield. The overriding concern for the area downstream of the wellfiled is due to the hydraulic profile of the Kiunyu wellfield groundwater catchment area. The rather steep profile means that the effects of over-abstraction downstream will be magnified upstream.

Piezometers' nests (at least 3) should therefore be installed along the profile of the narrow catchment. The installation of such piezometers will take into account to tap into the regional flow rather than local or perched aquifers. An appropriate spacing along the catchment will be determined.

Typically, a water allocation plan shall be developed for the wellfield catchment. The plan should give priority to local domestic water supply, public water supply and the wellfield abstraction requirements. The plan will be dynamic, to allow for conjunctive use between the surface water sources to Nairobi and the groundwater. Pumping will typically be reduced in the wet season when dams will be full, and scaled up from mid-dry season when reservoir levels begin to drop. Although the wellfields are designed on the premise of a fixed production per day, operational dictates will govern the final pumping regime.

11.5.3 Ruiru Wellfield

The wellfield is located at the base of the volcanic pile that rises onto the Kikuyu escarpment. Its catchment is heavily populated and intensively farmed. The catchment area of 252 square kilometres has forest cover of nearly 25% of the total, situated in the upper catchment.

Farmers in the catchment plant food crops, practice zero grazing for dairy animals, rear poultry and have small plots of coffee and tea (the latter in the higher zones). Horticulture has taken root and a small acreage of greenhouses exists. Large coffee estates are found at the lower end of the wellfield catchment. The wellfield is located within a coffee estate, but upstream of the main coffee growing zone.

a) Water Resources

The Ruiru wellfield catchment area has fewer surface water sources than Kiunyu catchment, yet is more intensely farmed. As a result, there is a lot of pressure on surface water sources which makes groundwater an attractive alternative. A lot of the groundwater is abstracted via boreholes, but there are also numerous hand-dug wells.

No hydrocensus of these hand dug wells which range in depth up to 50 metres has been done. Certainly there is a significant amount of groundwater being drawn from these wells that is unaccounted for.

b) Water Use Priorities

Like at Kiunyu, domestic water supply takes precedence over other uses. Due to the significant dairy and poultry population, demand for livestock water supply is important. The catchment has favourable climate for rain-fed agriculture in its upper reaches, but in the lower reaches some water is required for irrigation, mainly through river abstractions but groundwater abstractions as well. A small amount of water goes into light industrial use, mainly for washing and pulping coffee.

Comparatively, there is greater water supply demand within the catchment than in Kiunyu.

c) Threats to Water Quality

There are similarities with the water quality problems likely to be encountered within the Kiunyu wellfield catchment due to similar land use patterns. Groundwater quality is threatened by:

- Nitrate loading from farming activities;
- Agricultural chemical pollution;
- Over-abstraction.

d) Threats to Aquifer Recharge

Land in the Ruiru wellfield catchment is gradually being transferred from agricultural to commercial developments, mainly residential estates. This is as a result of the expansion of Nairobi city metropolis, making it attractive to reside in the suburbs of Greater Nairobi. In fact, the Nairobi Metro 2030 Plan indicates the whole catchment will be a residential area. These developments result to increased runoff, at the expense of infiltration. Furthermore, pollution of recharge water could occur.

Population in the upper reaches of the catchment is currently about 1/5th of the density in the lower part of the catchment: this augurs well but future increases in population density will stress the catchment.

Uncontrolled surface water abstraction for irrigation poses a unique danger because aquifers in this area share a cyclic relationship with streamflow; groundwater provides baseflow in sections of streams which also recharge groundwater in certain zones. Over abstraction of rivers at some sections may end up disrupting this relationship.

e) Catchment Management Measures

All the recommendations proposed for riparian land in Kiunyu catchment are applicable. Additionally, ways of managing the changing land-use pattern in the catchment should be devised. For example, the abstraction of groundwater for domestic use by private developers will increase if unchecked. Mechanisms could be put in place to ensure appropriate allocation of groundwater that allows for a high percentage of Ecological Reserve.

Minimising Pollution Vulnerability: As with Kiunyu, a radial distance of 150 metres around the wellfield should be declared a GPA. This will minimise groundwater pollution risk, especially since the wellfield is surrounded by coffee estates. A positive aspect of the change of land use is that there will be less loading of agricultural chemicals and organic livestock waste products. However, the expected increased anthropogenic waste must be managed well, for example through environmentally sound landfill sites and regulated handling of inorganic waste.

Declaration of GPA around Ruiru Wellfield: Similar to Kiunyu, it is recommended that a groundwater protection area be declared around the Ruiru wellfield, with the same regulations for activities that may not be allowed within this area. The implication for Ruiru is that the coffee

estate owners may require greater compensation because a larger area than that taken by the wellfield will be required by the water services board.

Managing Groundwater Abstraction: A water allocation plan for the catchment within which the Ruiru wellfield is located shall be drawn. The plan must balance the need for private water supply – which is set to rise in the area given the changing land use pattern, and public water supply from the wellfield. The interests of local water users must be accounted for in the allocation plan, because most of the abstraction from the wellfield shall be for transfer.

Piezometers will be required along the axial profile of the wellfield catchment to monitor short and long-term water level changes, data that will be used to manage conjunctive use and long term abstraction effects.

It should be noted that if the results of exploratory deep drilling are positive, there will be an abstraction component recharged by the local flow and the other by the regional flow. Local domestic water supply will largely come from the shorter recharge path and the public supply transferred to Nairobi will be from the regional recharge path. The allocation plan shall therefore be responsive to this scenario.

11.6 Recommendations

The following recommendations have been made with respect to aspects which need to be monitored and carried out so as to overcome problems that can arise from the development and utilisation of water sources and continued sustainability of the sources:

- An extension of the river gauge network to include all impacted rivers. Regular monitoring of flows upstream and downstream of all diversion structures and storage reservoirs,
- Frequent bathymetric surveys in reservoirs to monitor sedimentation effects,
- Periodic surveys of aquatic fauna upstream and downstream of all of the intake weirs and proposed storage reservoirs,
- Changes in demand for water downstream of the intakes. This should include household water supplies with changes in household numbers and population densities, as well as changes in demand related to increased demand for agricultural production,
- Changes in the quality and availability of water supplies from rivers and associated streams and impacts on public health, including those communities dependant on downstream flows. This should include regular testing for chemical pollution from agricultural inputs upstream of intake points and reservoirs,
- Upstream land use and land cover, including forest cover in the Aberdares catchment area, as well as agricultural activities in the catchment areas,
- Land use and land cover downstream of proposed intake weirs and storage reservoirs,
- Assessment of environmental impacts on water courses due to wastewater discharges into rivers from water users and from water treatment facilities,
- Monitoring of the proposed development plan for mobilising new water sources for Nairobi and the Satellite Towns to ensure that sources are developed and utilised in a coordinated and structured manner as planned.

Hydrological monitoring has been neglected in recent years, and this is a handicap to effective water resources management. It has also been a handicap to this Study. Accurate

hydrological and climatological data is the basis upon which water resources development and management decisions can be effectively made.

It is thus essential that the original river gauging stations be restored to full functionality, and that they are maintained thus by the Water Resources Management Authority (WRMA). The key gauging stations for the Northern Collector Rivers are tabulated in Table 5.34 of the Consultants Water Sources Options Review Report, Version 01, dated August 2011. They include RGS 4BD6, 4BD7, 4BE1, 4BE6, 4BE7, 4BE8, 4BE9, and 4CB5. In addition, key stations on the Chania River, and on rivers close to Nairobi, should all be restored and maintained.

At each river gauging station, the twice-daily river water level gauge readings are a minimum requirement, and continuous water level recorders should also be contemplated. It is essential that the gauging stations be visited regularly, at least once a month, by teams equipped and trained to undertake current meter gaugings. The equipment used for this purpose also needs to be calibrated according to the manufacturer's recommendations. The current meter gaugings are essential to ensure that changes to the station rating equations be picked up. This will ensure good data quality.

It is fortunate that many Governmental organisations have continued to file daily rainfall returns with the Kenya Meteorological Department in Nairobi, and they should be encouraged to continue to do so. These include the Kenya Forest Service, Kenya Wildlife Service, Ministry of Water Development, meteorological stations, various schools, Police stations, and private individuals, to name a few. A list of key stations was included in Table 5.27 of the Consultant's Water Sources Options Review Report, Version 01, dated August 2011.

Hence, the following is recommended:

- At every river diversion point, the flows being diverted will need to be measured, and the downstream release should also be simultaneously measured. This exercise will ensure that the operation rules are adhered to. The method of flow measurement will depend on the final hydraulic design that is adopted for the diversion structure. It is recommended that continuous water level measurement instrumentation be incorporated, and that a rating curve be established at each measurement point. The automatic measurement equipment should be backed up by a fixed staff gauge, which is read manually twice daily by operational staff, or by someone trained from the local community. This should be agreed with the Water Resource Users Association, as this Association will have a vested interest in ensuring that operating rules are sustained as agreed.
- The numerical addition of the diverted flow plus released flow will equate to the total river flow reaching the diversion structure. It is strongly recommended that the nearest WRMA river gauging station continue to be operated, as it is at these points that the long-term record exists. It is essential that this long-term recording be continued, as this record provides one of the benchmarks for monitoring hydrological change. Provided accurate records are maintained of the upstream diversions, the naturalised flow sequence at the gauging station can continue to accumulate, thereby extending the valuable historical database that exists.
- This study was hampered by the absence of accurate licensed abstraction records, especially in the reaches upstream of the key river gauging stations. It is absolutely essential that these abstraction records be obtained to a sufficient level of accuracy, such that naturalised hydrological sequences can be derived on an on-going basis, at each station. It is also essential that WRMA visit each rural water supply intake to

ensure that these intakes are constructed in accordance with WRMA's license requirements, to ensure that each intake includes provision for the specified compensation releases, and that the structure's hydraulic designs cannot allow by-passing. The Consultants have seen a community water supply intake on the Honi River within the Aberdare National Park, which effectively sucks the river dry. WRMA has the task to ensure discipline in the operation of all community water supply intakes within the protected areas, and that the water is effectively distributed with minimal leakage losses. Otherwise, the temptation will be to compensate pipeline losses or wasteful usage by over-abstraction, which will be to the detriment of downstream users, and will lead to conflicts. The intakes and pipelines within the protected areas are remote, and there is abundant dangerous wildlife, hence communities are inclined to only visit when there is total supply failure. A programme of pipeline and intake inspections needs to be co-ordinated with the Kenya Forest Service, and Kenya Wildlife Service, and these inspections should be documented as part of the water supply operational procedures.

- The daily rainfall database should continue to be collected, and reinforced in the case of stations that have a high proportion of missing data. The existing rainfall stations are generally located at Government establishments with permanent staff presence, where daily reading can be assured without interruption. However, some stations are at schools, and measurement often ceases during the school holidays. For selected stations, this eventuality should be mitigated through commitment to measurement continuity.
- Previous studies have established rainfall stations in more remote parts of catchments, but this is not recommended here due to the logistical difficulties presented. Perhaps some short-term stations in these remote areas can be contemplated, but only for sufficient time to establish correlation with existing long-term stations lower down the catchment. The options should be considered during the detailed design stage of the project.
- The climate stations at the Sasumua Dam, Ndakaini Dam, and at existing water treatment plants should be sustained. New climate stations should be installed at new storage dams and treatment plants. The data should be compiled and compared with data from national climate stations, with correlations established.
- Each of the existing river intakes contributing to the Nairobi water supply should be equipped to continuously record water abstractions and downstream releases. A thorough review should be undertaken at the detailed design stage to determine what sustainable methods of measurement can be implemented. This review would first review and co-ordinate with the instrumentation recommendations of other studies for AWSB by other Consultants.
- The instrumentation will include dam safety instrumentation. It will include continuous water measurement on spillways, and flow measurement at all dam water outlet points, including the pressure relief galleries within the dams, to ensure that the reservoir water balance is being constantly monitored, and that dam safety is ensured.
- A catchment map based on satellite imagery should be included in the database, and this imagery should be revised from time to time and examined for obvious catchment deterioration and change in vegetation cover.
- A programme of sediment sampling has been established by WRMA, and this should be integrated / expanded to ensure full coverage of all project rivers.

A comprehensive integrated instrumentation system can be set up for the Nairobi water supply, supported by data collection systems operated by other agencies. A combined database should be maintained, with monthly reporting that includes an analysis of trends and comparison with expectations.

At the same time, a water balance model can be established for the entire system. The hydrological data should be input to the model so that water balancing becomes an integral part of the AWSB monitoring.

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Chapter 12 - Risk Management

1 Introduction

Water is a finite and vulnerable environmental resource essential for life, social and economic good. The allocation of scarce water resources among competing uses has fundamental effects on the ecosystems and national economic development in terms of employment and the generation and distribution of income and poverty alleviation. Such policies can also have a significant impact on land use planning and the movement of population from rural to urban areas. The access to suitable amounts of water for basic human needs is therefore essential to be incorporated in the formulation and implementation of economic policies for resource development and allocation.

Fresh water resources are clearly of critical importance, for urban and rural areas, for households and industry, for agricultural crops and livestock, for human health, for the environment, and for the maintenance of the environmental services upon which all of these depend. Potentially conflicting demands for fresh water supplies may threaten the sustainability of this essential resource, with significant economic, social, and environmental consequences. Decreasing availability of usable water supplies, coupled with increases in demand can potentially lead to the inefficient and unsustainable use of water resources with significant economic, social, and environmental consequences.

An integrated system of water resources management is required that assesses and manages risks throughout all of the requirements within the hydrological cycle, and throughout the watersheds. Managing risks in water resources is essential to alleviate damage and the consequences of natural disasters such as flooding and droughts and to increase agricultural production to ensure food security for the country. Understanding the types of risks in each area helps planners to select the right policies and actions to apply in the right place and time in order to reduce risks and mitigate damages.

A risk is considered as an uncertain event or condition that, if or when it occurs, has a positive or negative effect on a programme's or project's objectives or outcome. Risks are inevitable and a component of any project. Project managers should regularly assess risks as standard practice and develop or modify plans to address them.

The active project level risk management plans should include an analysis of potential risks, including those with both high and low impact, as well as proposed mitigation strategies to help in counteracting negative consequences should problems arise. **Risk Management Plans should be periodically reviewed (preferably every 5 years, if not more frequently) by the project team to avoid having the analysis becoming stale and not reflective of actual potential project risks**. In practice, the levels of risk involved in a specific course of action are compared to expected benefits to provide evidence for decision making. Hazards and risks can be defined as follows in Table 12-1.

Table 12-1: Definition of Project Hazards and Risks

Hazard	A situation or biological, chemical or physical agent that may lead to harm or cause adverse affects.
Risk	The potential consequence(s) of a hazard combined with their likelihoods/probabilities. The likelihood or probability of an adverse outcome or event.
Risk Assessment	The process of evaluating the consequences of hazards and their likelihoods or probabilities. For example, the failure of a technology may result in economic loss and associated risks. Environmental Risk Assessment is a process that evaluates the likelihood or probability that adverse effects may occur to environmental functions, as a result of human activities. Risk assessment also provides a mechanism for managers to communicate forecasted risks associated with decisions, such that stakeholders and the public are informed of the implications.
Risk Management	The process of appraising options for responding to risk and deciding which to implement. Risk management should be periodically or continually re-assessed.
Environmental Value	An aspect of the environment that is important because of its ecological, economic or social significance to an ecosystem, the potential consequences of its loss, and/or its economic or social importance, including for example the ability of the environment to support agriculture, and to support tourism, or the human health hazards associated with deterioration in environmental services.

Risks are often complex and may derive from a wide variety of factors, including uncertainty in financial markets, project or business failures, legal liabilities, credit risk, accidents, and natural causes or disasters. Importantly, risks may also derive from unintended or unrecognised consequences of developments associated with individual projects, not necessarily directly connected to the programme under consideration, and from the cumulative impacts of a variety of different factors.

Assessing a risk involves an analysis of the consequences and likelihood of a potential hazard being realised. In decision-making, low-consequence or low-probability risks are typically perceived as acceptable and therefore only require monitoring. In contrast, high-consequence or high-probability risks are perceived as unacceptable and a strategy is required to manage the risk. Other risks may require structured risk assessment to better understand the features that contribute most to the risk, and to assist with the development of countermeasures.

In the wake of the recent global economic problems, risk management is increasingly seen as an important executive-level issue and a process that needs to be incorporated in day-to-day decision making. Similarly, risk management should also be viewed as an enabler of long-term profitability and competitive advantage.

In general, risk management is considered to include the following elements:

1. Identify, categorise and assess potential threats.
2. Assess the vulnerability of critical components or assets to specific threats or to combinations of different threats.
3. Determine the risk and consequences of specific threats.
4. Identify mechanisms whereby those risks may be reduced.

5. Prioritise risk reduction measures, and include regular reviews of all threats as an integral component of programme management, ensuring that risk management is dynamic and responsive to change.

The assessment of potential risks linked to the Master Plan for Developing New Water Sources for Nairobi and Satellite Towns covers an area that includes the watersheds supplying all of the proposed and existing water resources. This includes both surface water and groundwater catchments. It also includes all areas downstream, for example the Tana and Athi basins where the water from upstream areas currently provides an important and vital resource, especially during the dry seasons.

Potential hazards or risks can be categorised as either environmental or economic risks, and these are considered separately below, although there are inevitable overlaps and linkages between these main categories. In the long-term, education and training in risk assessment and management should be considered for managers dealing with the water supplies and related sectors. Furthermore, the precautionary principle should also be adopted when considering and assessing risks, particularly where hazards have long environmental lifetimes or accumulative or irreversible consequences.

2 Environmental Risks

A range of potential environmental risks can be expected from the proposed abstraction of water resources from rivers at weirs linked to the proposed Northern Collector Tunnel, and from the abstraction of groundwater resources. The primary aim is the abstraction of water from upstream resources and the use of this water in urban and adjacent areas.

Environmental and socioeconomic impacts are expected to include impacts resulting from:

a. Construction and development of groundwater well fields in Kiunyu then in Ruiru areas,

b. Construction of weirs, and other structures associated with intake facilities on rivers flowing from the Aberdares to supply the Northern Collector,

c. Construction of the Northern Collector Tunnel,

d. Construction of dams and reservoirs,

e. Construction of transmission pipelines and treatment works,

f. Resettlement and compensation,

g. Operation of these systems, and

h. Changes to the downstream hydrology of the river basins and downstream availability of water as a result of reduced flow in the rivers following abstraction at the intake sites.

In addition, it will be necessary to ensure adequate protection of the watersheds covering the proposed raw water supplies. A significant part of this area is currently included in the protected areas of the Aberdare National Park and adjacent protected forest reserves. **It is considered essential that the risk management procedures ensure that the current protection status continues and that the land cover in the forest reserves is maintained in conditions that are suitable for watershed protection**. It may also be necessary to designate additional areas where land use is limited to those categories that are suitable for watershed protection.

Downstream impacts on riverine ecosystems are considered to be the primary environmental impacts associated with the development of these water supply abstraction sites. The most important mitigation measures are the release of good quality Reserve Flows capable of maintaining important downstream environmental services, and at the same time capable of

satisfying downstream household and other water requirements. Additional impacts are related to a) construction and b) operation of the diversion sites themselves and associated transmission pipelines.

The major long term potential environmental and socioeconomic impacts are considered to be related to the changes in hydrology resulting in reduced downstream flows. Impacts resulting from construction, for example of intake structures and pipelines, are considered as short term impacts that will be manageable with the adoption of recommended mitigation measures.

Potential categories of risks include:

- Changes in precipitation and temperature as a result of climate change (see the section on climate change below).
- Hazards resulting from construction of weirs, intake structures and tunnels, as well as dams and reservoirs. Risk management procedures will need to be incorporated in the detailed designs and operating procedures for all of these structures.
- Impacts resulting from the changes in downstream flow in rivers supplying the Northern Collector Tunnel, including cumulative impacts from the combined changes in downstream flow of all of these rivers.
- Public health risks, resulting from reduced water quality as a result of reduced flows. This may result in increased health risks for downstream communities or households, especially those reliant on untreated river water if adequate reserve flows are not released.
- Changes in local groundwater regime are possible as a result of reduced downstream flows.
- Degradation of aquifers as a result of the increased abstraction of groundwater resources from boreholes. This is a longer term risk but groundwater replenishment needs to be incorporated in risk management strategies.
- Hazards and risks encountered during the operation of the water abstraction, storage and distribution system.
- Risks resulting from potential Seismic Activity. Although considered as infrequent, this could potentially be a major hazard, and this could have potential risks on the Northern Collector tunnel and on dams, and seismic risk management strategies need to be incorporated in detailed designs.

2.1 Climate Change

The world's climate is predicted to change substantially, with changes in temperature, precipitation and frequency of storms, and with subsequent effects on hydrology especially in the drier areas. A rapid rise in temperatures over the globe in the likely range of 1.1 to 6.4°C is expected. Precipitation patterns are expected to change significantly, and extreme weather events (severe storms, floods, droughts, and heat waves) are expected to become more intense and more frequent. From the water resources perspective, the increased incidence of drought periods represents a potentially serious risk. The generally increased temperatures also represent a risk to water resources.

Agricultural output is predicted to be impacted by increased temperatures and changes in precipitation and runoff. It is considered that many countries in Africa may suffer productivity losses of more than 25 percent (World Bank, 2011)[1]. Such losses are projected to be acute in the Sahel, the Horn of Africa, and in East and South-West Africa – areas that are projected to experience significant decreases in precipitation alongside increases in temperature. Further work focussed on Kenya also confirms that global warming will have adverse effects on agriculture in Kenya (Kabubo-Mariara and Karanja, 2007)[2]. As a result, the ability to provide water for downstream environments and for irrigation purposes is likely to be of increasing importance, especially when coupled with the increasing food requirements of an increasing urban population.

Most models do not agree on the extent of projected changes in precipitation. However, there is a general agreement between models that there will be increases in temperature. Whilst the actual extent of changes in precipitation are currently uncertain, models do indicate that changes will occur. The IPCC indicates that drought severity is expected to increase, especially in areas that are already dry. This will have inevitable implications for water and food security.

The risks from climate change can therefore be considered to be:

- Most areas in East Africa are projected to have an increase in the number of consecutive dry days.
- There will be an increase in temperatures.
- Water demands are expected to increase. Crop water requirements are expected to be higher for both rain-fed and irrigated crops as temperatures rise. Similarly, livestock are likely to require more water.
- Water-related public health could also be compromised by climate change. Hydrologic and temperature change may modify the natural habitat boundaries of disease vectors such as mosquitoes, and other water borne diseases.

The impacts on agriculture can be expected to include potentially significant risks of not providing the quantities of agricultural produce required by an increasing urban population in Nairobi and adjacent areas. Produce will most likely become increasingly expensive as transport costs are increased. The continued increase in the international oil prices (and reduced availability of crude oil) will only reinforce this trend towards increased costs of food products.

Given the difficulties of averting global warming, adaptation to climate change is considered essential to counter the expected impacts of long-term climate change. Improved management and conservation of available water resources, water harvesting and recycling of waste water are likely to play important roles.

Based on the combined temperature and precipitation changes, Climate Vulnerability Indicators include the following:

[1] World Bank (2011). *Africa's Water Resources in a Changing Climate: Toward an Operational Perspective. Summary Report.* Africa Region, Sustainable Development Department, The World Bank.

[2] Kabubo-Mariara, J. and Karanja, F.K. (2007). *The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricardian Approach*. World Bank, Policy Research Working Paper 4334.

- **Agriculture**
  - ✓ Increased water requirements.
  - ✓ Change or reduction in water availability.
  - ✓ Reduction in area irrigated, and reduction in future irrigation potential.
  - ✓ Reduction in agricultural yield.
- **Energy**
  - ✓ Change in hydropower energy production (including dependable capacity).
  - ✓ Change in reliability of reservoir volumes and levels.
- **Livestock**
  - ✓ Decrease in meat and dairy production.
- **Health**
  - ✓ Adverse changes in the prevalence rate of water borne and climate sensitive diseases.
  - ✓ Changes in conditions that support spread of climate sensitive diseases.
- **Biodiversity and Ecosystems**
  - ✓ Reduction in the reliability of minimum guaranteed river flows.
  - ✓ Change in the number and diversity of aquatic and riparian species.

The majority of the above Vulnerability Indicators will also be directly impacted by the reduction in downstream flows following abstraction of water for the Nairobi water supplies. The combined impact including climate change risks will therefore be greater.

Risk Management procedures will need to include a regular assessment of the current climatic situation, as well as a regular monitoring of the river flows, agricultural water requirements, and water related public health issues.

There are naturally concerns about the sustainability of the water sources with the evolving challenges of climate change. In southern Africa, very large runoff reductions are being forecast. In Kenya, some warming is expected, which will increase evaporation. Rainfall variability is also expected, but annual rainfall totals are not expected to decline. World Bank's 2011 Report "Towards a Strategic Analysis of Water Resources Investments in Kenya" has concluded in its "Climate Change" assessment that "….changes of +/- 10% in the skewness of annual flow do not significantly affect the estimated dimensionless draft (yield)…..". The Northern Collector River flow database studied by this project did not show any reductions in annual average flows in recent years.

Climate Change Analysis has been carried out at a National Level as part of the ongoing update of the National Water Master Plan to Year 2030 (NWMP 2030) being prepared by Japan International Agency (JICA) and Nippon Koei Co. Ltd. Results have been reported in the Interim Report dated April 2012 for the 6 major catchment areas defined by the Water Resources Management Authority (WRMA). These are the Rift Valley, Ewaso Ngiro North, Tana, Athi, Lake Victoria North and Lake Victoria South catchments.

The Report outlines the future climatology patterns which have been determined using results from the General Circulation Models (GCM) hosted by World Climate Research Programme (WCRP) Working Group on Coupled Modelling (WGCM), Phase 3 of the Coupled Model Intercomparison Project (CMIP3). Daily data sets from 17 GCMs were used for the periods 1981-2000 and 2046-2065 and the monthly data sets for years 2021-2040 were used.

The results of the GCM Analyses concurred with the World Bank findings[3] that the annual rainfall will not decrease over the country. Furthermore, temperatures are set to increase thus increasing the evaporation. The analysis of rainfall frequency showed a high probability of increase for the 50 year return period whilst the number of rainy days will also increase over the country. Main climate parameters like annual rainfall, temperature and evapotranspiration were used to simulate expected future runoff using a Rainfall – Runoff Model.

Run off simulations showed an increase in renewable surface water resources for the Athi and Tana catchments. However, the annual renewable groundwater resources decreased initially for the year 2030 climate and increased thereafter for the 2050 climate for the aforementioned two catchments. The Present and Future water resources by catchment are given in Table 12-2.

Table 12-2: Present and Future Water Resources by Catchment

(Unit: MCM/year)

Catchment	Catchment Area (km^2)	Renewable Water Resources			Differences	
		2010	2030	2050	2030-2010	2050-2010
Lake Victoria North	19,202	5,168	5,507	6,005	339	837
Lake Victoria South	24,019	7,178	8,137	9,449	959	2,271
Rift Valley	115,718	20,861	21,320	22,495	459	1,634
Athi	64,726	5,952	6,055	6,542	103	590
Tana	93,901	17,529	18,850	19,241	1,321	1,712
Ewaso Ngiro North	255,053	19,922	20,605	19,851	683	-71
Total	572,618	76,610	80,474	83,583	3,864	6,973

Source: JICA Study Team

The Annual Water Budget for the Tana and Athi Catchments which summarise the Annual Renewable Water Resources is given in Figure 12-1 and Figure 12-2 respectively.

In conclusion, the NWMP 2030 Update reported the spatial distribution of renewable water resources do not change drastically in the future. Whilst the renewable water resources in northern and eastern half of the country are expected to be similar to the present condition, the resources in the central mountainous area and the western side around Lake Victoria are anticipated to increase. Therefore, the runoff from the Northern Collector Rivers may increase in the future. However, this has to be viewed considering the inherent uncertainty of the GCMs results and the runoff database used is at National Level (average monthly runoffs for various River Gauging Stations) and not project specific daily flow data which has been analysed under the hydrological analysis.

Appendix 12.1 outlines a detailed Synopsis on Climate Change Analysis carried out under the NWMP 2030 Study.

[3] World Bank, 2011. Towards a Strategic Analysis of Water Resources Investments in Kenya.

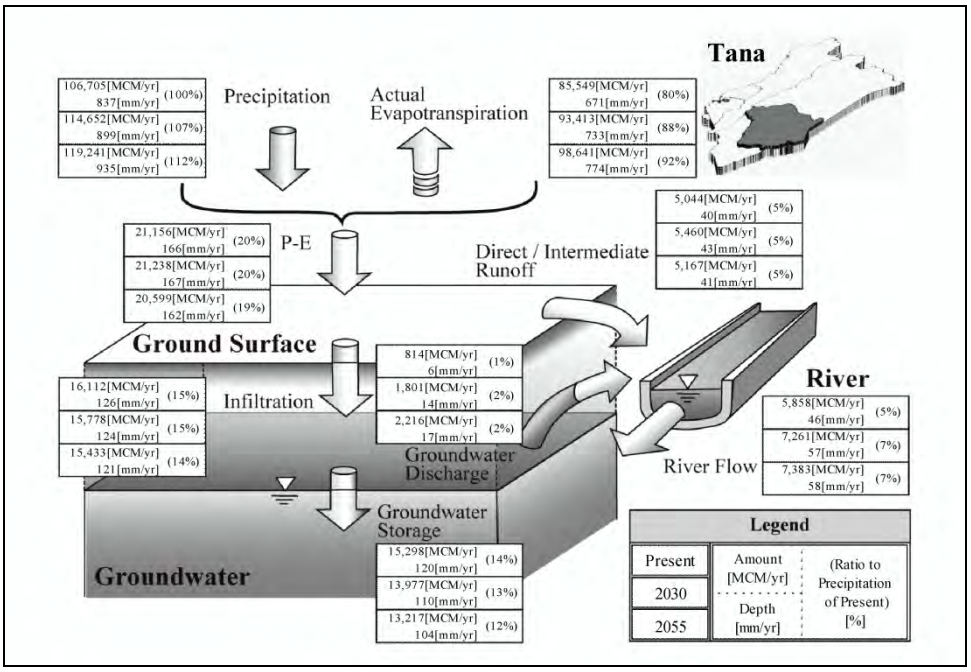

Figure 12-1: Climate Change Impact on Annual Water Budget for Tana Catchment

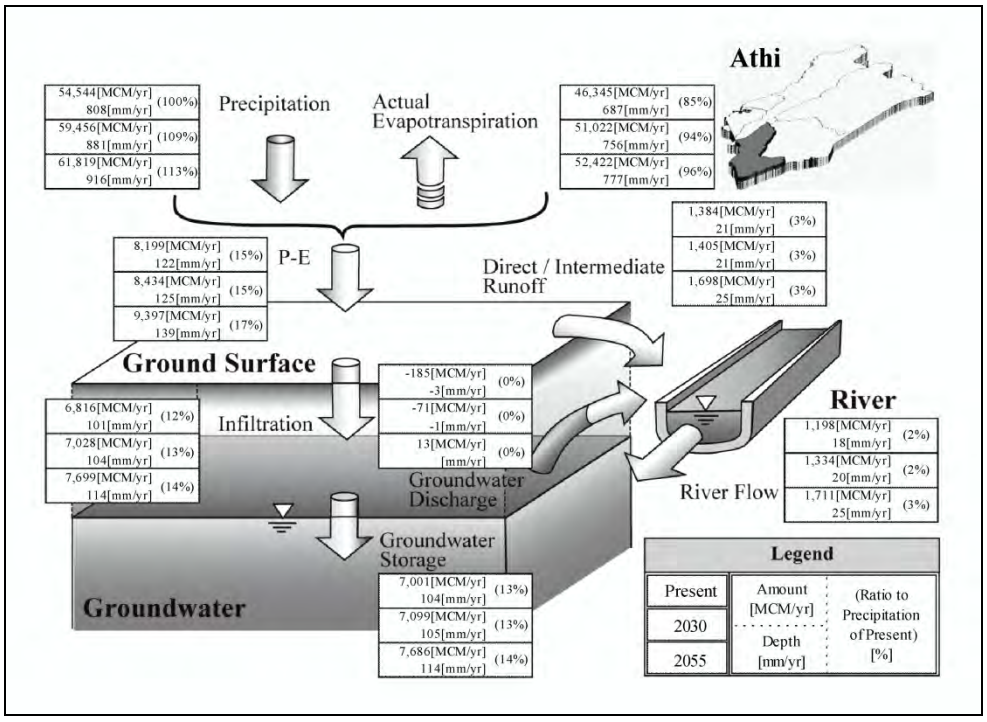

Figure 12-2: Climate Change Impact on Annual Water Budget for Athi Catchment

This present Master Plan Study has focussed on the Northern Collector River System from the Eastern Aberdare mountain forests and moorland. It was established many years ago that these rivers are amongst the most productive in the country, with very high unit runoff, and with strong baseflow components as a result of the boggy upper catchment and forest cover. The potential of these rivers to supply Nairobi with water was beyond doubt, and this project set out to confirm that these facts had not changed since the conclusive studies reported some years ago.

Since the last major reports were produced nearly 20 years ago, the hydrological database and analysis was in need of updating to confirm yields established at that time. This project therefore sought all available river flow data collected since that time for the Northern Collector Rivers. Although, hydrometric data collection systems have collapsed in Kenya in recent years (to an alarming extent), sufficient data was obtained by this study (and by a parallel AWSB study in the Sasumua / Chania catchment), with which to allow data infilling and the derivation of extended flow sequences. The analysis of these flow sequences established (within the data constraints) that the hydrological yield of the Northern Collector Rivers has not changed. This was as anticipated, as the rivers in question drain exclusively from the Eastern Aberdares, whose catchments are within the “Aberdare Conservation Area”. The “Aberdare Conservation Area” very effectively protects one of Kenya’s principal and most important water towers. The Aberdare water tower serves a very large proportion of Kenya’s population, both directly and indirectly, and the Kenya Government is totally committed to its protection, and there is no prospect of any change in this position. The conservation area comprises high altitude moorland with lower altitude bamboo and forest belts. Whilst there has been forest destruction in the past, especially in the northern Aberdares, this catchment destruction has been halted, and in some cases, is being reversed.

A very detailed review of previous hydrological studies was conducted for the Northern Collector Rivers. Particular attention was placed on studying the yield performance of the existing Thika Dam at Ndakaini, as this provided a very useful benchmark for the Nairobi Water Sources. The study concluded that the hydrology of the potential sources has not changed over the last 40 years. In fact precipitation rates and run-offs have been consistent over the study period.

It is known that Kenya has a poor record of water resource management (World Bank, 2006), and this is an ongoing concern. There are upstream community water supply intakes that continue to be constructed within the protected Aberdare forest area, with little control. If these abstractions are not “managed”, water quality will be affected, the river low flows will reduce and this will alter the hydrology and affect planned run-of-river abstractions. This project assumes that the water sources for Nairobi will be afforded careful resource management to optimise the considerable investment in the infrastructure. This also assumes effective catchment protection to ensure the sustainability of the flow resource and its quality.

Kenya has prepared a new law that is intended to tackle activities that aggravate climate change as the country seeks to promote a greener economy and conform to the Vision 2030 strategy. The enforcement measures are detailed in a new draft climate change law, The Climate Change Authority Bill, 2012 that is expected to be debated by Parliament in September[4]. The objects and purposes of the act are to provide:

a) A framework for mitigating and adapting to the effects of climate change on all sectors of the economy;

[4] Kenya Gazette Supplement No 61. The Climate Change Authority Bill 2012. Nairobi, 18th June, 2012

b) Appropriate response strategies in relation to climate change; and

c) Mechanisms for the financing, coordination and governance of matters of climate change.

The proposed authority will coordinate activities related to climate change and have the power of monitoring and investigation. It is also proposed that the authority will initiate programs on adaptation, mitigation, emission levels and trends, education and creation of awareness, assessment of climate change vulnerability, climate change threats, and capacity building in strategic climate sectors.

The clear and strong strategic links between water supplies, the environment, agriculture and climate change will make it important that Risk Management strategies and procedures related to the water supplies for Nairobi and adjacent satellite towns are carried out in conjunction and collaboration with this new authority.

2.2 Risks from Construction

Potential negative impacts that can be expected from construction of the proposed weirs, together with the construction of the Northern Collector Tunnel and access shafts, and the construction of the tunnel outfall, are detailed in the Preliminary EIA for the Selected Scenario: Nairobi Water Sources, Phases 1 & 2, including the draft environmental management plan covering the pre-construction and construction phases.

In general the impacts related to such construction activities are understood and can normally be planned for and mitigated against. As such the risks from construction can generally be considered to be minor. The major risks would therefore result from pre-construction phase and construction phase environmental management plans not being fully prepared in advance and not being followed and activities monitored in detail.

An important component of the risk management in the pre-construction phase will be to set up a series of important long-term monitoring systems that will be capable of providing the important information required during the construction phase and also during the subsequent operational phase. Chief amongst these are the establishment of additional river gauges required to provide important and comprehensive information on the downstream flows so as to ensure adequate Reserve Flows, together with an up-to-date monitoring and complete listing of all abstractions of water from all of the relevant rivers – including both licensed and unlicensed abstractions. Regular daily monitoring of all flows will be required together with a system for reporting of this information so that adequate downstream Reserve Flows can be maintained at all times under operational conditions.

The disposal of material excavated from the Northern Collector tunnel represents a potential hazard if not planned and carried out so as to result in minimal social, economic and environmental impact. It is recommended that no permanent “spoil dumps” are used. Instead of considering the excavated material as “spoil” requiring disposal, it should be used as raw material for a range of activities such as road repair and construction, and for use as building material, including the making of bricks for buildings.

2.3 Changes in Downstream Hydrology

Changes in downstream hydrology are considered to be the major environmental and socio-economic impacts. These are also expected to contribute to the greatest risks associated with the water supply and distribution network.

Primary environmental risks resulting from operation of the intake weirs and Northern Collector Tunnel are related to the significant change in downstream hydrology that will be an inevitable impact of upstream abstraction. This will result in changes to water flow patterns, changes in

quantity (in particular the loss of flood events), and also a deterioration in water quality. Changes in water quality are themselves a direct response to the changes in flow. In addition, the normal or base flows will, after installation of the intake weirs and abstraction of water, change to flows that are similar to those currently classified as extreme low flows.

Important risks that will require detailed assessment and management include:

- Reduction in the flow reaching Masinga Reservoir, and a resulting reduction in capacity for hydropower production.
- If downstream flows are inadequately monitored and upstream abstractions are not managed so as to provide adequate downstream Reserve Flows, there is a risk of short periods with zero flow in areas downstream of the proposed intake weirs.
- Reduction in the flow available downstream for use in current and future agricultural activities, especially for use during dry periods, in order to provide food required by the increasing population of Nairobi and adjacent Satellite Towns.
- Reduction in the downstream flow available for rural water supplies.
- Public health risks resulting from reduced river flows in downstream areas.

Risk management will need to include the collection of up-to-date information on all downstream abstractions from the rivers, including both licensed and unlicensed abstractions for all uses. This will need to be combined with collection of river flow data from an expanded network of flow monitoring sites in downstream areas.

An important component of risk management is likely to be the development of improved rural water supply networks covering all of the affected areas downstream of the proposed Northern Collector tunnel abstraction weirs.

Risks that will also require detailed monitoring and regular risk assessment include:

- Periods of extreme climatic conditions, including droughts and floods.
- Reduced water resources available for agriculture.
- Changes to riparian vegetation resulting from reduced downstream flows.
- Loss of aquatic species, including potential extinction of endemic fish species as a result of significantly reduced downstream flows, coupled with barriers preventing upstream migration.
- Livestock faecal contamination, especially of water resources where flow is significantly reduced due to upstream abstraction.
- Septic tanks and other faecal contamination.
- Contamination by agricultural fertilisers, and agricultural fungicides or pesticides.
- Change in water temperature, which may result in conditions more favourable to certain parasites i.e. Malaria causing parasites.

Important parts of the environments downstream of the Northern Collector abstraction weirs are involved in food production. Meeting the food demand from a growing population with potentially changing diet preferences, with more food per capita and an increase in water demanding food items, will increase the pressure for greater volumes of consumptive water use in agriculture

(Rockström and Barron 2007)[5]. Increasing urban and industrial water demands will be likely to appropriate much of the available water and reduce the water resources available for use in agriculture. If food has to be transported greater distances, this will result in increased costs – exacerbated by the expected increases in international crude oil prices (these may double by about 2018). Risks of increased food costs and potentially reduced availability will need to be incorporated within risk management and planning.

Based on the monitoring and assessment of downstream water use requirements, risk management strategies should include the updating and adjustment of Reserve Flow provisions to ensure adequate water resources for all downstream users (compensation flows), whilst at the same time maintaining adequate environmental flows. There are also risks of unacceptable low flows in downstream areas. It will therefore be necessary to ensure that there are no unnecessary periods with unacceptable low flows or zero flows in downstream reaches of the rivers. At such times, increased release of flows at the intake sites is likely to be able to correct these potential problems. In some cases it may also be necessary to restrict abstractions by selected downstream users in order to ensure maximum provision of water resources to downstream communities. Similarly, at times of extended dry periods, there are likely to be risks of excessive water consumption in urban areas and it may be necessary to ration or otherwise restrict water supplies.

It will be necessary to conduct regular monitoring of riparian habitats, and to carry out surveys of aquatic fauna and bird populations in riparian zones. Results of these surveys will provide indicators of the risks from potential changes or loss of habitat downstream as a result of changed hydrological regimes, including cumulative downstream impacts. Depending on the nature and specific locations of observed changes, those management authorities concerned with the maintenance river flows and of riparian zones will need to propose and carry out mitigation or corrective measures. These may for example include release of environmental flows that include high flow pulses.

2.4 Public Health Risks

Water quality will be a key component of the water supplies for Nairobi and Satellite Towns. The quality of the raw water should be good enough to produce drinking-water or domestic water supplies of a safe and acceptable standard when treated. The raw water should also come from a source that can consistently provide sufficient required quantity and quality. In many cases it can be better to protect the quality of the raw water than to provide additional, and costly, treatment after it has become contaminated. Contaminated and poorly managed water sources can contain chemical, microbiological or radiological hazards which can lead to sickness, and which may be very difficult to remove.

The events associated with raw water that are considered to create the greatest risks are animal or human waste, or toxins from algae and or other micro-organisms, which may be allowed to enter the water sources. This can be exacerbated by reduced volumes of the available water resource, resulting in increased concentrations of contaminants. The most important preventive measures that should be incorporated in risk management procedures will be:

[5] Rockström, J. and Barron, J. 2007. *Water productivity in rainfed systems: overview of challenges and analysis of opportunities in water scarcity prone savannahs.* Irrig. Sci. 25: 299-311.

- Regular and comprehensive monitoring, to decide if and where contamination of the water is occurring. This is best done when contamination of the raw water sources is most likely, but should also be carried out on a regular basis.
- Detailed knowledge of where the catchment (surface water) or re-charge zones (groundwater) of the water sources are, and the nature of the land and all of the land use and/or land cover in these areas. For example, extensive spraying of crops with agricultural chemicals and/or application of nitrogenous fertilisers may result in unacceptable raw water standards.
- Identifying source protection zones for the sources, so that possible sources of contamination that require to be managed can be identified. This could for example, include the legal establishment of a series of Nitrate Vulnerable Zones (NVZs) within the watersheds. Within each NVZ guidance on land use would be provided, and limits established to reduce nitrogen losses from agriculture to water. (NVZs are established within the European Community).

Monitoring of water quality will need to be carried out on a regular basis, including tests for pollutants and biological contamination in order to determine potential risks to human health. Ideally, monitoring should be carried out, at a minimum, at all river gauge sites on a regular monthly basis. Detailed monitoring of water quality should also be carried out at the Ngorongo Water Treatment Works.

Reduced nutrient availability in downstream areas, resulting from the reduction in downstream flows, may result in a reduction in the productivity of downstream systems, including cultivation in alluvial and other riparian areas downstream. In such cases it may be necessary to carry out mitigation or corrective measures, for example through the release of high flow pulses or flood events to induce sediment transport.

The risks of reduced water quality as a result of reduced flows will result in increased health risks for downstream communities, especially for those households dependant on untreated river water. A change in faecal bacterial concentrations and waterborne pathogens as a result of reduced flows and from inflow of contaminants from upstream is likely and needs to be monitored.

As an integral component of risk management procedures, water quality data will need to be analysed and made available on a regular basis to all authorities involved with the management of these water resources and related issues.

2.5 Changes in Groundwater Levels

The flow in rivers contributes to local groundwater levels. In addition, during low flow periods groundwater contributes towards base flow in rivers and streams. However, the details of this relationship are not known for the rivers in question. The risk is therefore that as a result of reduced downstream flows there may be a reduction of recharge to groundwater from the impacted rivers.

Changes in groundwater levels may also occur as a result of extraction of water from the proposed well fields.

As part of risk management plans, it will be necessary to install an increased network of river gauges and recording stations in order to cover the potentially impacted areas. Regular, daily monitoring and reporting of these river gauges will be necessary.

Existing springs and dug water supply wells in the areas within the geological strata affected by the proposed groundwater well fields will need to be identified and mapped. The yields from these sources will need to be recorded and monitored. Alternatively, piped water supplies will

need to be provided in those cases where these water sources are impacted by reduced groundwater levels resulting from abstraction

2.6 Operational Hazards

A number of hazards are inevitable during the operation of a complex system of water abstraction, distribution, treatment and delivery. These include:

- Periods of extreme climatic conditions, including droughts and floods.
- Leakage, including insufficient water supply resulting from bursts or accidental damage.
- Microbiological contamination of water sources and reservoirs, including parasites, bacteria, viruses, fungi.
- Natural contamination, including minerals.
- Contamination by agricultural fertilisers, and agricultural fungicides or pesticides.
- Contamination from industrial sources.
- Contamination from septic tanks and faecal contamination.
- Contamination of drainage channels and downstream water sources as a result of poorly or inadequately treated wastewater.
- Turbidity.
- Groundwater extraction resulting in reduced water table and potential loss of available water in existing shallow wells and boreholes.

Risk management plans will need to take account of such operational hazards and incorporate risk reduction strategies. In addition, there are risks associated with the potential increases in demand for water by consumers. It may therefore be necessary to publicise and promote a series of water saving strategies.

2.7 Seismic Activity

Seismic risks are linked to potential economic, social and environmental consequences of hazardous seismic events. The proposed Northern Collector Tunnel is in an area with recorded seismic activity. Data are recorded at the seismic station at Kilima Mbogo. Seismic activity could have an impact on the tunnels, as well as the existing Thika Reservoir, and proposed reservoirs.

Risks will need to be fully assessed as part of detailed design, and risk reduction measures incorporated. Similarly, there will need to be an assessment of seismic risk and risk reduction measures incorporated in the design of the water transport and distribution network.

Annual inspections of the Northern Collector Tunnel and all dams should be conducted, and there should be a contingency plan to be followed in the case of earthquakes.

3 Economic Risks

The use of pricing policies and other economic instruments are essential for the effective and equitable allocation of the resource taking into account social and economic criteria as well as basic human needs. Economic evaluations need to consider positive and negative impacts on health, human and ecosystems. Inadequate economic policies have often contributed to the poor performance of water utilities thus decreasing their ability to attract financial resources from the public and private sector as well as the international community.

While the public sector has traditionally played a major role in financing water resources development, there is an increasing recognition of the need for the involvement of other stakeholders (local private sector and community based organisations) and financial sustainability.

Financial support for the collection, processing and dissemination of timely, reliable and demand-oriented information is essential to the effective management of water resources.

In addition, the number of water related natural disasters (flood, drought) have been rising rapidly over the past decades. Therefore, the economic evaluation for the losses due to these phenomena and financial provision for their prevention and mitigation should be of priority.

3.1 Multicriteria Evaluation and Risk Analysis of Proposed Investment Scenarios

The Least Cost Analysis applied for the economic evaluation of alternative means of meeting the projected water demand for Nairobi City and the Satellite Towns over the study period 2013– 2035 took into account the different capital and operational costs and investment schedules of the various options. For Nairobi City, the study investigated and evaluated four main potential investment scenarios and two sub-scenarios that were identified for the development of additional water resources for the city's water supply, while for the Satellite Towns, three options were considered:

i) independent – developing independent supplies for each Town;

ii) strategic – bulk supply from a central provider integrated with the Nairobi City water supply system; and

iii) a hybrid mixed system – combining features of an independent supply with bulk supply.

The Least Cost Analysis determined the most economically efficient means of delivering water to meet the projected demand, through a normalisation process allowing for the options different configurations, to show the Average Incremental Economic Cost of water (AIEC) for each option expressed as US$/m^3 of water. Sensitivity tests were applied to show the effect of changes in the key parameters – capital costs, O&M costs, and discount rate.

Following the Least Cost Analysis, a Multicriteria Analysis was applied considering six key sustainability issues taking account of natural resources, economic performance, technical issues, O&M institutional and policy issues, environmental issues and social sustainability. Each aspect was scored and weighed according to its importance and the overall score used to determine the best option and strategy.

The Multicriteria Analysis was designed to allow for other factors affecting the risk and sustainability of the development option that were not fully reflected in the economic Least Cost Analysis which uses the monetised capital and O&M costs. Risks were accommodated in the Multicriteria Analysis by taking into account several factors, particularly those relating to the scheme's ongoing operation and maintenance, including: the security of the water source; water supply schemes technical complexity and number of management entities involved; susceptibility to prioritisation and conflict in water allocation in times of scarcity; multiplicity of water treatment works; conformity to national water supply policy; and the degree of variability in water tariffs/ potential for a standardised tariff.

The results of the Multicriteria Analysis reflect the preferred option and strategy for meeting future water demand that is best suited to manage the potential risks.

3.2 Key Issues and Recommended Actions

a. Water must be integrated into the national economy, recognising it as a social and economic good, vital for ecosystem functioning and applying economic instruments in its management. As such, economic policies must consider "intangibles" such as social and environmental values of water as well as the special conditions in non-monetary sector economies.

b. Actions should be oriented towards applying demand based management approach taking into account the notion of users' willingness and ability to pay. Resources must help in the collection, dissemination and transfer of international experiences in economic evaluation and financial management of water resources. Where possible, support should be provided to strengthen private sector, community based participation as well as the development of appropriate and low cost technologies. Also, assistance should continue in favour of public institutions in improving their role.

c. Efficiency, transparency and accountability are keys to sustainable financial management of water resources. For these, several actions are required. Information should be made public for performance indicators, procurement procedures, pricing policies and components, cost estimates and revenues. Determination and allocation of subsidies, cross-subsidies, charges should be transparent in order to maintain confidence and improve investment revenues in the sector. Instruments such as auditing could help achieve this goal.

d. Integrated water resource management requires closed partnership between public and private sectors. As such, a clear definition and distinction should be made of the role of government, the private sector and other stakeholders, where appropriate to local situations. In doing so, it is important that the institutional and legal environments be conducive for private sector investment and the emergence of local water service providers. Particular attention has to be given to financial and economic risk assessment.

e. Regardless of policies, financial sustainability is a prerequisite for sustainable integrated water resource management. Therefore, it is a necessity to facilitate a gradual transition towards full cost recovery, criteria for financial burden sharing and the development of financial and regulatory instruments. Also, measures needed include adapted financial policies for the poorest and rural areas and the allocation of resources from water charges to research and development purposes. Emphasis should be placed on participation of users, training of local entrepreneurs and the diversification of sources of funding. Furthermore, a strong link should be made with the de-centralisation process.

f. At the same time, it is important to ensure adequate financing of the water sector. Related issues in this case concern the adequacy of absorptive capacity and availability of financial resources within the sector, the lack of political awareness and will to implement strategies aimed at recovering costs as well as the requirements of external funding sources which limit the flows of resources to the sector. Thus, actions should be aimed at improving donor-recipient dialogue on financing, the creation of national fund for financial resources mobilisation and allocation in the water resources sector. The international community and Governments (donors and recipients alike) should be urged to maintain and be encouraged to increase their assistance to the water resources sector in a predictable manner and targeted to solve specific problems. Value can be added by improving communication and co-operation among sources of financing as well as the mobilisation of largely untapped community financing resources and through the provision of credit mechanisms which foster self-help efforts by individuals. This includes the mobilisation of innovative source of funding.

g. Financing of water resources data knowledge base is a basis for analysis and research for better understanding and decision making. Decision making relies, to a large extent, on the

existence and the availability of data and their analysis. Thus, it is essential that adequate financial resource be provided for better understanding of water resource knowledge base. This implies, among others, the fostering of links between physical, socio economic and environmental impact assessment with data base development, the creation of national water funds. Support should similarly be mobilised for integrated water resource information systems and their management, particularly early warning systems. Also, awareness for understanding the need for data collection, decision making, policy impact assessment and public information as well as education deserves attention.

h. The frequency of extreme events has increased in recent decades. Therefore, provision should be made for economic costs analysis of these events and for the management measures for chronically prone areas to flooding and drought. Several main actions may be concurred to achieving this goal. The creation of mechanisms of regional consultation, regional solidarity funds, drought and flood preparedness programs and early warning systems, mitigation plans at local and national levels, regional emergency funds and insurance programs for extreme events could be considered.

i. In a broader perspective, several priority activities should be financed including institutional and capacity building, integrated water resources planning and management. Particularly, local support should be provided for sustainable solutions to communities, associations, local authorities and emerging local private sector.

j. Finally, financial resources can be best attracted to the sector when efforts are made to increase financial accountability and to reduce cost in particular. For this, specific actions could include restructuring of existing institutions, improving existing management through demand management/leak reduction, promoting competition in service provision, data collection and creating financial incentives, participation as well as the use of low cost technologies.

3.3 Priority Areas in Need of Financing

Areas in need of financing are grouped into institutional and capacity building, integrated water resources planning and management, support to underprivileged areas and investment initiatives:

- Institutional capacity building/support to policy including support to policy and legislation;
- Integrated Water Resources Management;
- Data collection, monitoring and integrated information management systems;
- Knowledge of hydro-ecosystems functioning;
- Demand and supply assessment;
- Feasibility and thematic studies; (g) National, sub-national and river basin action plans;
- Local support for sustainable solutions to communities, associations, local authorities and emerging local private sector;
- Investment for those without access to basic needs.

3.4 Strategies / Action for Cost Reduction

Several strategies and actions could be recommended in addressing economic and financial issues related to Integrated Water Resources Management. Among the measures of particular interest are cost reduction means including:

- Restructuring of existing institutions to reduce cost;
- Improving existing management such as demand management/leak reduction;
- Promoting competition in service provision;
- Improving existing data collection network;
- Provision of financial incentives, including tax exemption for equipment and for private sector;
- Investing in under privileged areas;
- Reliance on low cost systems and appropriate technologies including indigenous technologies;
- Increasing accountability in system management.

4 Risk Management Plan

An important component of the risk management will be the establishment of a set of systems for monitoring and recording relevant information. The management of risk will depend on this set of comprehensive and up-to-date records. Some of this is already in place, for example the rainfall monitoring stations run by the Kenya Meteorological Department. The available information from some other important sets of information that will be required are considered to provide inadequate coverage or may be out of date. In such cases, existing monitoring systems will need to be augmented or new records established. For example, a more comprehensive system of river gauge monitoring stations will be required in all downstream areas in order to ensure that adequate Reserve Flows are provided. Similarly, the provision of adequate compensation flows depends on accurate and up-to-date records of downstream household and community requirements. These monitoring activities are considered as long-term and will need to be continued as a regular component of monitoring as a component of the risk management plan. Details of the environmental monitoring requirements and a draft environment management plan are also included in the Preliminary Environmental and Social Management Plan.

Table 12-3: Major Risks, Mitigation Methods, Indicators, Monitoring & Reporting

Major Risks or Issues	***Mitigation Methods***	***Key Indicators***	***Monitoring / Reporting***
Changes in runoff patterns as a result of changes in land cover and land use within the watershed. Considered as low- risk but long term.	Maintain the current protection status of the Aberdare National Park and adjacent protected forest reserves. It may also be necessary to designate additional areas where land use is limited to those categories that are suitable for watershed protection.	Land use and land cover. Changes in river flow patterns.	Land use and land cover within the watersheds. Daily flow records.
Changes in downstream hydrology including significant reduction in water available for rural communities and for maintenance of environmental flows	Release Reserve Flow adequate to sustain all required downstream water resources, including both Compensation Flows and Environmental Flows.	Daily river flow volumes.	Daily records from an expanded system of river gauge monitoring stations.

Major Risks or Issues	*Mitigation Methods*	*Key Indicators*	*Monitoring / Reporting*
Reduction in the downstream flow available for rural water supplies.	Development of rural water supply schemes covering all affected downstream communities.	Numbers of households using untreated surface water such as rivers, and an inventory of all needs.	Surveys of household water sources. Surveys of all licensed and unlicensed abstraction from rivers in downstream areas.
Reduced flow of nutrients downstream resulting from reduced sediment transport.	Release of environmental flows including high flow pulses and small floods	Productivity of downstream alluvial cultivation.	Daily flow records. Sediment transport.
Loss of productive tea growing areas as a result of on-site storage of soil from excavated tunnels.	Avoid spoil storage areas where tea is grown. Transport all spoil off-site for storage in suitable areas, e.g. old quarries. Ensure maximum use of spoil as raw material for other activities.	Loss of productive land in areas close to the Northern Collector tunnel.	Monitoring of land use in area impacted by construction of tunnels.
Nutrients captured in reservoirs and at weirs. No longer available to systems downstream and possible eutrophication in reservoirs.	Incorporate sediment release capabilities in weirs. Incorporate sediment release capability in all reservoirs.	Eutrophication of reservoirs. Productivity of downstream systems.	Sediment transport. Water quality in reservoirs.
Public health risks resulting from reduced river flows in downstream areas.	Treated rural water supply schemes. Monitoring of water quality.	Compliance with recognised water quality standards. Incidence of diseases.	Regular monitoring of water quality and potential sources of contamination and microbiological health hazards.
Change in water temperature resulting in conditions more favourable to certain parasites i.e. Malaria causing parasites.	Increased disease control measures	Incidence of diseases.	Records from health centres
Reduction in the flow available downstream for use in current and future agricultural activities	Release of adequate Reserve Flows	Requirements for subsistence irrigation, commercial irrigation, and other commercial or industrial needs, e.g. tea factories, as well as livestock requirements	Surveys of agricultural areas, crop types and water requirements.
Reduction in the flow reaching Masinga Reservoir, resulting in reduced capacity for hydropower production.	Provision of alternative power production, including hydropower at Northern Collector tunnel outflow.	Daily river flow volumes, and relative contribution from impacted rivers to total inflows at Masinga.	Daily records from river gauge monitoring stations, and levels in Masinga Reservoir.

Major Risks or Issues	*Mitigation Methods*	*Key Indicators*	*Monitoring / Reporting*
Periods with very low or zero flow in downstream reaches of affected rivers.	Release of adequate Reserve Flows. Water rationing or restrictions may be required during extended dry periods.	Daily river flow volumes.	Daily records from an expanded system of river gauge monitoring stations.
Loss or extinction of endemic aquatic species, resulting from low flows and construction of barriers to movements between feeding and breeding areas.	Release of environmental flows and construction of fish passes / ladders at all existing and new barriers.	Surveys of aquatic species. Numbers of high flow pulses and small floods.	Daily flow records. Regular surveys of aquatic species, including endemic fish species.
Change or loss of riparian habitat downstream as a result of changed hydrological regime with potential erosion of stream bank stability.	Release of environmental flows including high flow pulses and small floods	Area covered by natural riparian vegetation. Stream bank stability and erosion.	Regular sampling and surveys of riparian vegetation together with surveys of bird species in riparian areas.
Leakage from pipelines and contamination of supply lines, resulting in loss of water and also public health risks.	Regular monitoring and maintenance. Early detection of leaks.	Detection of leaks. Incidence of water-borne diseases.	Regular monitoring and maintenance.
Contamination by agricultural fertilisers, and agricultural fungicides or pesticides	Identification and establishment of Source Protection Zones, e.g. Nitrate Vulnerable Zones (NVZs)	Water quality, including nitrate concentrations in raw water sources.	Land use and agricultural practice, including livestock numbers and fertilizer application, throughout the watersheds.
Risk of changed runoff patterns from areas within the watershed as a result of changes in land use.	Identification and establishment of Source Protection Zones focussed on land use.	Changes in land use and land cover.	Regular monitoring of daily flows.
Long-term risk of Reduced availability of groundwater resources due to unsustainable levels of abstraction.	Control of groundwater abstraction.	Changes in groundwater levels	Analysis and reporting of groundwater recharge and abstraction.
Reduced contribution of groundwater to base flow in downstream areas.	Increased release of Reserve Flow to compensate for reduced groundwater contribution.	Changes in groundwater levels. Daily river flow volumes.	Regular monitoring of daily flows.
Seismic Risks. Long-term risk, infrequent but potentially serious.	Development of seismic risk management plans. Seismic risk management strategies need to be incorporated in detailed designs.	Seismic activity	Seismic activity

Major Risks or Issues	*Mitigation Methods*	*Key Indicators*	*Monitoring / Reporting*
Increase in the number of consecutive dry days as a result of Climate Change.	Plans established and put in place for potential restrictions on water use by households and by industry in the case of extended dry periods or droughts.	Rainfall records and river flow records. Increased requirement for water by certain agricultural sectors.	Monitoring of weather patterns. Active monitoring of all water storage.

In addition there are a series of potential risks that are related to or linked with Climate Change. These are, for example, likely to alter or increase the water requirements of downstream communities, as well as the requirements for agriculture, and for other water related sectors of the economy. The relevant sectors are likely to include: Agriculture, Energy, Health, Biodiversity and Ecosystems, as indicated above under the section on Climate Change. Risk management related to Climate Change will need to be carried out in conjunction and collaboration with the new Climate Change Authority, expected to be established by Bill of Parliament during September 2012.

Similarly, there are long-term risks associated with the onset of Peak Oil, and predicted increases in crude oil prices, resulting in increased costs and changes to sectors of the economy. Current trends in the international crude oil prices, based on daily price data from the year 2000 to the present, indicate a trend towards a doubling of current crude oil prices by the year 2018. Such cost increases may result in changes in the tendency for population increase in the major urban areas to an increase in adjacent Satellite Towns and adjacent rural areas. Such changes would modify the demands for distribution of water supplies. Risk management therefore needs to be aware of this potential situation and the possible requirements for changes in the water distribution network / area.

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Chapter 13 - Summary and Recommendations of the Master Plan

1 Introduction

This Chapter gives an overview of the Key Findings and Recommendations of Master Plan Study. The details of specific aspects of the Study are given in the preceding Chapters 1 to 12.

The Principle Objective of the Master Plan Study is to review and identify potential water sources for Nairobi City and Satellite Towns to cater for its water supply requirements upto the year 2035 and recommend a strategy for their development taking into consideration the hydrological, social, economic and environmental factors.

The Study Area as defined in the Terms of Reference includes: Nairobi City and the Satellite Towns of Kikuyu, Ruiru-Juja, Kiambu, Karuri, Githunguri, Mavoko Municipality, Ngong Township, Ongata Rongai, Thika, Gatundu, Limuru, and Tala-Kangundo (all Towns are within a radius of 70km from the City).

A number of studies have been carried out previously to identify bulk water sources for the Nairobi City and its environs. Key among them is the Long Term Development Plan (Regional studies), June 1986, prepared by Howard Humphreys. The Study investigated the water resources and demand, required immediate measures, short term implementation plan and long term development plan to meet the year 2010 regional water demand. The Study considered surface water sources and underground water development for low demand areas located at higher elevations. Primary sources identified for water supply to Nairobi City were the Northern Collector Rivers emanating from the Aberdare Forest.

The Long Term Development Plan (1986) by Howard Humphreys was never fully implemented and major investments in water supply infrastructure have lagged since 1994 with the completion of the Third Nairobi Water Supply Project. The result is that presently the water demand in the Study Area far outstrips supply.

Table 13-1 gives a comparison of capacity of existing water sources with the present and forecast year 2035 water demand for Nairobi and the Satellite Towns.

Table 13-1: Existing Water Sources, Present and Forecast Water Demands

Demand Area	Existing Sources	Capacity, m^3/d	Water Demand, m^3/d	
			Year 2010	Year 2035
Nairobi	Kikuyu Springs	4,800		
	Ruiru Dam	21,700		
	Sasumua Dam	56,200		
	Thika/Chania/Ng'ethu System	414,700		
	Groundwater Sources Contribution	45,000		
	Total	**542,400**	**578,643**	**1,205,322**
Satellite Towns	Ruiru W.S. - Ruiru River	1,500		
	Juja W.S. - Ndarugu River	2,000		
	Ongata Rongai W.S. - Mbagathi River	3,000		
	Gatundu W.S. - Ndarugu River	3,000		
	Thika W.S. - Chania River	26,000		
	Mavoko W.S. - Nol Turesh System	970		
	Various Groundwater Sources	14,300		
	Total	**50,770**	**128,223**	**451,204**

Some of the Satellite Towns are located within the vicinity of Nairobi City Boundary and should apparently be considered as part of the Greater Nairobi. These Towns include; Kikuyu, Ruiru-Juja, Karuri, Mavoko Municipality, Ngong Township and Ongata Rongai and fall within the "Effective Envelop of the Nairobi Water Demand". The population growth is occurring not only within the Town boundaries but is also infilling the land available between the Satellite Towns in the Effective Envelop and the Nairobi City Boundary. The location of the Satellite Towns with respect to Nairobi and the Nairobi Envelop are given in Figure 13-1 on page 13-3.

Various surface and ground water sources have been investigated to determine their potential to meet the forecast water demands. The selection criteria for additional water sources and the best development strategy for mobilising new water sources for the study area are briefly discussed in the following sections. The Water Resources Management requirements, Risk Management Plan and Recommendations for further action have also been discussed.

2 Water Demand Assessment

2.1 Introduction

Details of the Study Area, land use, socio-economic and demographic trends for Nairobi City and individual Satellite Towns are presented in Chapter 3 of the Master Plan Report. The water demand estimates and the methodology used are presented in detail in Chapter 4 of the Report.

The categories of public water supply consumers considered in the water demand assessment have been broadly classified into domestic, institutional, commercial and industrial consumers.

The population projections used in water demand estimates are based on the 2009 housing and population census carried out by the Central Bureau of Statistics. The water consumption guidelines recommended in the MWI Practice Manual (2005) have been used in the water demand calculation.

Low, Medium and High projections of population growth and water demand to year 2035 have been made. The three levels of projection are influenced by the population growth rate and the rate of growth of the institutional, commercial, industrial sectors, economic growth / trends, migration factors, etc.

The Medium water demand projection has been considered to be the most plausible and realistic for planning purposes. A summary of the methodology used in the water demand calculation and results obtained for Nairobi and Satellite Towns is given in the following Sections.

2.2 Nairobi City

The existing NCWSC network can be considered largely as the most important demand centre of water for Nairobi. A 92% coverage of Nairobi population means that approximately 2.9 million inhabitants of Nairobi City rely on NCWSC water supply at present.

However, the per capita water coverage and consumption in Nairobi's informal settlements is very low with the demand being far above the supply. Access to water in these areas is a major problem due to the high cost of water purchased from water vendors as a result of inadequacy and unreliability of the existing water distribution network.

In the water demand calculation, it has been assumed that the high and medium income population has 100% water supply coverage by the public (NCWSC) network and is served by individual water connections. This has been assumed to remain constant within the planning period.

Figure 13-1: Location of Satellite Towns with respect to Nairobi and the Nairobi Envelop

The consumption rates recommended in the Ministry of Water and Irrigation (MWI) Practice Manual (2005) have been used in the water demand calculation. The consumption rates include 20% unaccounted for water (UfW) which has been subtracted in the rates and a more practical UfW component applied.

The adopted per capita consumption rates for Nairobi City excluding UfW are given in **Table 13-2**.

Table 13-2: Adopted Domestic Consumption Rates for Nairobi City

Consumer	Unit	Urban Areas		
		High Class	Medium Class	Low Class
People with individual connections	l/capita/day	200	120	60
People without individual connections	l/capita/day	_	_	30

A per capita consumption rate of 30 l/c/d has been adopted for low income earners with no individual connections and for population residing in areas with no water supply network.

For the low income earners, it has been estimated that presently all the households in the informal settlement get water from NCWSC with only 9% getting water through individual connections while the remaining 91% obtain water through other means e.g. water kiosks, water vendors etc. The connection ratio in the low income areas is however expected to increase progressively within the planning period from the present 9% to 24% by year 2035.

Overall, the population served by the public network through individual connections presently stands at 65% and this is expected to increase to 80% at the ultimate planning period, year 2035 as new interventions to meet forecast water demand are developed.

It is expected that the increase in population within the planning period coupled with increase in water supply coverage through increased number of households served by individual connections will require substantial investment by Athi Water Services Board (AWSB) and the Water Service Provider – Nairobi City Water & Sewerage Company (NCWSC).

The water demand for commercial, industrial, government, community projects and social services has been estimated from the present consumption patterns obtained from NCWSC. This water demand is expected to grow at a higher growth rate than the population, based on the industrial growth aspirations of the Country which are entrenched in the Vision 2030 Goals outlined by the Government of Kenya.

A UfW component of 53% of the Net Water Demand has been applied in the water demand calculation at the start of the planning period. This includes 40% distribution losses, 4% Transmission losses and 5% Treatment losses. The Distribution losses are however expected to reduce within the planning period to 25% which has been considered practically achievable.

The population and water demand forecast for Nairobi City based on the medium water demand projections is summarised in Table 13-3.

Table 13-3: Nairobi City Population and Water Demand - Medium Projection

Year	2010	2017	2020	2030	2035
Population Forecast	3,250,338	4,040,325	4,403,791	5,693,457	6,444,969
Population Growth Rate	3.6%	3.2%	2.9%	2.6%	2.5%
Gross Water Demand, m^3/d	**578,643**	**671,018**	**728,309**	**1,018,528**	**1,205,322**

2.3 Satellite Towns

Similar to Nairobi City, the water demand forecast for each Satellite Town has been calculated based on low, medium and high projections growth rate.

The percentage of population supplied by individual connections through the public water supplier varies from one Satellite Town to another. The individual connections have been assumed to increase within the planning period based on increased water supply.

The domestic water demand consumption rates as recommended in the Working Paper for Development of Water Sources for Satellite Towns - Version 01 (October 2011) have been used. The rates are based on Variant 4 which was recommended after comparisons with percapita rates in other cities in the developing and developed countries. The adopted percapita consumption rates for Satellite Towns excluding UfW are given in Table 13-4.

Table 13-4: Adopted Domestic Consumption Rates for Satellite Towns

Consumer	Unit	Urban Areas		
		High Class	Medium Class	Low Class
People with individual connections	l/capita/day	150	100	50
People without individual connections	l/capita/day	_	_	30

For peri-urban areas with individual connections, a per capita rate of 90 l/c/d has been used while for urban and peri-urban areas without individual connections, a per capita rate of 30 l/c/d and 20l/c/d has been used respectively.

The water demand for commercial, education, institutional, health, industrial and administration sectors has been estimated based on the present socio-economic infrastructure obtained for each of the Satellite Towns. The consumption rates recommended in the MWI Practice Manual (2005) have been used in estimating these demands.

At present, the UfW in some of the Satellite Towns is very high and unsustainable. An average UfW component of 53% of the Net Water Demand has been applied in the water demand calculation at the start of the planning period for the Satellite Towns. This includes 40% distribution losses, 4% Transmission losses and 5% Treatment losses. The Distribution losses are expected to reduce within the planning period to 25% by year 2035 which has been considered practical and achievable. This is based on the assumption that interventions to reduce the high UfW will be carried out.

The population and water demand forecasts for each Satellite Town based on the Medium water demand projections are summarised in Table 13-5.

Table 13-5: Satellite Towns Water Demands - Medium Projection

Satellite Town	Yr 2010	Yr 2017	Yr 2020	Yr 2030	Yr 2035
1. Kikuyu					
Population Forecast	224,117	281,951	309,911	416,280	481,423
Population Growth Rate	3.5%	3.3%	3.2%	3.0%	3.0%
Gross Water Demand, m^3/d	17,959	23,604	27,540	44,716	55,526
2. Kiambu					
Population Forecast	91,769	114,011	125,071	163,598	187,040
Population Growth Rate	3.1%	3.1%	3.1%	2.7%	2.7%
Gross Water Demand, m^3/d	8,280	10,317	11,753	17,175	20,730
3. Karuri					
Population Forecast	134,234	167,433	183,139	241,188	276,110
Population Growth Rate	3.3%	3.2%	3.0%	2.8%	2.7%

Satellite Town	Yr 2010	Yr 2017	Yr 2020	Yr 2030	Yr 2035
Gross Water Demand, m^3/d	10,854	13,515	15,100	22,898	28,566
4. Ruiru-Juja					
Population Forecast	342,086	534,564	637,178	1,060,559	1,289,990
Population Growth Rate	6.6%	6.6%	6.0%	5.2%	4.0%
Gross Water Demand, m^3/d	26,193	41,416	51,937	103,759	131,978
5. Mavoko Municipality					
Population Forecast	143,278	253,840	310,722	522,319	638,005
Population Growth Rate	9.6%	8.5%	7.0%	5.3%	4.1%
Gross Water Demand, m^3/d	17,022	27,094	34,897	64,396	80,222
6. Ngong, Ongata Rongai & Kiserian					
Population Forecast	223,324	315,018	359,643	509,706	601,663
Population Growth Rate	6.0%	5.0%	4.5%	3.5%	3.4%
Gross Water Demand, m^3/d	13,686	20,984	25,253	44,041	54,246
7. Limuru Town					
Population Forecast	38,739	47,372	51,449	63,233	69,814
Population Growth Rate	3.0%	2.9%	2.8%	2.1%	2.0%
Gross Water Demand, m^3/d	4,330	5,215	5,954	8,039	9,208
8. Githunguri Town					
Population Forecast	18,147	21,279	22,714	27,688	30,570
Population Growth Rate	2.4%	2.3%	2.2%	2.0%	2.0%
Gross Water Demand, m^3/d	3,060	3,281	3,420	4,169	4,603
9. Gatundu Town					
Population Forecast	15,474	16,799	17,352	18,968	19,799
Population Growth Rate	0.9%	1.2%	1.1%	0.9%	0.9%
Gross Water Demand, m^3/d	2,658	2,665	2,700	2,993	3,149
10. Thika Town					
Population Forecast	145,133	197,633	222,425	311,501	360,777
Population Growth Rate	4.6%	4.5%	4.0%	3.4%	3.0%
Gross Water Demand, m^3/d	22,331	29,832	33,885	50,432	59,545
11. Tala-Kangundo Towns					
Population Forecast	19,386	21,738	22,767	26,271	28,202
Population Growth Rate	1.6%	1.6%	1.6%	1.4%	1.4%
Gross Water Demand, m^3/d	1,850	2,032	2,202	2,987	3,432

2.4 Summary of Population and Water Demands

The Population and Water Demands Forecasts based on medium projections for Nairobi City / Nairobi City and Satellite Towns within the Effective Envelop / Nairobi City and All Satellite Towns are given in Table 13-6 and Figure 13-2 and Figure 13-3 respectively.

Table 13-6: Summary of Population and Water Demands

Demand Area	Yr 2010	Yr 2017	Yr 2020	Yr 2030	Yr 2035
1. Nairobi City					
Population Forecast	3,250,338	4,040,325	4,403,791	5,693,457	6,444,969
Population Growth Rate	3.6%	3.2%	2.9%	2.6%	2.5%
Gross Water Demand, m^3/d	578,643	671,018	728,309	1,018,528	1,205,322
2. Nairobi + Satellite Towns within Effective Envelop					
Population Forecast	4,409,147	5,707,142	6,329,455	8,607,108	9,919,200
Population Growth Rate	4.1%	3.8%	3.5%	3.2%	2.9%
Gross Water Demand, m^3/d	672,636	807,948	894,789	1,315,513	1,576,589
3. Nairobi and Satellite Towns					
Population Forecast	4,646,027	6,011,962	6,666,161	9,054,769	10,428,362
Population Growth Rate	4.1%	3.8%	3.5%	3.2%	2.9%
Gross Water Demand, m^3/d	706,865	850,972	942,950	1,384,134	1,656,526

Figure 13-2: Population Forecasts

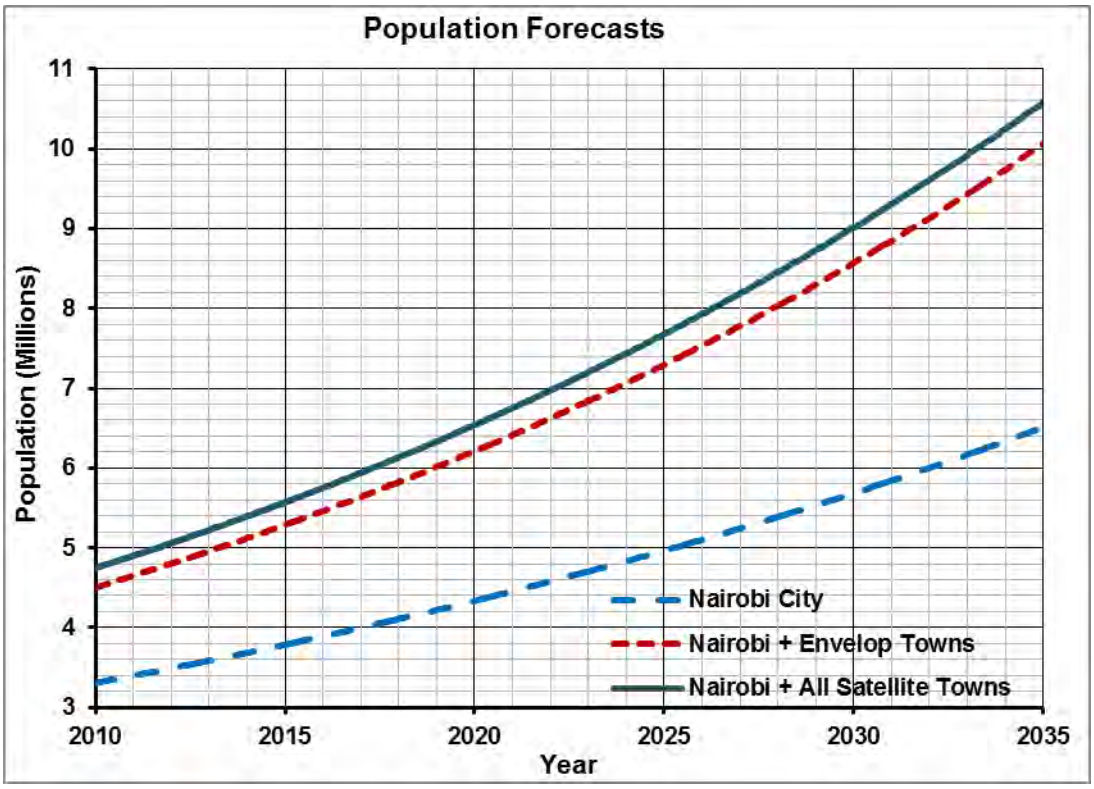
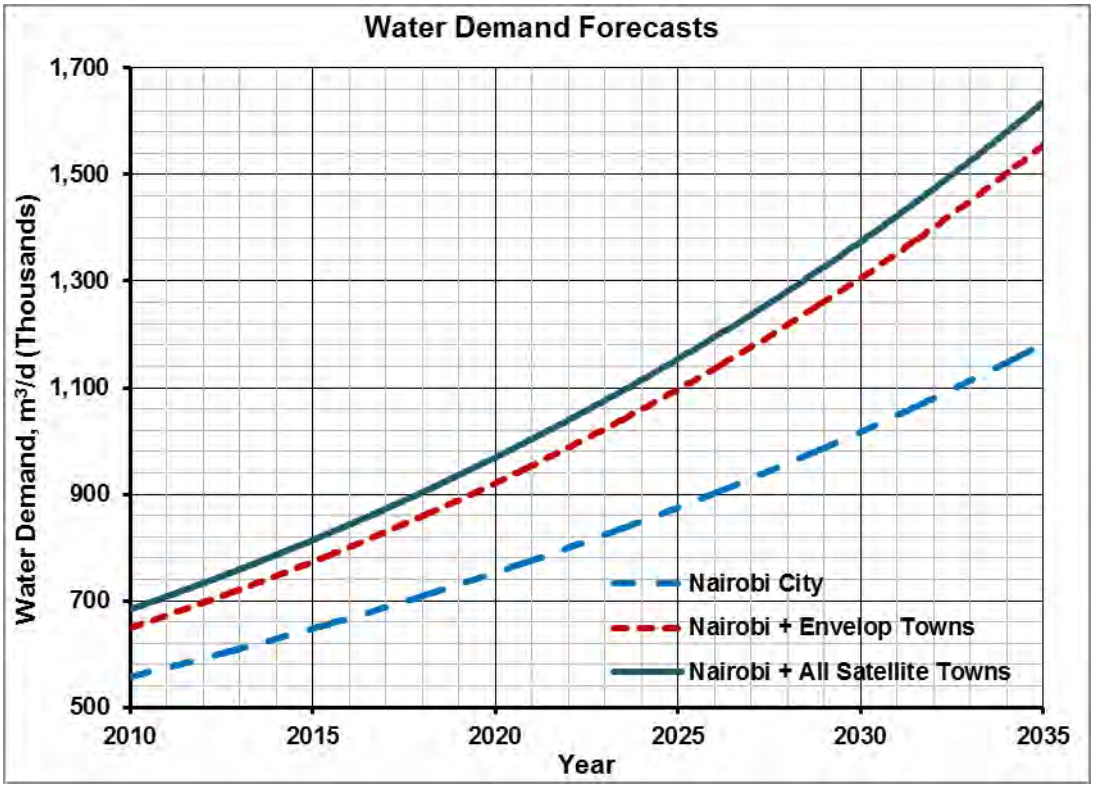


Figure 13-3: Water Demand Forecasts



3 Water Resource Development

The strategy for Nairobi and Satellite Towns' Water Supply is to ensure that:

- all water supply demands are fully met up to the Year 2035 horizon,
- new sources of development are considered,
- all supplies are created to a common standard for potable water supply,
- New water sources and facilities increase the reliability and security of water supply for Nairobi and Satellite Towns through:
    - optimal use of the existing facilities,
    - an increase of surface water storage sources,
    - diversification of water sources (surface water, groundwater, rainfall harvesting) , etc. when appropriate,
    - Development of local or mixed water supply systems for satellite towns.

To meet these broad strategic objectives, the following key principles have been considered for preparing the Long Term Development Strategy:

- The water sources development strategy should meet the growing demand for water supply up to Year 2035, through a staged investment process;
- The water sources development strategy should make the optimal use of the existing facilities (reservoirs, transmission lines, water treatment works, etc.);
- The strategy should propose diversification of water sources and the development of schemes providing more safety and operational flexibility;
- Small water production schemes for Nairobi City should be limited in order to avoid complexification of the Water Supply systems, to reduce costs and optimize the operation.
- Independent water schemes should be preferred for the satellite towns where local surface or groundwater water sources are available;
- Water tapping from the main transmission lines to Nairobi City water scheme for local needs should be avoided or limited to the minimal in case no sufficient source is identified;
- Efforts to reduce to minimum level physical water losses along the system (intakes, transmission pipes, treatment works, distribution schemes, etc.)
- Diversification of sources:
    - promote the steady development of boreholes to tap groundwater;
    - promote alternative water sources such as rainwater harvesting;
- Limit or avoid when possible competition between water users on the water source (hydropower production, agriculture & livestock, downstream users and environmental flow);
- Priority to be given to scenarios with less social and environmental impacts;
- Minimize the cost of the new water sources facilities through (i) limiting the length of water distribution, (ii) limiting or avoiding pumping requirements and maximize gravity transmission, (iii) optimizing dam reservoir size and dam location, and (iv) best use of existing water system infrastructure through rehabilitation/upgrading, interconnection and expansion;

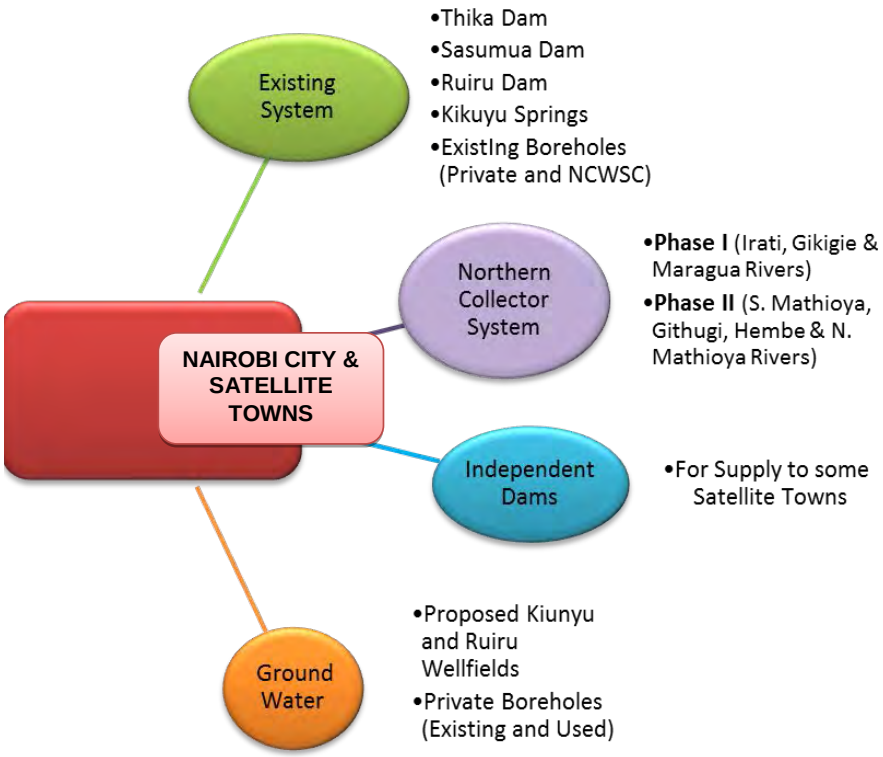
- Consistent phasing of investments: any new step in the development of new sources, should be consistent with the previous ones and with the next planned steps;

The above principles compose the strategy for the development of new water sources for Nairobi Water Supply.

The following summarises the Approach and Methodology applied in the analysis and selection of suitable Alternative Sources for Augmenting Water Supply to Nairobi City and Satellite Towns to meet the Future Water Demand (Year 2035).

Under this Study, various potential sources for water supply were investigated which would operate conjunctively to address the demand deficits within the supply areas. Figure 13-4 shows the Existing and Proposed Infrastructure Development adopted in this Study.

Figure 13-4: Schematic of Sources for Nairobi City and Satellite Towns



The Yields from Existing and Northern Collector Systems were simulated using the Water Evaluation and Planning (WEAP) computer model whereas available yields from all potential dam sites and boreholes were investigated independently in a parallel exercise.

3.1 Hydrology

Detailed hydrological study has been carried out based on the current hydrological data and data assimilated during previous hydrological studies undertaken for the Nairobi Water Supply over a 20-year period between 1970 and 1990. The previous studies presented data since the late 1940s, and some very good quality databases and analyses were reported in detail.

Based on the conclusive findings of the previous studies, this Study focused on the Northern Collector Rivers System emanating from the Eastern Aberdare Mountain Forests and Moorland. It has been established many years ago that these rivers are amongst the most productive in the

Country, with very high unit runoff, and with strong baseflow components primarily due to the boggy catchment in the upper parts and forest cover. The potential of these rivers to supply Nairobi for some future time with water was beyond doubt, and this Study set out to confirm that these facts had not changed since the conclusive studies reported some years ago.

Since the last major reports were produced nearly 20 years ago, the hydrological database and analysis was in need of updating to confirm yields established at that time. This Study therefore sought all available river flow data collected since that time for the Northern Collector Rivers. Although, hydrometric data collection systems have collapsed in Kenya in recent years, sufficient data was nonetheless obtained by this Study (and by a parallel AWSB study in the Sasumua / Chania catchment), which allowed data infilling and the derivation of extended flow sequences. ***The analysis of these flow sequences established (within the data constraints) that the hydrological yield of the Northern Collector Rivers has not changed***. This was as anticipated, as the rivers in question drain exclusively from the Eastern Aberdares, whose catchments are within the "Aberdare Conservation Area". The "Aberdare Conservation Area" very effectively protects one of Kenya's principal and most important water towers. The Aberdare water tower serves a very large proportion of Kenya's population, both directly and indirectly, and the Kenya Government is totally committed to its protection, and there is no prospect of any change in this position.

A very detailed review of previous hydrological studies was conducted for the Northern Collector Rivers. Particular attention was placed on studying the yield performance of the existing Thika Dam at Ndakaini, as this provided a very useful benchmark for the Nairobi water sources.

The hydrological analysis produced extended continuous daily flow sequences for the main Northern Collector Rivers. These sequences were then input to the WEAP Water Balance Model for the purpose of deriving conjunctive use yields of the rivers and reservoirs under study. Many different water source combinations were studied. The yield methodology is conventional, and the reliability criterion is also conventional, with 90% reliability being adopted, as per the earlier studies on Nairobi's water supply (based on annual event failure methodology[1]) The yield studies have been conducted with appropriate compensation flow allowances into the rivers downstream of the proposed diversion intakes and reservoirs.

In addition, the Study was required to study the yields of a large number of water sources in closer proximity to Nairobi (for master planning purposes). It was beyond the Scope of this Study to conduct detailed hydrological studies to the same level as for the Northern Collector Rivers. This was fully appreciated during the Project's Inception Phase, and in order to fulfil the Master Planning requirements, general hydrological characteristics were established for all rivers close to Nairobi. As these rivers have unit runoff 1/10th of the Northern Collector Rivers, they are hydrologically far less attractive, and are only likely to be feasible for local water supplies provided there is adequate storage provision. It was agreed during the Inception Phase that a generalised method of reservoir yield analysis would be adopted. Hence, a previously developed generalised non-dimensional reservoir yield method was re-worked for the purpose of this Report, and results were verified using modern methods (Mein & McMahon). If any of these schemes are chosen for implementation by AWSB, the scheme's individual hydrology must be subjected to proper feasibility study. The results presented under this Study are for Master Planning purposes.

[1] This is the Annual Occurrence based concept of Reliability which defines all failures within any one year as a single failure for that particular year irrespective of the magnitude of the failure.

It is known that Kenya has a poor record of Water Resource Management (World Bank, 2006), and this is an on-going concern. If abstractions from surface water sources are not "managed", water quality will be affected, the river low flows will reduce and this will alter the hydrology and affect planned run-of-river abstractions. This Study assumes that the water sources for Nairobi will be afforded careful resource management to optimise the considerable investment in the infrastructure. It also assumes effective catchment protection to ensure the sustainability of the flow resource and its quality.

In mitigation, and consistent with World Bank Studies (World Bank, 2006), this Study has recommended a Scheme that exploits the considerable run-of-river potential in the immediate term, but with substantial storage provision added in the early stages of Project Implementation. The storage provision is fundamental to providing a buffer against the variability associated with climate change, and also the consequences of upstream run-of-river abstraction needs. However, these buffer zones are not designed to buffer poor water resource management that alters the natural hydrology, and causes deterioration in water quality.

Chapter 5 presents a detailed review of past hydrological analyses including revised hydrological characteristics and the safe yield of various water source combinations.

3.2 Yield Assessment of Existing and Proposed Sources

The Water Evaluation and Planning (WEAP) software is a desktop tool for Integrated Water Resource Planning which has been developed by the Stockholm Environment Institute's (SEI) Boston Center. Over the past fifteen years since its first application in the Aral Sea region, the Model has undergone major improvements such as a user-friendly graphical user interface (GUI), a more robust water allocation algorithm and the integration of hydrologic sub-modules that include a conceptual rainfall-runoff, a groundwater and stream water quality Model. Furthermore, additional coupling options to external models such as Modular Three Dimensional Groundwater Flow Model (MODFLOW) and QUAL2E water quality model is also available in case the Modeller finds the built-in sub-modules inadequate.

The WEAP Model is a user-friendly tool that incorporates an integrated approach to Water Resource Management, which over the last decade, has placed more emphasis on demand side management, water quality and ecosystem preservation and protection. The Model integrates simulation of both the natural and engineered components of a water resource system by placing demand side issues such as water use patterns, equipment efficiency, re-use strategies, costs and water allocation schemes on an equal footing with supply-side resources such as available surface and groundwater, reservoir storage and inter-basin transfers. This gives the water manager the freedom of a more comprehensive view of the consequences of various planning and operation decisions on the system.

New water sources for augmenting water supply to Nairobi and its environs have been investigated in this Study. The principles were largely based on the previous study by Howard Humphreys[2] and the proposals therein reviewed using updated data, operational information and a new modelling approach.

[2] Howard Humphreys (K), 1998. Third Nairobi Water Supply Project, Northern Collector Scheme Feasibility Report Volume I

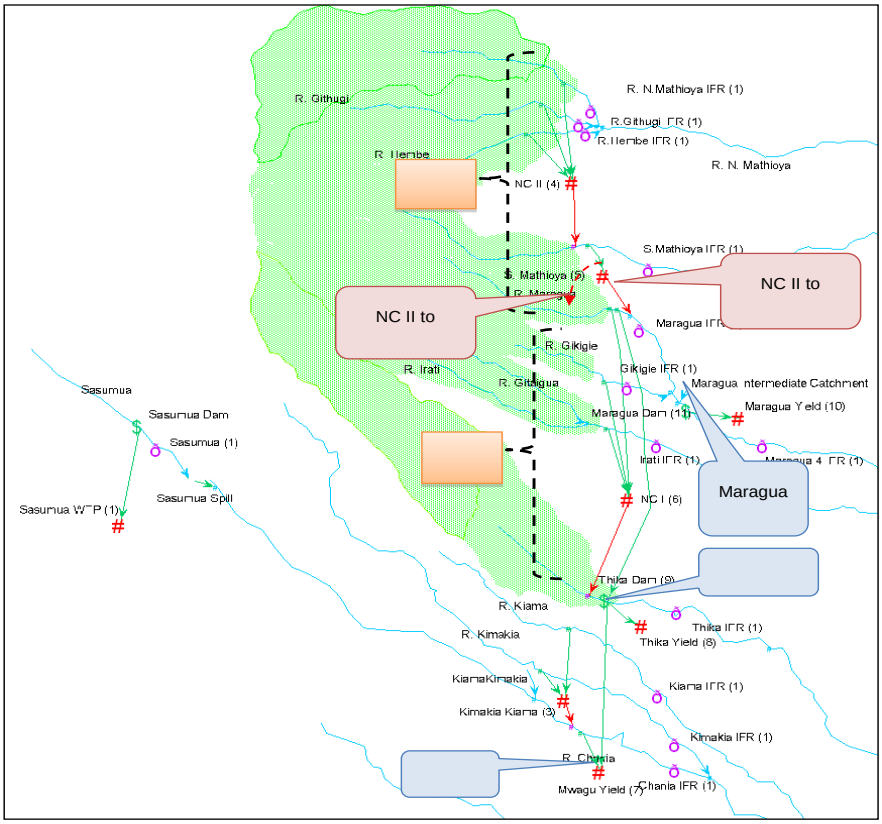
Yield analysis was carried out for the Existing and Proposed Sources for water supply to Nairobi City and Satellite Towns.

The Existing and Northern Collector Systems are collectively referred to as the Integrated System and comprises of the:

- Existing System – Sasumua and Thika Dams with diversions from Kiama, Kimakia and Chania Rivers. Water is abstracted at Mwagu Intake on Chania River.
- Northern Collector System which is divided into:
  - Northern Collector Phase I which will divert water from Irati, Gikigie and Maragua Rivers into Thika Dam.
  - Northern Collector Phase II which will divert water from South Mathioya, Hembe, Githugi and North Mathioya Rivers into Thika Dam and Proposed Maragua 4 Dam.

Figure 13-4 shows a schematic of the Northern Collector System analysed using the WEAP Model.

Figure 13-5: WEAP v2 Schematic of the Entire Water Resources System



The Water Evaluation and Planning (WEAP) Computer Model was used to simulate the Integrated System. Furthermore, different combinations of development were simulated to identify the combination which produces maximum yield at 90% reliability of supply. The definition of Reliability adopted in this Study is founded on the Annual Occurrence based concept which defines all failures within any one year as a single failure for that particular year irrespective of the magnitude of the failure.

The following sections summarises the Yield Analysis for the Existing System, Northern Collector (Phase I + II) with Maragua 4 Dam, Independent Dams and assessment of the Groundwater potential for water supply to Nairobi City and Satellite Towns.

3.2.1 Existing System

The WEAP Model was first setup and run to determine the available yield at existing Mwagu Intake and the gross yield available at Thika Dam. The following parameters were used for modelling:

- The Chania River Instream Flow Requirement (IFR) has been set at 0.158m^3/s. This was in accordance with the assumption of a parallel study on the Ngethu- Sasumua System[3]. Thika Dam release has been set at 0.125m^3/s as per the current operation of the dam.
- Thika Dam was simulated with and without Reservoir Operational Rules with a variable release to Chania River mainly to supplement deficits in flows from Kiama and Kimakia Rivers.

The results of the simulation are presented in Table 13-7.

Table 13-7: Yield Analysis of Existing System

	90% Reliable Yield (m^3/s)	
	Without Operational Rules at Thika Dam	**With Operational Rules at Thika Dam**
Thika Dam (Gross)	2.20	-
Mwagu (Chania IFR = 0.158m^3/s)	5.03	4.60

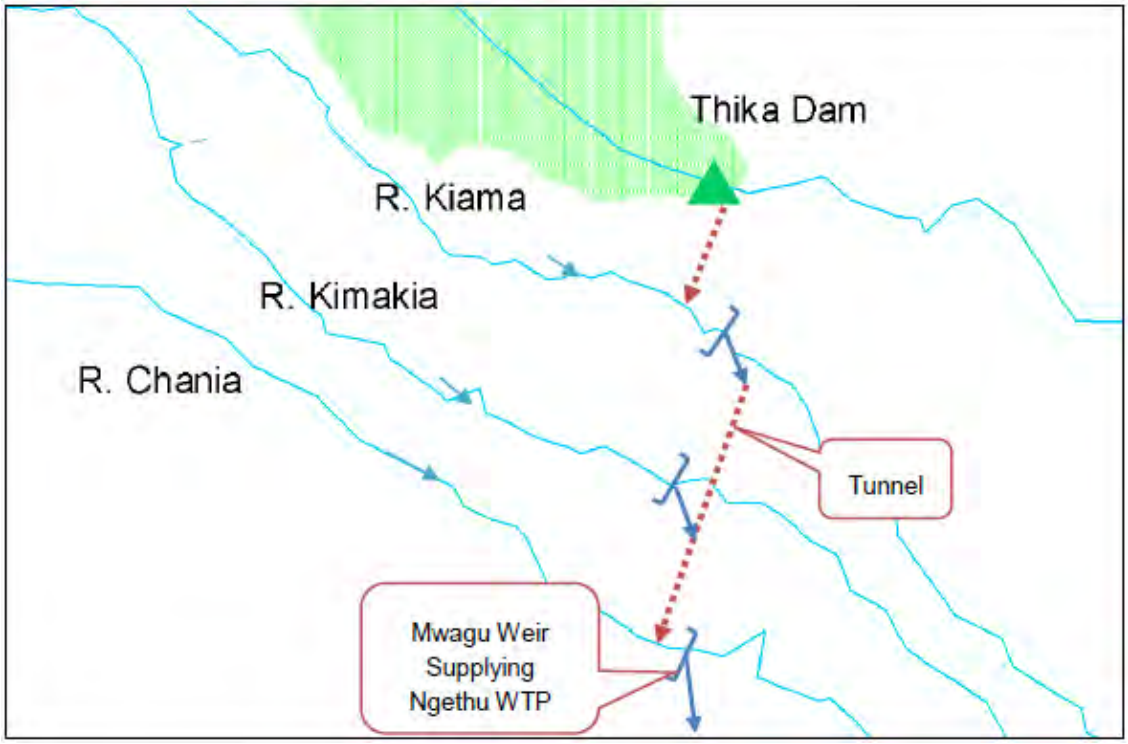
The current average abstraction from Mwagu Weir is approximately 4.6m^3/s.

The Design Capacity of the Existing System is 5.3m^3/s. However, the maximum abstraction at Mwagu Intake on Chania River was limited to 4.8m^3/s based on the operational capacity of the Ngethu System.

Figure 13-6 shows the schematic of the Existing System.

[3] BRLi Ingenierie in Joint Venture with Seureca, 2011. Consultancy Services for Hydrological Study and Water Management for the Ngethu – Sasumua System. Client: Athi Water Services Board.

Figure 13-6: The Existing System



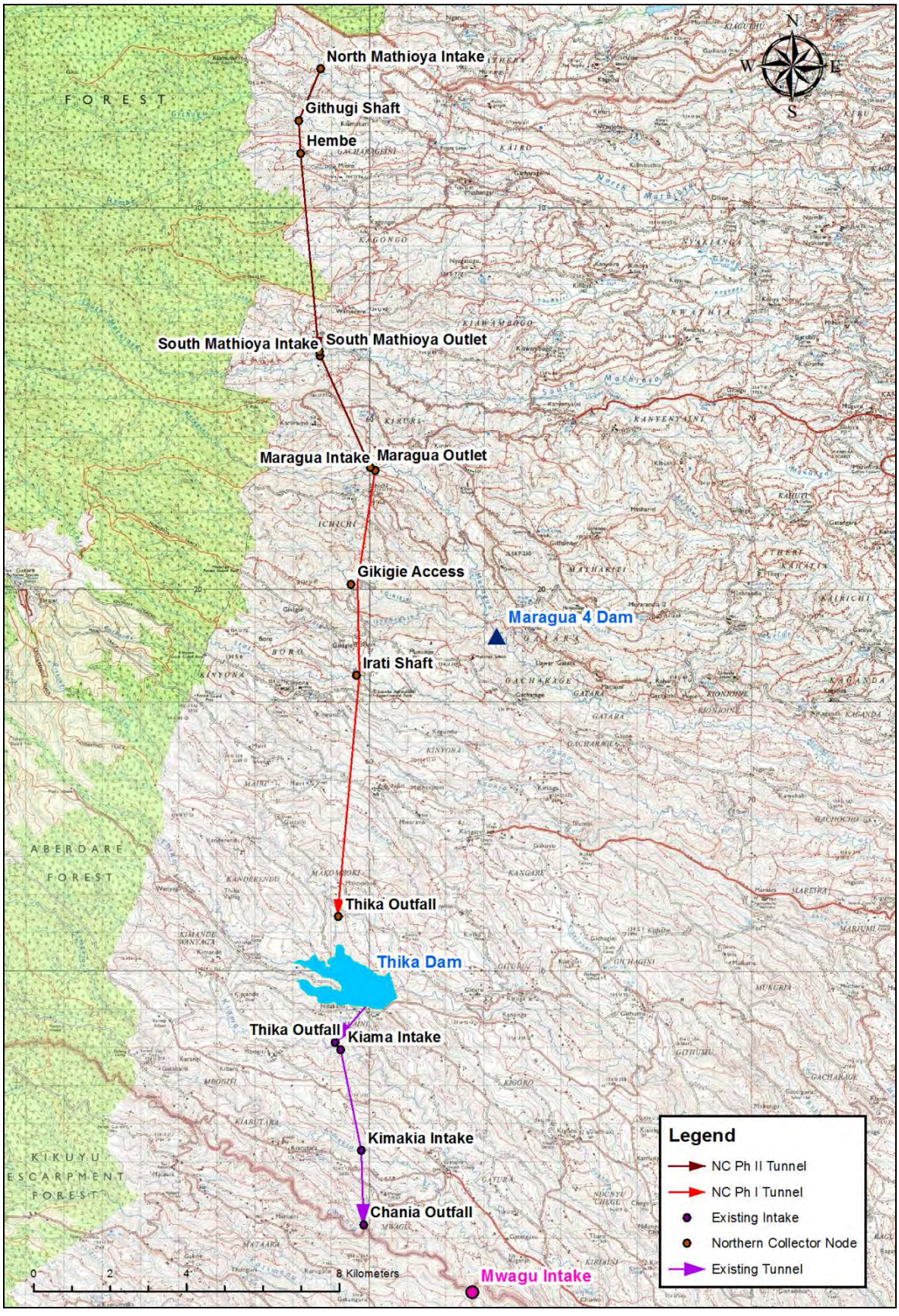
3.2.2 The Northern Collector (NC) System and Maragua 4 Dam

The Principle of the Model Setup was to have the existing Thika Dam as the main storage facility for additional water from the NC System. Thus, the System Yield was assessed by modelling the additional yield which would be available for use at Thika Dam when the NC System is implemented.

The following criteria were adopted under this simulation:

- The IFR of 0.158m^3/s for Chania River corresponds to the minimum statutory requirement for downstream release. Therefore, a higher value of 0.3m^3/s used previously by Howard Humphreys as well, was adopted for further simulation.
- Considering the importance of the riverine environment and requirements of downstream users, an IFR of Q_{95} was adopted for all rivers contributing to the NC System except Irati River which was set at 1.4Q_{95} due to additional downstream requirements.
- In addition, the abstraction capacities of Proposed Intakes were also individually set as per recommendations of the Northern Collector Scheme Feasibility Study (1998) carried out by Howard Humphreys.
- The NC System was modelled in two phases namely Phase I and II. Individual diversions from Irati and South Mathioya Rivers which are part of NC I and NC II respectively were also investigated.
- A range of storage capacities from 30 – 120Mm^3 for Maragua 1 Dam was analysed.
- The Maragua River Intake is simulated to stop diverting water when Thika Dam is full. Therefore, surplus water is automatically passed downstream to Maragua 1 Dam.

Figure 13-7: Location Map of the Existing and Northern Collector Systems



The Simulated System Yields based on the above principles is given in Table 13-8.

Table 13-8: Summary of Final System Yields (m^3/s)

	System Yield (m^3/s)	
Component	**NC I**	**NC I + NC II**
Mwagu	4.80	4.80
Additional Thika Yield	1.40	3.30

It was apparent from the Model simulation that the introduction of NC I and NC II results in increased spill at Thika Dam. This implies that additional storage is required in the System to capture the additional flows from the Water Transfers. If additional storage is not provided, then the water diverted through the NC System will result in excessive spill from Thika Dam. The spill over can be regulated by installing controls on the NC River Intakes to regulate abstraction especially during flood flows and when Thika Dam is full.

Howard Humphreys (1998) briefly investigated possible options for providing additional storage within the System. These were reviewed and the option of providing independent reservoirs on one or more of the Northern Collector Rivers but with no connection to the Northern Collector was recommended.

The Chania-Thika Study Supplementary Report by Howard Humphreys (1980) investigated eight potential dam sites to the north of Chania-Thika catchment and recommended provision of storage on Maragua River downstream of the NC diversion site at the confluence with Gikigie River. This is henceforth referred to as Maragua 4 Dam.

The location of the Maragua 4 Dam is advantageous within the Integrated System as it will allow the option of either sharing the NC II water with Thika Dam or diverting it entirely to Maragua 4 Dam depending on the location of the NC II tunnel outfall.

Maragua 4 Dam was incorporated in the WEAP Model and Additional Yields at Thika and Maragua 4 Dams were simulated for ten (10) different configurations of water transfer infrastructure and four (4) different storage capacities of Maragua 4 Dam.

Table 13-9 gives the System Yields for the optimum configuration of the Northern Collector System and Maragua 4 Dam.

Table 13-9: Summary of Maximum Available System Yield Simulated in WEAP (m^3/s)

Component		**Yield (m^3/s)**	**System Yield (m^3/s)**
Additional Yield at Thika (after implementation of NC I & II)		3.30	
Maragua 4 Dam Storage (Mm^3)	**30**	1.02	**4.32**
	60	1.68	**4.98**
	90	2.25	**5.55**
	120	2.64	**5.94**

Reference is made to **Chapter 7** and the **Report on Extended Yield Analysis of the Northern Collector System** for further details on the modelling exercise and results.

3.2.3 Independent Dams

Potential Dam Sites were identified using 1:50,000 scale topographical maps of the region primarily for water supply to the Satellite Towns. Reservoir characteristics were extracted based on these maps and with the aid of a digital terrain model[4]. The Potential Yield from Independent Dams was assessed using standardised Yield-Storage Relationships derived using reservoir characteristics and historical river discharge data for available gauging stations within the Region.

Table 13-10 gives the details of various dams and their respective possible net yields available for supply to Nairobi City and Satellite Towns.

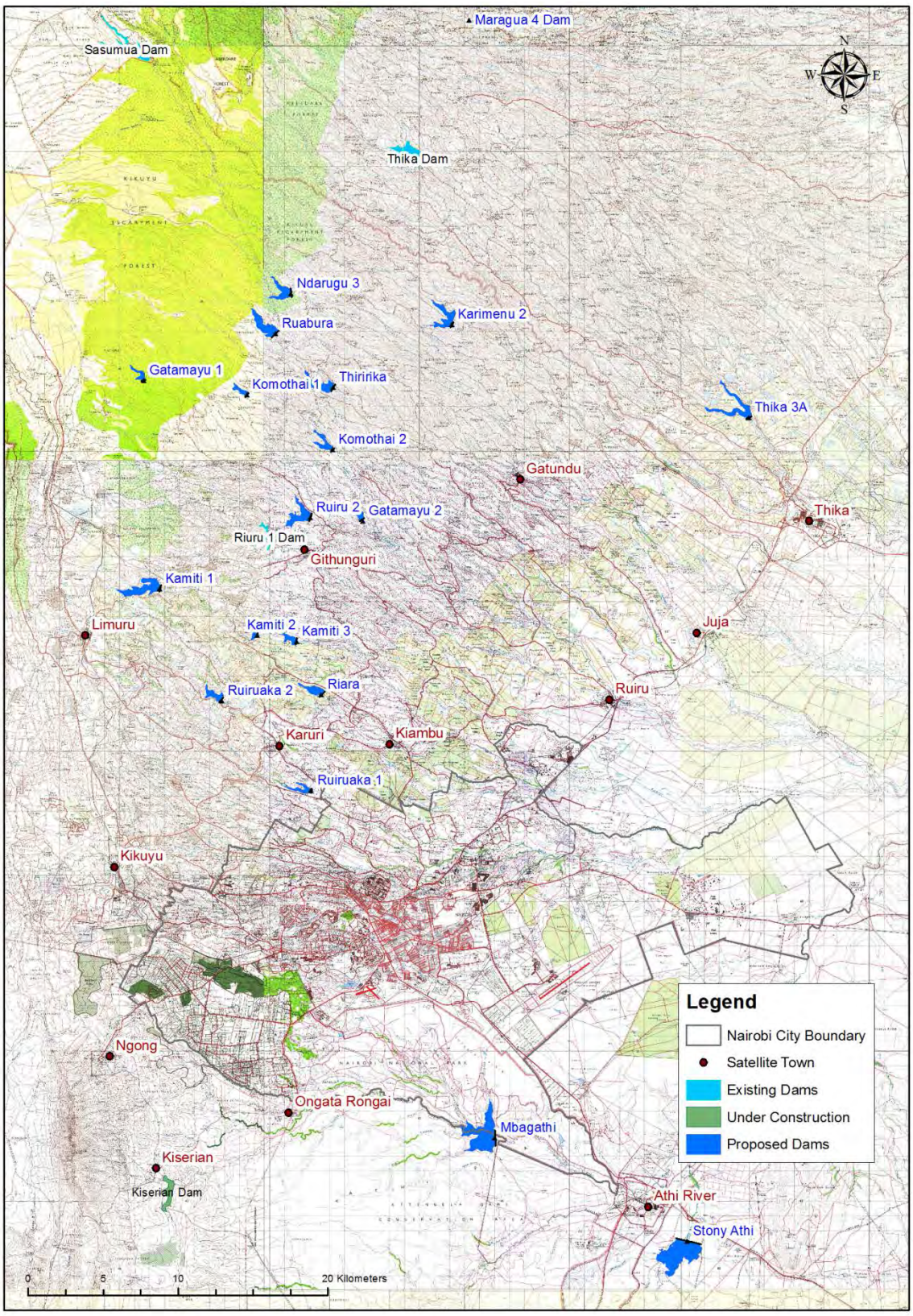
Table 13-10: Summary of All Investigated Dam Sites and Respective Net Yields

Proposed Dam Site	Dam Height	Storage Capacity	Yield	
	m	Million m^3	m^3/s	m^3/d
Kamiti 1	50	16.4	0.19	16,416
Kamiti 2	25	1.72	0.06	5,184
Kamiti 3	30	3.75	0.10	8,640
Ndarugu 3	50	11.2	0.24	20,736
Riara	30	7.3	0.14	12,096
Komothai 1	35	3.47	0.13	11,232
Komothai 2	30	4.9	0.18	15,552
Ruiru 2	50	13.2	0.46	39,744
Ruiruaka 1	20	2.89	0.10	8,640
Ruiruaka 2	20	2.13	0.07	6,048
Karimenu 2	40	14.2	0.54	46,656
Gatamayu 1	30	3.17	0.15	12,960
Gatamayu 2	50	7.1	0.38	32,832
Thiririka	50	14.7	0.39	33,869
Stony Athi	25	23.1	0.70	60,480
Mbagathi	35	53.4	0.64	55,123
Ruabura	65	26.5	0.44	38,016
Thika 3A	40	13.0	0.46	40,000
		Total Yield	**4.76**	**411,520**

Figure 13-8 shows the locations of the Dam Sites investigated for potential water supply to Satellite Towns.

[4] Using the Shuttle Radar Topography Mission (SRTM) data available at http://srtm.csi.cgiar.org/

Figure 13-8: Locations of Investigated Dam Sites for Water Supply to Satellite Towns



3.2.4 Ground Water

Ground Water is a significant contributor to the water supply for Nairobi City and Satellite Towns especially as an emergency source during the drought periods. There are a large number of private boreholes which meet some of the water supply deficits as a result of inefficient and inadequate surface water sources, shortcomings in distribution systems etc.

Two sites near Ruiru and Kiunyu have been identified with potential to supply a minimum yield of approximately 65,000m^3/day. These Wellfields will augment water supply to Nairobi City. For the Satellite Towns, independent investigations were carried out to determine the groundwater potential for each Town. Table 13-11 gives the potential groundwater allocations for the Satellite Towns.

Table 13-11: Maximum Groundwater Allocations to Satellite Towns

Satellite Town	Production Capacity	
	m^3/s	m^3/d
Kikuyu	0.21	18,000
Ngong & Ongata Rongai	0.03	2,500
Limuru	0.09	8,000
Githunguri	0.05	4,000
Gatundu	0.01	740
Tala-Kangundo	0.04	3,600
Total	**0.43**	**36,840**

Detailed analysis of the groundwater potential for water supply to Nairobi City and Satellite Towns has been presented in **Chapter 6** of this Report.

3.3 Proposed Alternatives

Development of Alternatives to address the investments required for improving water supply to Nairobi City and Satellite Towns was divided into two Components as follows:

a) Development of Alternatives for augmenting bulk water supplied to Nairobi City

b) Development of Alternatives for improving water supply to Satellite Towns by development of Independent Dams or ground water supply. These Alternatives will mainly increase bulk water supplied to Satellite Towns but will also augment supply to Nairobi City.

It should be noted that the Recommended Alternative is an amalgamation of the above two Components and will eventually work as a single system to supply water to Nairobi City and Satellite Towns.

3.3.1 Development of Alternatives for Nairobi City

The Scenarios involved the combination of different sources, arrangement of the Northern Collector Tunnel and scheduling. The various sources considered in the Scenarios are:

- Wellfields in Kiunyu and Ruiru Areas
- Northern Collector Phase I to Thika Dam
- Irati River Transfer to Thika Dam
- South Mathioya River Transfer to Thika Dam
- Maragua 4 Dam at the confluence of Maragua and Gikigie Rivers
- South Mathioya River Transfer to Maragua 4 Dam

- Northern Collector Phase II to Thika Dam
- Northern Collector Phase II to Maragua 4 Dam
- Ndarugu 1 Dam at the confluence of Ndarugu and Komu Rivers
- Chania River Transfer to Komu River.

A brief description of Scenarios considered and the sequences of development of the new water sources is given below:

- **Scenario 1**: Wellfields in Kiunyu and Ruiru followed by Northern Collector Phase I, Maragua 4 Dam with S. Mathioya Transfer to the Dam, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. In this Scenario, water transmission of additional water at Thika Dam will be via Ndunyu Chege Water Treatment Works to Gigiri Reservoirs.
- **Scenario 1A**: Similar to Scenario 1 but transmission of additional water at Thika Dam will be via Ngorongo Water Treatment Works to Kabete Reservoirs.
- **Scenario 2:** Wellfields in Kiunyu and Ruiru followed by Northern Collector Phase I, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. Transmission of additional water at Thika Dam will be via Ngorongo Water Treatment Works to Kabete Reservoirs.
- **Scenario 3**: Wellfields in Kiunyu and Ruiru followed by Northern Collector Phase I, S. Mathioya River Tansfer to Thika Dam and Maragua 4 Dam, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. Transmission of additional water at Thika Dam will be via Ndunyu Chege Water Treatment Works to Gigiri Reservoirs.
- **Scenario 3A**: Similar to Scenario 3 but transmission of additional water at Thika Dam will be via Ngorongo Water Treatment Works to Kabete Reservoir.
- **Scenario 4**: Wellfields in Kiunyu and Ruiru, Northern Collector Phase I (Irati River Transfer to Thika Dam), Maragua 4 Dam with S. Mathioya River Transfer to the Dam, Northern Collector Phase II, Ndarugu 1 Dam and Chania to Komu River Transfer. Transmission of additional water at Thika Dam will be via Ndunyu Chege Water Treatment Works to Gigiri Reservoirs.

The Northern Collector System with Maragua 4 Dam was modelled independently using WEAP Model with variations in the configuration of its sub components to determine the optimum configuration which resulted in maximum System Yield.

Reference is made to **Chapter 7** and the **Report on Extended Yield Analysis of the Northern Collector System** for indepth analysis of the various configurations investigated for transfer of water from the Northern Collector System.

The NC System primarily seeks to increase bulk water supply to meet Nairobi City and Satellite Town water demands. However, the additional bulk water is still inadequate to meet the entire water demand. Therefore, additional water sources have been identified to augment the bulk water supply from the NC System.

3.3.2 Development of Alternatives for Satellite Towns

To propose technically and economically feasible solutions, the water supply to Nairobi and Satellite Towns has been analysed based on the following:

- Water Supply to Nairobi and Satellite Towns within Nairobi Envelop

- Water Supply to other Satellite Towns outside the Nairobi Envelop.

Three water supply Options have been studied to meet the water demand for Satellite Towns. These are as follows:

- **Independent Water Supply Option** – Demands met by Independent Water Sources. Water supply systems to be managed by Independent Water Service Providers
- **Strategic Water Supply Option** – Demands met by a limited number of major resource developments (strategic sources). All Strategic Sources supply Nairobi City with en route off-takes and bulk transfers to Satellite Towns
- **Mixed Water Supply Option** – Demands met by a combination of Independent and Strategic Sources on the basis of Technical and Economic viability.

The Strategic and Mixed Water Supply Options comprise of an Integrated Plan in which sources are shared between Nairobi and the Satellite Towns.

Chapter 9 gives the detailed description of the philosophy and individual characteristics of the Development Strategies proposed for Satellite Towns.

4 Recommended Options

4.1 Recommended Option for Water Supply to Nairobi City

Multicriteria Analysis was adopted to compare and select the most viable Option for Water Supply to Nairobi City. Briefly, the Multicriteria Analysis has considered the following criteria to assess the impact of each Option against the following six key sustainability issues:

- **Natural Resources Criteria**: essentially these are mandatory water quantity indicators on the impact on downstream environmental flows and competition with alternative downstream/upstream uses; the security of the water resource and the diversity/ reliability of the resource to meet the water demand of the satellite towns.
- **Economic Sustainability**: options are compared through their respective indicators of least cost analysis: *Average Incremental Economic Cost of water (AIEC),* the present value of the total capital and O&M costs of an option divided by the present value of water outputs for that option over the period 2012-2037. *Present Value of Economic Costs (PVEC**),*** an indicator of the scale of the capital investment costs and O&M costs*; Present Value of Operation and Maintenance Costs (PVO&M)*, a measure of the relative cost of operating the system over its life.
- **Technical Aspects**: Options are rated on the flexibility of the new infrastructure to allow for further development of the resources and flexibility in supply to adjust to changes in population and future demand, and the complexity of the scheme in the number of new resources that have to be developed.
- **Operation and Management**: Five aspects of Operation and Management are considered: the complexity and number of management entities involved; susceptibility to prioritisation and conflict in water allocation in times of scarcity; multiplicity of water treatment works, conformity to national water supply policy; and the degree of variability in water tariffs/ potential for a standardised tariff.
- **Environment Sustainability**: Options are compared against their downstream impacts of water quantity releases on the environment; the impact they have on water quality issues for

upstream land use; and potential environmental impacts on downstream ecosystems during the construction and operational stages.

- **Social Sustainability:** Options are compared against their potential impact on resettlement, land losses and compensation through the development of the infrastructure.

Results of the Multi Criteria Analysis ranked Scenario 3A as the highest due to the following reasons:

- Additional storage provided in Phase II from the construction of Maragua 4 Dam
- Water supply from Maragua 4 Dam to the network is by gravity
- Chania / Komu Transfer to Ndarugu 1 Dam is not required to meet the 2035 Horizon Demand (under Scenario 2 this would be required and as supply from Ndarugu 1 Dam is by pumping, this option will have higher operations costs).

The Recommended Option for Nairobi City is Scenario 3A which includes the following development:

- Groundwater Wellfields in Kiunyu and Ruiru Areas.
- Northern Collector Tunnel Phase I diverting water from Irati, Gikigie and Maragua Rivers to Thika Dam.
- Northern Collector Tunnel Phase II diverting water from South Mathioya, Hembe, Githugi and N. Mathioya rivers together with the new Maragua 4 Dam. The Outfall of NC II will be upstream of the Maragua River Intake for NC I.
- Ndarugu 1 Dam

The proposed outfall of NC II on Maragua River is located upstream of the Maragua Intake for NC I thus enabling sharing of the additional water between Thika and Maragua 4 Dams. Therefore, during situations when Thika Dam is full, surplus water in Maragua River NC II will flow downstream to Maragua 4 Dam.

The construction of NC II will be done in two phases, with the diversion from S. Mathioya River implemented earlier followed by the diversions from the other 3 rivers i.e. Hembe, Githugi and N. Mathioya Rivers at a later stage.

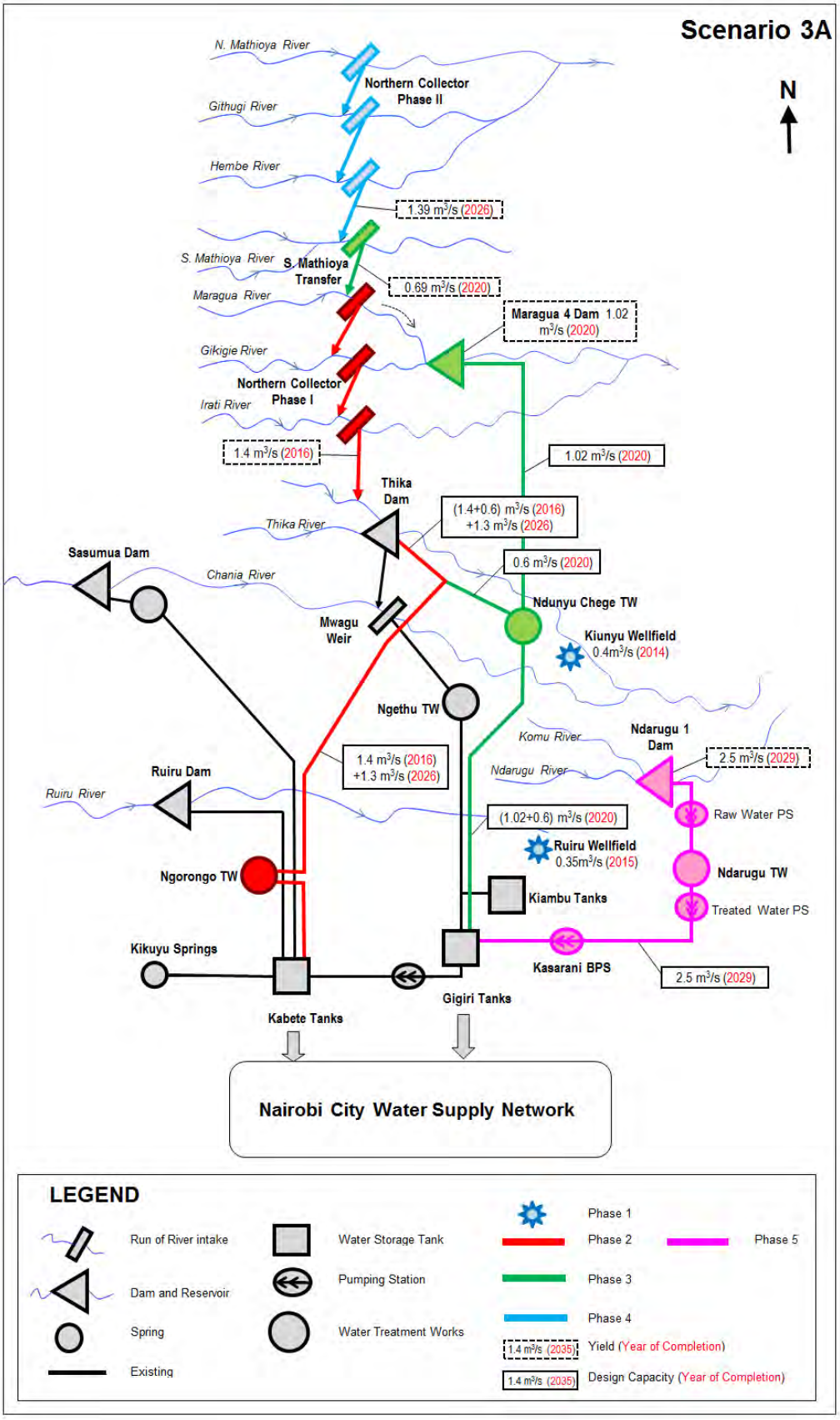
Figure 13-9 gives the Schematic of the Recommended Option for NC System with the respective Yields and Implementation Years.

The Simulated Yields for the Recommended Option for NC System is given in Table 13-12.

Table 13-12 : Simulated Net Yields

Component	Yield (m^3/s)
Mwagu Intake	4.80
Additional Yield at Thika Dam	3.30
Maragua 4 Dam	
Capacity	
30Mm^3	1.02
60Mm^3	1.68
90Mm^3	2.25
120Mm^3	2.64

Figure 13-9 : Recommended Option Scenario 3A with System Yields and Implementation Years



4.2 Recommended Option for Satellite Towns

Three Options for Water Supply to the Satellite Towns have been briefly elaborated in Section 3.3.1 and in more detail in **Chapter 9**. Based on the conceptual engineering, estimates of Capital and Operation & Maintenance Costs for the three Options have been prepared and used in the Least Cost Analysis for all three Options. Resulting key Economic Parameters were thereafter imported into the Multicriteria Analysis (MCA) to select the best Option for development of Water Supply to the Satellite Towns.

According to the MCA, the Recommended Option to augment bulk water for the Satellite Towns is the Mixed Water Supply Option.

The general criteria and assumptions used in developing the Mixed Water Supply Strategy are listed below:

- Supply from local sources to be considered as a priority
- Storage to augment existing local run of river schemes
- Groundwater development considered where no local surface water sources are available
- Supply from strategic sources to supplement the local sources

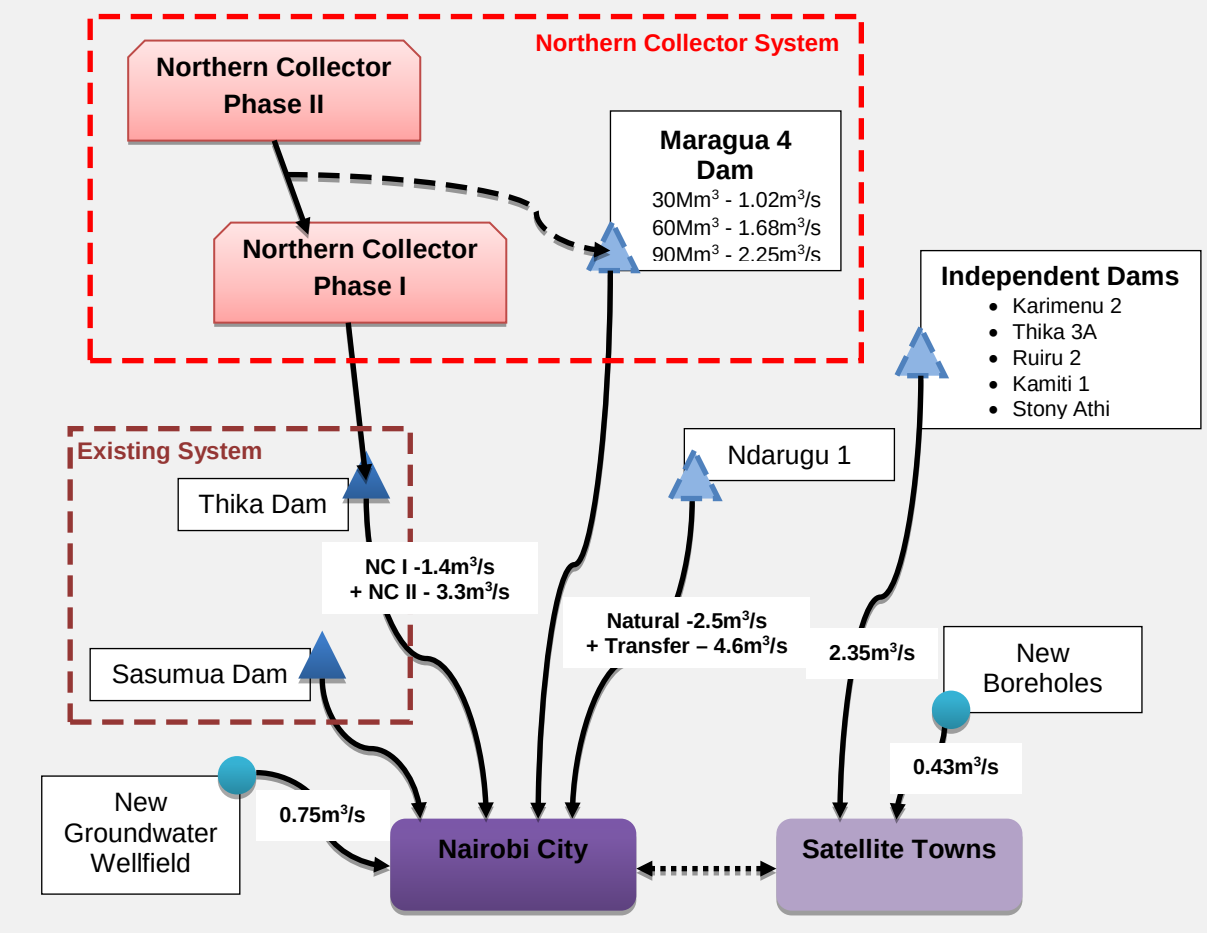
In this Option, the existing local water sources will remain and will be supplemented by additional localised water sources. In the cases where there are inadequate local sources to supply the Satellite Towns, then supply using the Strategic Sources which supply Nairobi City will be introduced. This concept forms an Integrated Utilization Plan in which Sources are shared between Nairobi and the Satellite Towns.

This development Option is similar in some ways to the recommendations made under the Long Term Development Plan by Howard Humphreys (1986) for regional water supply. The existing NCWSC Bulk Supplies to the Satellite Towns have been retained in this Option.

Figure 13-10 shows a schematic of the combined NC System and Mixed Option with respective Additional Yields.

A Layout Plan showing the Recommended Strategy under the Mixed Option is given in Figure 13-11.

Figure 13-10: Schematic of the Recommended Option for Nairobi City and Satellite Towns with Respective System Yields



- Maragua 4 Dam Yields are for different Storage Capacities of Reservoir
- Ndarugu 1 Dam inflows augmented with Transfer from Chania/ Komu
- Independent Dams Yield is the total potential available from all Dams

Figure 13-11: Long Term Development Strategy – Mixed Water Supply Option

5 Implementation Plan

5.1 Implementation Plan for Scenario 3A

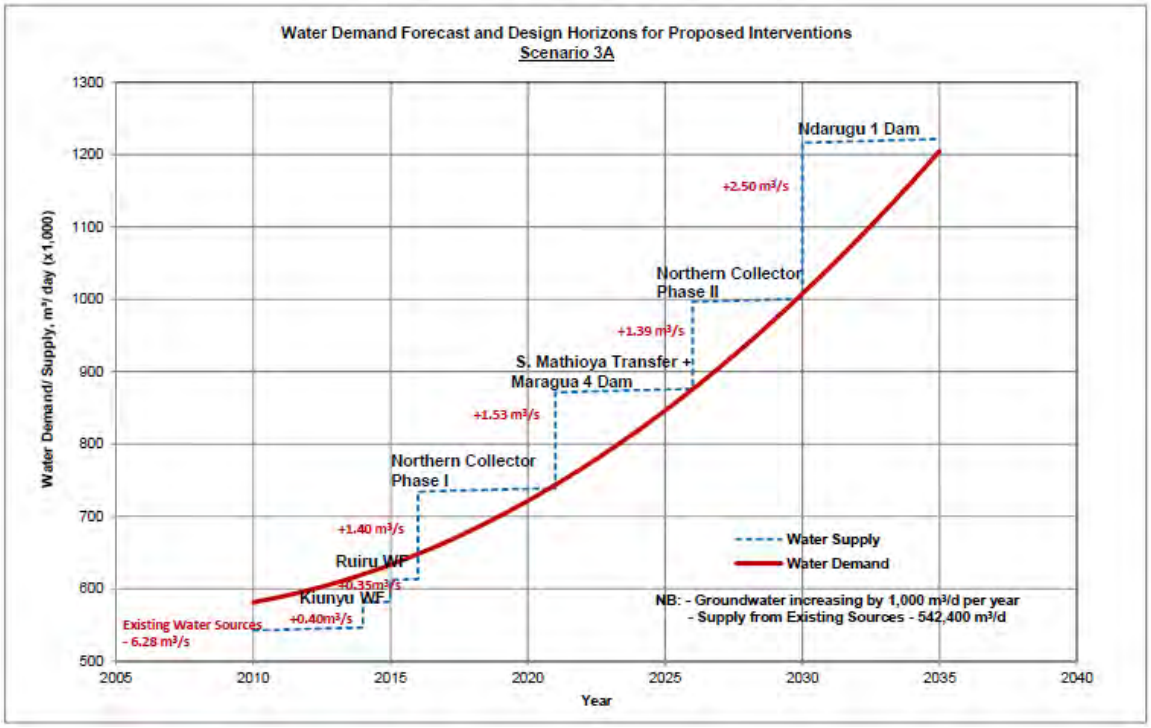
The Implementation Schedule for proposed Scenario 3A for Nairobi City is given in Table 13-13.

Table 13-13: Sequential Development for Scenario 3A

Phase	Implementation Period	Details of Schemes Development	Water Demand Horizon Met
1	2012-2013	Wellfields in Kiunyu and Ruiru Areas	<2015
2	2013-2016	Northern Collector Phase I Transfer to Thika Dam Raw Water Gravity Main to Ngorongo New Ngorongo Treatment Works Treated Water Gravity Main to Kabete Reservoirs	2021
3	2017-2021	Maragua 4 Dam + S. Mathioya Transfer to Thika Dam Raw Water Gravity Main from Thika and Maragua to Ndunyu Chege New Ndunyu Chege Treatment Works Treated Water Transmission Main	2026
4	2022-2026	Northern Collector Phase II Transfer to Thika Dam Raw Water Gravity Main from Thika to Ngorongo WTW New Ngorongo Treatment Works Treated Water Gravity Main to Kabete Reservoirs	2030
5	2025-2029	Ndarugu I Dam Raw Water Main + Pumping Station Ndarugu Water Treatment Works + Treated Water Pumping Station Treated Water Transmission Main to Gigiri Reservoir + Boosting Pumping Station	>2035

The Water Balance for Nairobi City Water Demand against the Proposed Water Infrastructure Development is given in Figure 13-12.

Figure 13-12: Water Balance for Scenario 3A



5.2 Implementation Plan for the Mixed Option

The Proposed Implementation Schedule for the Mixed Option for Water Supply to Satellite Towns is given in Table 13-14.

Table 13-14: Proposed Developments and Implementation for Mixed Option

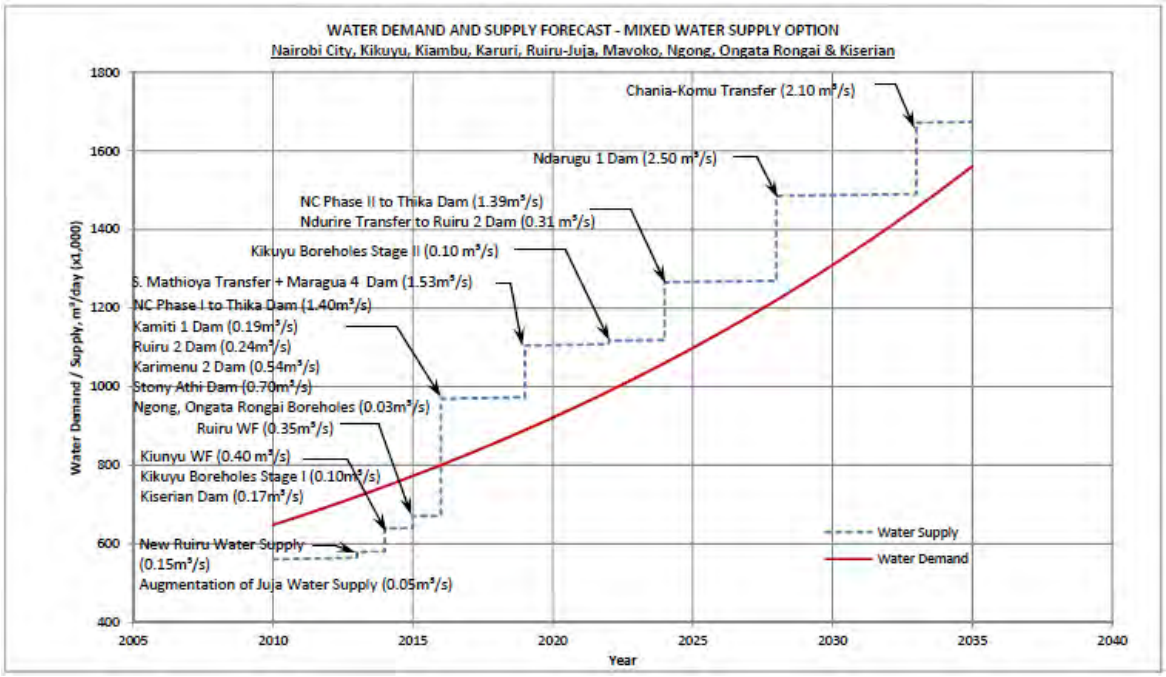
	Town / Component		Operational Year
1	**RUIRU-JUJA**		
	a.	Karimenu 2 Dam, Height 40m, Net Yield of 46,650m^3/d with • Treatment Works of capacity 46,650m^3/day • Treated Water Gravity Main from Dam to System Storage of Capacity 46,650m^3/d, Diameter 700mm, Length 18km • System Storage of Capacity 23,300m^3 • Treated Water Gravity Main from System Storage to Ruiru-Juja Towns of Capacity 46,650m^3/d, Diameter 700mm, Length 16km	2016
	b.	Ndurire Transfer to Ruiru 2 Dam with an additional Yield of 26,700m^3/d at Ruiru 2 Dam (Ruiru 2 Dam to serve Kiambu and Karuri Towns) • Transfer Tunnel from Ndurire River to Bathi River of Diameter 3.2m, Length 1.7km • Augmentation of Ruiru 2 Dam Treatment Works by 26,700m^3/d • Augmentation Treated Water Gravity Main to System Storage by 26,700m^3/d Capacity pipeline of Diameter 500mm and Length 15km • Ferrous Bulk Water Gravity Main from System Storage to Ruiru-Juja Towns of Capacity 26,700m^3/d, Diameter 500mm and Length 20km	2024
	c.	Bulk Supply of 38,000m^3/day from NCWSC off Ndarugu-Kasarani Rising Mains • Rising Main off Ndarugu-Kasarani Rising Mains to High Level Storage of Capacity 38,000m^3/d, Diameter 500mm and Length 2km	2029

	Town / Component		Operational Year
		• High Level Storage of Capacity 19,000m^3	
2	**MAVOKO**		
		Stony Athi Dam, Height 25m, Net Yield of 60,500m^3/day with • Treatment Works of capacity 60,500m3/day • Pumping station from Treatment Works to Storage • Ferrous Bulk Gravity Main from Treatment Works to Storage, Diameter 800mm, Length 5km • System storage of 30,000m^3 • Ferrous Bulk Gravity Main from Storage to Mavoko, Diameter 800mm, Length 4km	2016
		Bulk Supply of 12,000m^3/day from NCWSC using the Existing 600mm dia. Pipeline from Nairobi presently serving Mavoko-EPZA	2032
3	**NGONG, ONGATA RONGAI & KISERIAN**		
		Groundwater sources with a total yield of 2,500m^3/day	2016
		Bulk Supply of 33,000m^3/day from NCWSC to Ngong and Ongata Rongai Towns • Rising Main from Dagoretti Reservoir to Ngong Town of Capacity 14,000m^3/d, Diameter 500mm and Length 10km • Gravity Main from Kabete Reservoirs to Ongata Rongai Town of Capacity 19,000m^3/d, Diameter 500mm and Length 17km	2018
4	**KIKUYU**		
		Wellfield in Kikuyu with a total yield of 9,000m^3/day	2014
		Kamiti 1 Dam, Height 50m, Net Yield of 16,416m^3/day with • Treatment Works of capacity 16,416m^3/day • Treated Water Gravity Main, Diameter 450mm, Length 27km • System Storage of 8,000m^3	2016
		Additional Wellfield with a total yield of 9,000m^3/day	2022
		Bulk Supply of 20,000m^3/day from NCWSC using the new Bulk Water Rising Main from Dagoretti Tank to Kikuyu Town, Diameter 500mm and Length 5km	2027
5	**KARURI**		
		Ruiru 2 Dam, Height 70m, Net Yield of 51,000m^3/day (shared with Kiambu) with • Treatment Works of capacity 51,000m^3/day (shared with Kiambu) • Treated Water Gravity Main, from Ruiru 2 Dam to System Storage of Capacity 51,000m^3/d, Diameter 800mm, Length 15km (shared with Kiambu) • System Storage of Capacity 25,500m^3 (shared with Kiambu) • Treated Water Rising Main from System Storage to Karuri Town of Capacity 30,000m^3/d, Diameter 500mm and Length 10km	2016
6	**KIAMBU**		
		• Ferrous Gravity Main from System Storage to Kiambu Town of Capacity 21,000m^3/d, Diameter 400mm and Length 4km	2016
7	**THIKA**		
		Augmentation of Existing Thika Water Supply by 10,400m^3/day	2014
		Thika 3A Dam, Height 40m, Net Yield of 40,000m^3/day with • Treatment Works of capacity 24,000m^3/day • Ferrous Bulk Rising Main from Treatment Works to System Storage, diameter 700mm and total length 0.5km • System Storage of 12,000m^3 • Ferrous Bulk Gravity Main from System Storage to Thika Town, diameter 700mm and length 6km.	2022

	Town / Component		Operational Year
8	**LIMURU**		
		• Wellfield with a total yield of 4,000m^3/day • System Storage of 2,000m^3	2014
		• Wellfield with a total yield of 4,000m^3/day • System Storage of 2,000m^3	2020
9	**GITHUNGURI**		
		• Wellfield with a total yield of 2,000m^3/day • System Storage of 1,000m^3	2014
		• Wellfield with a total yield of 2,000m^3/day • System Storage of 1,000m^3	2018
10	**TALA-KANGUNDO**		
		• Wellfield with a total yield of 1,800m^3/day • System Storage of 900m^3	2014
		• Wellfield with a total yield of 1,800m^3/day • System Storage of 900m^3	2018
11	**GATUNDU**		
		• Wellfield with a total yield of 740m^3/day • System Storage of 400m^3	2031

The combined Implementation Schedule for Nairobi and the Satellite Towns under the Nairobi Water Demand Envelop together with the mobilisation plan for proposed future sources is shown in Figure 13-13.

Figure 13-13: Combined Implementation Plan for Scenario 3A and Mixed Water Supply Option



6 Investment Costs

6.1 Assumptions for Project Costs

The costs included in the Analysis are the (i) initial capital costs, (ii) replacement costs and (iii) future O&M costs (fixed and variable costs).

The following assumptions are used:

- Costs are expressed in US$ using the rates applicable in January 2012, and where necessary foreign costs are converted to KES at the rate of KES 90 = US$1.0 and KES117 = 1.0 Euro.
- Costs are assumed to be free of Kenyan customs and excise duty, unless stated otherwise.
- Costs are assumed to be free of VAT of 16%, unless stated otherwise
- An allowance of 15% is applied to all construction costs to allow for preliminaries and general items.
- An allowance of 9% of construction costs is applied to allow for engineering and works supervision services.
- A physical contingency of 10% is applied to all construction costs to allow for underestimation in bill of quantities and unforeseen costs.
- In the Financial Analysis, Price escalation (financial contingency) is included at the rate of 1% per year for foreign costs and 5% per year for local costs over the five year capital investment period.

6.2 Investment Costs for Scenario 3A

Table 13-15 gives the Capital Costs for Scenario 3A.

Table 13-15: Capital Costs for Scenario 3A

US$ Million 2012 Constant Prices		Total Capital Cost
Phase	**Component and Phase**	**US$ Million**
1.	**Groundwater Well Fields (2013-2015)**	
1.1.	Groundwater Investigations	3.00
1.2.	Ruiru and Kiunyu Well fields	73.40
	Subtotal	**76.40**
2.	**Nairobi Network Rehabilitation (2012 – 2014)**	
2.1	Hydraulic Rationalisation and New Storage (Phase I)	39.00
3.	**Nairobi Tertiary Development (2012-2016)**	
3.1	Tertiary Distribution System	15.60
3.2	Individual Metered Connections	6.50
3.3	Informal Settlements Upgrade	6.50
	Subtotal	**28.60**
4.	**Northern Collector - Phase 1 (2013 - 2015)**	
4.1.	Tunnels, Shafts, Intakes & Outfall	95.78
4.2	Thika Dam – Ngorongo WTW Pipeline (Phase I)	58.18
4.3	Ngorongo WTW (Phase I)	52.45
4.4	Ngorongo WTW – Kabete Reservoirs Pipeline (Phase I)	18.35
	Subtotal	**224.76**
5.	**Nairobi Network Rehabilitation (2016-2020)**	
5.1	Hydraulic Rationalisation and New Storage (Phase II)	27.40
6.	**Maragua 4 Dam and S. Mathioya Transfer (2017-2020)**	
6.1	Maragua 4 Dam (33Mm^3)	81.74
6.2	Tunnel, Intake and Outfall	28.41
6.3	Raw Water Gravity Mains to Ndunyu Chege WTW	23.80
6.4	Ndunyu Chege WTW	60.69
6.5	Treated Water Gravity Main to Gigiri Reservoirs	39.68
	Subtotal	**234.32**
7.	**Northern Collector Tunnel Phase II (2022-2025)**	
7.1	Tunnels, Shafts, Intakes & Outfall	66.24
7.2	Thika Dam – Ngorongo WTW Pipeline (Phase II)	50.87
7.3	Ngorongo WTW (Phase II)	48.70
7.4	Ngorongo WTW – Kabete Reservoirs Pipeline (Phase II)	15.82
	Subtotal	**181.63**
8.	**Ndaragu 1 Dam (2026 - 2029)**	
8.1	Ndaragu Dam (300Mm^3)	58.85
8.2	Raw & Treated Water Pumping Stations and Storage	20.25
8.3	Raw Water Pumping Main	8.09
8.4	Ndarugu WTW	93.66
8.5	Treated Water Pumping Mains	65.71
	Subtotal	**246.56**
	TOTAL	**1,058.27**

Notes *(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision*

(ii) no financial contingencies included

Table 13-16 shows the Implementation Schedule for Scenario 3A over the Planning Period (Year 2012- 2017).

Table 13-16: Implementation Schedule for Scenario 3A (2012 – 2017)

	Totals Including Contingencies						US$'000	Euro'000	
Project Components by Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Total**	**Total**	1.3
A. Wellfield Development									
1. Groundwater investigation	1,520	1,560	-	-	-	-	3,080	2,369	
2. Kiunyu wellfield	-	15,660	29,428	-	-	-	45,088	34,683	
3. Ruiru wellfield	-	2,654	27,888	-	-	-	30,542	23,494	
Subtotal	1,520	19,874	57,316	-	-	-	78,710	60,546	
B. Northern Collector Phase I								-	
1. Tunnell	13,029	29,612	27,388	20,661	-	-	90,691	69,762	
2. River offtakes and shafts	-	2,499	3,060	-	-	-	5,559	4,276	
Subtotal	13,029	32,111	30,448	20,661	-	-	96,250	74,038	74,038
C. Ngorongo Highlevel Water Treatment Works and Water Mains								-	
1. Ngorongo WTW	-	12,259	22,479	21,744	-	-	56,481	43,447	
2. Transfer mains	-	15,852	31,661	29,948	-	-	77,461	59,585	
Subtotal	-	28,110	54,140	51,692	-	-	133,942	103,032	103,032
D. Nairobi City Network Modification	8,387	18,303	12,311	-	-	-	39,001	30,001	30,001
E. Nairobi City Tertiary Network								-	
1. Tertiary distribution system	2,272	5,417	7,911	-	-	-	15,601	12,000	12,000
2. Individual metered connections	-	1,560	1,603	1,647	1,692	-	6,502	5,001	5,001
3. Informal settlements upgrade	-	1,560	1,603	1,647	1,692	-	6,502	5,001	5,001
Subtotal	2,272	8,538	11,116	3,293	3,385	-	28,604	22,003	22,003
Total PROJECT COSTS	**25,208**	**106,937**	**165,332**	**75,646**	**3,385**	**-**	**376,507**	**289,621**	**229,075**

Note. US$: Euro exchange rate of Euro 1.0 = US$1.30

6.3 Investment Costs for the Mixed Option for Satellite Towns

Table 13-17 gives the Capital Costs for Proposed Water Infrastructure Development for Satellite Towns under the Mixed Option.

Table 13-17: Capital Costs for Mixed Supply Option

	Satellite Town	Total Capital Cost US$'000
NAIROBI BULK SUPPLY		**185,796**
	Chania-Komu Transfer	107,124
	Extension of Proposed Ndarugu WTW	78,672
1.	Kikuyu	87,983
2.	Kiambu	70,215
3.	Karuri	125,139
4.	Ruiru-Juja	205,375
5.	Mavoko	110,417
6.	Ngong, Ongata Rongai & Kiserianl	9,173
7.	Thika town	64,178
8.	Limuru	5,476
9.	Githunguri	3,261
10.	Gatundu	977
11.	Tala-kangundo	3,316
	TOTAL	**871,306**

Notes

(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works supervision

(ii) No financial contingencies included

The Chania Komu Water Transfer will come into operation in the Year 2033 and will augment inflow into the Ndarugu 1 Dam constructed under Scenario 3A for Nairobi City. The increased bulk water will be used by the System to meet the deficits in water demand where required.

Table 13-18 shows the Summary of Capital Expenditure for the Mixed Supply Option over the Planning Period (Year 2010- 2035).

Table 13-18: Summary of Capital Expenditure for the Mixed Supply Option

Item	Satellite Town	Total initial capital cost US$	Investment Schedule				
			2010-2015	2016-2020	2021-2025	2026-2030	2031-2035
	NAIROBI BULK SUPPLY	185 796,42				34 265,00	151 531,42
	Chania-Komu Transfer	107 124,03				34 265,00	72 859,03
	Chania-Komu WTW	78 672,38					78 672,38
1.	KIKUYU	87 983,22	61 873,29	20 260,85	4 467,68	1 100,94	280,46
2.	KIAMBU	70 215,35	43 261,07	17 848,68	9 105,60	0,00	0,00
3.	KARURI	125 139,08	87 060,81	25 809,76	12 268,51	0,00	0,00
4.	RUIRU-JUJA	205 374,60	80 961,81	16 234,15	106 504,22	1 674,42	0,00
5.	MAVOKO	110 416,76	62 582,27	18 962,82	27 736,85	457,31	677,50
6.	NGONG ET AL	9 173,44	2 267,60	6 857,14	48,69	0,00	0,00
7.	THIKA TOWN	64 177,63	0,00	23 776,22	40 401,41	0,00	0,00
8.	LIMURU	5 476,33	2 543,40	2 543,40	129,84	129,84	129,84
9.	GITHUNGURI	3 261,39	1 533,31	1 533,31	64,92	64,92	64,92
10.	GATUNDU	976,68	0,00	0,00	0,00	976,68	0,00
11.	TALA-KANGUNDO	3 315,59	1 552,62	1 552,62	70,12	70,12	70,12
	TOTAL:	**871 306,48**	**343 636,19**	**135 378,95**	**200 797,85**	**38 739,23**	**152 754,26**

Notes
(i) All capital costs include 15% preliminaries and general items, 10% physical contingencies and 9% for engineering & works super
(ii) No financial contingencies included

7 Water Resources Management

7.1 Introduction

Chapter 11 of this Report gives an in-depth analysis on the Water Resources Management Governance established for monitoring, managing, regulating, conserving, and developing water resources. Proper governance is key in overcoming the challenges facing the management of Water Resources in the Study Area. The Chapter also outlines specific Water Resources Management issues facing Existing and Future Water Sources for Nairobi and Satellite Towns and the necessary monitoring requirements.

Governance arrangements for Water Resources Management are exercised through the formulation and implementation of policies, laws and regulations; the establishment of institutions with properly-defined functions and mandates; and by ensuring that those institutions are adequately resourced and have proper knowledge, and financial and technical capacity.

Kenya's Current Policy, Legislation and Institutions for the Management of Water Resources deal more broadly also with natural resources, and with land use and physical planning. Therefore a discussion on the National Policies on Water Resources Management, Environmental Management and Land Use Planning has been carried out in order to provide a complete picture of the arrangements for Water Resources Management.

7.2 Water Resources Management Governance

The following key components have been reviewed in the assessment of the Water Resources Management Governance in Kenya and in the identification of the key challenges facing these arrangements.

a) Policy

The following policy documents have been reviewed for the purpose of ascertaining the policy provisions on Water Resources Management:

- National Policy on Water Resources Management and Development,
- National Land Policy,
- Policy on Environment and Development,
- Report on Groundwater Governance, and
- Integrated Urban Water Management in Africa.

b) Legislation and Regulations

An in-depth discussion on the governance structures which are presently available with relation to the following aspects has been carried out:

- Water Rights and Water Permits,
- Controls on Development in Recharge / Discharge Zones and Pollution,
- Water Management Plans and Land Use Planning and
- Stakeholder Participation.

It has been determined that there is a comprehensive legal framework for the management of water resources. Water resources are vested in the State, and its control is vested in the Minister in charge.

However, the legislation has weaknesses; enforcement has been weak, and many of the provisions have not been implemented. By way of example, despite there being provision for the designation of groundwater conservation zones, none has been declared since the Water Act 2002 came into effect. Furthermore, many water abstractors do not have permits and do not pay water charges for the water abstracted. Weak implementation is due to a perception that water is an inexhaustible resource, because of poor knowledge on water resources, weak institutional capacity, poor funding and weak political commitment at senior policy-making level. The result is that over-abstraction and poor management has continued.

c) Institutions

Key institutions like MoWI, WRMA, CAACs, WRUAs, WSRB, WSBs, WSPs, WSTF, WAB, NWCPC, KEWI, and NIB have been established by the Water Act, 2002. The relation between each other and hierarchy among the different Sector Organisations and the Roles and Responsibilities of these institutions is discussed in Chapter 11 of this Report.

One of the key institutions when it comes to Water Resources Management is WRMA. While the technical capacity generally exists in terms of skill-sets, inadequate staff numbers and limited resources, allied to a lack of strategic focus, means that Water Resources Management at the National and Catchment area level is ineffective.

Devolution in WRMA has been made up to catchment levels (CAACs). The capacities of the CAACs have not been made full use of, and because they have no powers, they are not always able to influence decision making in WRMA. Consequently, their effectiveness in respect of water resources management has been limited.

d) Suggested Reforms for Enhancement of Management Arrangements

The measures required for enhancing water resources management arrangements and capacity include the following:

- Amending and Streamlining Sectoral and Cross-Sectoral Policies,
- Creating Awareness on the general public on their Rights and Responsibilities and,
- Ensuring knowledge and Capacity

e) The Constitution of Kenya 2010

The need to realign the policy, legal and institutional framework for water resources management to the Constitution of Kenya 2010 provides an opportunity to streamline the water resources management framework. Proposals on how to streamline the management framework are discussed in detail in Chapter 11 of this Report.

f) Threats, Actions Needed and Responsibility

The Threats on Water Resources, Actions required, Responsible parties and the applicable laws and regulations have been identified and are discussed in Chapter 11. The Threats identified cover issues relating to:

- Protection of Sources of public water supply,
- Protection of downstream competing uses,
- Catchment protection,
- Groundwater protection,
- Environmental Impacts from proposed developments,
- Permit for siting of septic tanks and pit latrines,
- Stakeholder participation and conflict resolution,
- Effluent discharge licensing, and
- Establishment & management of a water resource database.

7.3 Management of Surface Water Sources

The forecast demand for water presently has started to equate or exceed the economically available finite water resources. It is therefore essential to integrate the development and hence, use water over the whole of the study area or even the catchment areas of the Tana and Athi Rivers rather than water development for individual WSPs. The Mixed Water Supply Option which has been selected as the most advantageous development plan for water supply to Nairobi and the Satellite Towns takes this into consideration.

Presently, limited monitoring systems have been put in place to ensure proper coordination of the different water users in the wider study area. Some of the existing hydrometric networks have already collapsed and an upgrade is urgently required.

On the existing water sources, it is recommended that the intakes on the Kiama and Kimakia Rivers be closed when transfers to the Chania are not required in order to maintain the natural flow regimes of the rivers as far as is possible. It is also recommended that flow measurements of the diversions from each of the two rivers into the Thika-Chania tunnel and the downstream flow should be carried out.

Regular flow measurements need to be also established on other run-of-river intakes serving the Satellite Towns like the Mbagathi, Ndarugu, Thika and Ruiru River intakes.

The present dam operational and management rules established in 1998 for the Nairobi water supply reservoirs are obsolete and inappropriate and therefore need to be revised in the context of present situation.

The discharge of untreated alum sludge and other backwash wastes has been known to cause unnecessary local distress to the receiving waters at times of very low river flows, particularly at Ngethu Water Treatment Works. This needs to be stopped and proper disposal and recycling of backwash waters established at all existing and proposed water treatment facilities.

The most significant impacts from the proposed abstractions are related to reduced flow levels in the rivers downstream of the points of abstraction. It is therefore imperative that river flows are regulated so that minimum reserve flows in the rivers are maintained after abstraction so that downstream users and aquatic ecology are not affected. The downstream flows should be such that they also allow for adequate dilution of agro-chemicals and sediment loads.

The provision of storage has been largely considered especially for Satellite Towns to increase the abstraction volume while sustaining the downstream demands. Operational rules need to be developed for these dams so as to ensure equitable, reliable and secure utilisation of the resource for the benefit of all water users and the environment.

Reports by WSPs indicate no significance level of chemical contamination on existing raw water sources emanating from agrochemical usage. However, as the population increases and the plot sizes decrease, increasing amounts of fertiliser and other agro-chemicals will be used so as to maximise crop yields. This will then affect the water quality of the river, which may require specialised treatment to eliminate phosphates, nitrates and other chemicals in order to render the water potable.

Monitoring of water quality, including tests for pollutants and biological contamination that may be related to potential human health issues will be necessary. Monitoring needs to be carried out at all river gauge sites on a regular monthly basis (or more frequently). Detailed monitoring of water quality should also be carried out at the proposed water treatment facilities.

7.4 Management of Groundwater Sources

Studies have shown the Nairobi Aquifer Suite to be the most heavily used aquifer in Kenya. The effects of this has been decline in groundwater levels in certain ‘hotspots’ and deterioration of the water quality.

One of the biggest challenges for groundwater use management in Nairobi and the Satellite Towns is poor governance or lack of it. The Nairobi Envelop is within an area that was declared a Groundwater Conservation Area (GCA), ratified in 1972 by the Government. However, the

declaration apparently carried no conditions with it, as the number of boreholes continued to increase at an exponential rate.

Groundwater will remain under great pressure in Nairobi and Satellite Towns due to the flexibility and spontaneity of use that it offers compared to surface water sources. Demand side management will therefore be a critical aspect of groundwater protection in this area. Water Allocation Plans (WAP) that respond to these needs must be drawn and operationalized.

The plan should consider how deep the water table in Nairobi will sustainably be allowed to drop. The Upper Athi Series aquifer is already depleted in some areas and pumping water levels are currently sustained above the Lower Athi Series. Should there be another episode of depletion, the pumping water levels will drop into the lower aquifer, yet the next aquifer layer may not be as productive as the first two. This means that pumping levels may drop to more than 250 metres below ground level. The question is whether such deep levels will be economical for private water users to pump small quantities from. If pumping water levels have to be maintained at the current 200 - 220m at the deepest, then a WAP must be drawn immediately and adhered to.

7.5 Recommendations for Water Resources Management

a) Governance

The recommendations made on the possible future policy changes required in addressing the problems affecting water resources management and conservation does not require additional or new legislation, except in respect of alignment to the Constitution of 2010. The principal requirement is action on key recommendations and policy objectives which have been made in policy statements over the years, the lack of attainment of which has been known for a considerable number of years.

Key among these is the development of a functioning mechanism for coordination of actions relating to water resources across diverse sectors which affect the sustainable management of water resources, including land, environment, and water resources.

Secondly, it will be necessary to give priority to water resources management in the activities and programmes of water sector management institutions. This requires providing them with resources – human, technical and administrative – necessary to discharge their mandates effectively.

Thirdly, action is to enforce the rules regarding the requirement for authorisations, permits and water charges, and to improve compliance needs to be taken. Such action would need to target influential individuals and strategic public sector institutions. Success depends, therefore, principally on political will and commitment, since the legal framework which is in place has the basic elements required to manage water resources sustainably. If the political will is present, the institutions mandated to manage water resources will also be provided with the technical and managerial capacity they require to successfully manage the resources.

b) Management of Surface Water Sources

The following recommendations have been made with respect to the aspects which need to be monitored and carried out so as to overcome present and future problems arising from the development and utilization of surface water sources within the wider study area so as to ensure sustainability of these sources:

- Regular monitoring of flows upstream and downstream of all diversion structures and storage reservoirs including operationalization and extension of the existing river gauge network

- Sediment monitoring and frequent bathymetric surveys in reservoirs to monitor sedimentation effects,
- Periodic surveys of aquatic fauna upstream and downstream of all of the intake weirs and proposed storage reservoirs,
- Monitoring of changes in demand for water downstream of intakes and reservoirs,
- Monitoring of changes in the quality and availability of water supplies from rivers and associated streams and impacts on public health, including those communities dependant on downstream flows,
- Monitoring of upstream land use and land cover, as well as agricultural activities in the catchment areas,
- Monitoring of land use and land cover downstream of proposed intake weirs and storage reservoirs,
- Assessment of environmental impacts on water courses due to wastewater discharges into rivers from water users and from water treatment facilities,
- Monitoring of the proposed development plan for mobilising new water sources for Nairobi and the Satellite Towns to ensure that sources are developed and utilised in a coordinated and structured manner as planned.

c) Management of Groundwater Sources

It is recommended that sound groundwater management be practiced as per the Preliminary Nairobi Water Allocation Plan (WAP) carried out by Norken (2010) and the Groundwater Governance Study (2011).

Also proper and continuous monitoring of groundwater sources to limit the effects of over abstraction, climate change, pollution from diffuse and point sources, urbanisation and large developments, agricultural activities and pesticides, etc., needs to be carried out.

8 Risk Management Plan

8.1 Introduction

An Integrated System of Water Resources Management is required that assesses and manages risks throughout all of the requirements within the hydrological cycle, and throughout the watersheds. Managing risks in water resources is essential to alleviate damage and the consequences of natural disasters such as flooding and droughts. Understanding the types of risks in each area helps planners to select the right policies and actions to apply in the right place and time in order to reduce risks and mitigate damages.

Active project level risk management plans should include an analysis of potential risks, including those with both high and low impact, as well as proposed mitigation strategies to help in counteracting negative consequences, should problems arise. Risk Management Plans should be periodically reviewed (preferably every 5 years, if not more frequently) by the project team to avoid having the analysis becoming stale and not reflective of actual potential project risks. In practice, the levels of risk involved in a specific course of action are compared to expected benefits to provide evidence for decision making.

Potential hazards or risks can be categorised as either environmental or economic risks, and these are summarised separately below, although there are inevitable overlaps and linkages

between these main categories. Detailed analysis and discussions about the potential risks and the management plan for major risks, mitigation methods, indicators, monitoring & reporting are presented in Chapter 12 of this Report.

In the long-term, education and training in Risk Assessment and Management should be considered for managers dealing with the water supplies and related sectors. Furthermore, the precautionary principle should also be adopted when considering and assessing risks, particularly where hazards have long environmental lifetimes or accumulative or irreversible consequences.

8.2 Environmental Risks

The primary aim is the abstraction of water from upstream resources and the use of this water in urban and adjacent areas. A range of potential environmental risks can be expected from the proposed abstraction of water from surface resources i.e. from rivers at weirs and dams, and from the abstraction of groundwater resources.

Environmental and Socio-Economic Impacts are mainly due to:

a. Construction and development of groundwater sources for Nairobi and Satellite Towns,
b. Construction of weirs, and other structures associated with intake facilities on rivers,
c. Construction of dams and reservoirs,
d. Construction of transmission tunnels and pipelines and water treatment facilities,
e. Resettlement and compensation,
f. Operation of these systems, and
g. Changes to the downstream hydrology of the river basins and downstream availability of water as a result of reduced flow in the rivers following abstraction at the intake sites.

In addition, it will be necessary to ensure adequate protection of the watersheds covering the proposed raw water supplies. A significant part of this area is currently included in the protected areas of the Aberdare National Park and adjacent protected forest reserves. It is considered essential that the risk management procedures ensure that the current protection status continues and that the land cover in the forest reserves is maintained in conditions that are suitable for watershed protection. It may also be necessary to designate additional areas where land use is limited to those categories that are suitable for watershed protection.

Downstream impacts on riverine ecosystems are considered to be the primary environmental impacts associated with the development of these water supply abstraction sites. The most important mitigation measures are the release of Reserve Flows capable of maintaining important downstream environmental conditions and meet water demands of the populations.

Potential categories of Risks classified as Environmental Risks include:

a) Climate Change

The world's climate is predicted to change substantially, with changes in temperature, precipitation and frequency of storms, and with subsequent effects on hydrology especially in the drier areas. Precipitation patterns are expected to change significantly, and extreme weather events (severe storms, floods, droughts, and heat waves) are expected to become more intense, more frequent and unpredictable.

From the water resources perspective, the increased incidence of drought periods represents a potentially serious risk.

The risks from climate change can therefore be considered to increase the number of consecutive dry days, increase in temperatures, increase in water demands for domestic and agricultural purposes, public health could also be compromised and hydrologic and temperature change may modify the natural habitat boundaries of disease vectors such as mosquitoes, and other waterborne diseases.

There are natural concerns about the sustainability of the water sources with the evolving challenges of climate change. In Southern Africa, very large runoff reductions are being forecast. In Kenya, some warming is expected, which will increase evaporation. Rainfall variability is also expected, but annual rainfall totals are not expected to decline. The impacts will be more defined in the drier areas of Kenya and minimal impact in the water shed areas such as the Aberdares.

b) Risks from Construction

These are hazards resulting from construction of weirs, intake structures and tunnels, as well as dams and reservoirs. In general, the impacts related to such construction activities are understood and can normally be planned for and mitigated against in the designs.

c) Changes in Downstream Hydrology

This will result in changes to water flow patterns, changes in quantity (in particular the loss of flood events), and also a deterioration in water quality. This can be minimized by mimicing of the river flow patterns which exists before major abstractions have been affected.

d) Public Health Risks

These are public health risks, resulting from reduced water quality as a result of reduced flows. This may result in increased health risks for downstream communities or households, especially those reliant on untreated river water if adequate reserve flows are not released.

e) Changes in Groundwater Levels

The flow in rivers contributes to local groundwater levels. In addition, during low flow periods groundwater contributes towards base flow in rivers and streams. However, the details of this relationship are not known for the rivers in the Northern Collector area. The risk is, therefore, that as a result of reduced downstream flows there may be a reduction of recharge to groundwater from the impacted rivers. However, groundwater is not a major resource for downstream users in the Northern Collector Riverine Areas.

Degradation of aquifers as a result of the increased abstraction of groundwater resources from boreholes is also a potential risk. This is a long term risk but groundwater replenishment needs to be incorporated in risk management strategies.

f) Operational Hazards

These are hazards and risks encountered during water abstraction, storage, transmission and distribution. Risk management plans will need to take account of such operational hazards and incorporate risk reduction strategies.

g) Seismic Activity

Although considered infrequent, seismicity can potentially be a major hazard. This could have potential risks on tunnels and dams. Seismic risk management strategies need to be incorporated in the designs.

8.3 Economic Risks

The use of pricing policies and other economic instruments are essential for the effective and equitable allocation of the resource, taking into account social and economic criteria as well as basic human needs. Inadequate economic policies have often contributed to the poor

performance of water utilities and their vulnerability to economic risks, thus, decreasing their ability to attract financial resources from the public and private sector as well as the international community.

While the public sector and the international community has traditionally played a major role in financing water resources development, there is an increasing recognition of the need for the involvement of other stakeholders like the private sector and community based organisations. Financial support for the collection, processing and dissemination of timely, reliable and demand-oriented information is essential to the effective management of water resources.

In addition, the number of water related natural disasters (flood, drought) have been rising rapidly over the past decades. Therefore, the economic evaluation for the losses due to these phenomena and financial provision for their prevention and mitigation should be of prioritized.

Several strategies and actions could be recommended in addressing economic and financial issues related to Integrated Water Resources Management. Among the measures of particular interest are cost reduction means including:

- Restructuring of existing institutions to reduce cost,
- Improving existing management such as demand management / leak reduction,
- Promoting competition in service provision,
- Improving existing data collection network,
- Provision of financial incentives, including tax exemption for equipment,
- Investing in under privileged areas,
- Reliance on low cost systems and appropriate technologies, and
- Increasing accountability in system management.
- Frequent adjustment of full cost recovery tariffs to generate adequate revenue to maintain self sustainability of the systems.

8.4 Recommendations for Risk Management

An important component of the Risk Management will be the establishment of a set of systems for monitoring and recording relevant information. The management of risk will depend on this set of comprehensive and up-to-date records. Some of this is already in place, for example, the rainfall monitoring stations run by the Kenya Meteorological Department. The available information from some other important sets of information that will be required are considered to provide inadequate coverage or may be out of date.

In such cases, existing monitoring systems will need to be augmented or new records established. For example, a more comprehensive system of river gauge monitoring stations will be required in all downstream areas in order to ensure that adequate “Reserve Flows” are provided. Similarly, the provision of adequate compensation flows depends on accurate and up-to-date records of downstream household and community requirements. These monitoring activities are considered as long-term and will need to be updated and continued as a regular component of monitoring as a component of the risk management plan.

In addition there are a series of potential risks that are related to or linked with Climate Change. These are, for example, likely to alter or increase the water requirements of downstream communities, as well as the requirements for agriculture, and for other water related sectors of the economy. The relevant sectors are likely to include: Agriculture, Energy, Health, Biodiversity and Ecosystems. Risk management related to Climate Change will need to be carried out in

conjunction and collaboration with the new Climate Change Authority, expected to be established by Bill of Parliament in 2012.

There are long-term risks associated with the onset of Peak Oil demand, and predicted increases in crude oil prices, resulting in increased costs and changes to sectors of the economy. Current trends in the international crude oil prices, based on daily price data from the year 2000 to the present, indicate a trend towards a doubling of current crude oil prices by the year 2018. This might lead to serious economic risks if not addressed early in the planning process.

Similarly, risks related to inability to pay, high operation and maintenance costs due to the increasing energy costs can result in inability to recover costs and slowed development of new water sources to meet the increasing water demand for Nairobi and Satellite Towns. Other factors include accountability and issues relating to high levels of unaccounted for water, unforeseen climatic changes, natural disasters etc.

The major environmental risks have been categorised, mitigation methods and key indicators determined and the monitoring and reporting requirements presented. These have been tabulated in Chapter 12 of this Report. Key issues and recommended actions relating to economic risks have also been detailed in Chapter 12.

9 Recommended Urgent Follow-up Actions

i) The Government of Kenya in association with Athi Water Services Board should acquire / allocate the necessary funding for the timely implementation of the various interventions proposed under the Master Plan.

ii) Demand Management Programmes should be instituted for Nairobi and Satellite Towns to reduce UfW to acceptable levels and therefore make more water available for consumers. This should also include awareness campaigns and programmes for water conservation / rainwater harvesting, etc., in local electronic and print media.

iii) Water Resources Management Authority – WRMA and Kenya Meteorological Department in association with AWSB should regularise the monitoring of River Gauging Stations, Rainfall Stations and Climate Stations within the Source Catchment Areas and Downstream Areas. This data is essential to monitor any changes due to climate or other man-made impacts. In addition to monitoring of existing stations, WRMA should install and commission additional stations to enable more accurate monitoring of the source catchment and Downstream Areas.

    In order to determine the impact of water abstraction for Nairobi from the Northern Collector Rivers, details of all registered downstream users including permitted abstractions should be updated. The issuance of water permits for abstractions should be on annual basis or a fixed minimum period of say 3 Years. All downstream abstractions should be measured to limit over abstraction.

    Catchment and management of riparian areas should be prioritised by WRMA.

iv) All Water Services Boards / Providers should institute a programme for expansion of water distribution network including installation of individual connections especially in low income high density areas. Programmes for regular rehabilitation and replacement of all leaking water mains should be implemented as a routine on-going exercise under the Water Service Providers' recurrent expenditure for Operation & Maintenance.

v) The Wastewater Master Plan should be updated. Waterborne system should be constructed in all areas where population density is higher than 260 persons per Ha.

vi) Optimise water production from existing installations / treatment works including recycling of backwash water from filters, etc. especially during the dry periods.

vii) Athi Water Services Board should regularise ownership of all Assets especially land where key installations have been constructed. Title Deeds should be acquired.

viii) Athi Water Services Board should now acquire and demarcate all land for expansion of the proposed water supply infrastructure i.e:

- Maragua 4 Dam
- Ndarugu 1 Dam
- Various Dam for Satellite Towns
- Various Sites for Treatment Works
- Pumping Stations
- Wayleave for Trunk Mains