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JAPAN INTERNATIONAL COOPERATION AGENCY
THE MINISTRY OF LAND RECLAMATION, REGIONAL AND WATER DEVELOPMENT
THE REPUBLIC OF KENYA

THE STUDY ON THE WATER SUPPLY FOR SEVEN TOWNS IN EASTERN PROVINCE IN THE REPUBLIC OF KENYA

FINAL REPORT

VOLUME II
SUPPORTING REPORTS
APPENDIX A - I

OCTOBER 1997

NIPPON KOEI CO., LTD.
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Abbreviations

A.I.A	Appropriation in Aid
AC	Asbestos Cement (Pipe)
AFW	Accounted - for Water
AIC	Average Incremental Cost
AIDS	Acquired Immune Deficiency Syndrome
ASK	Agricultural Society of Kenya
BHN	Basic Human Needs
BPT	Break Pressure Tank
CH1	Survey Points in Chogoria
CK2	Survey Points in Chuka
CWS	Community Water Supplies
dia	diameters
DWE	District Water Engineer
DWO	District Water Office
EIA	Environmental Impact Assessment
GI	Galvanized Iron
GOK	Government of Kenya
GPS	Global Positioning System
ha	Hectares
I5	Survey Points in Isiolo
IEE	Initial Environmental Examination
ITCZ	Intertropical Convergence Zone
JICA	Japan International Cooperation Agency
km	Kilometer
Kshs	Kenya Shillings
KEWI	Kenya Water Institute
KNUT	Kenya National Union of Teachers
lcd	Litres per Capita per Day
l/sec	Litres per second
m3/day	Cubic Meters per Day
M6	Survey Points in Meru
MLRRWD	Ministry of Land Reclamation, Regional and Water Development
MOCSS	Ministry of Culture and Social Services
MOWD	Ministry of Water development

N1	Survey Points in Nkubu
NCCK	National Council of Churches of Kenya
NEAP	National Environmental Action Plan
NWCPC	National Water Conservation and Pipeline Corporation
NWMP	National Water Master Plan
O/M	Operation and Maintenance
ODA	Overseas Development Assistance
PE	Polyethylene Pipe
PH	Plan and Height Point
PIO	Project Implementation Office
PVC	Poly Vinyl Chloride
RDF	Rural Development Fund
RGS	River Gauging Station
S, T, ST, TT	Trigonometric Station Points
SIDA	Swedish International Development Agency
SOI	School of Infantry
SOK	Survey of Kenya
Sq. KM	Square Kilometers
TDS	Total Dissolved Solids
TW	Tigania Water Points
UFW	Unaccounted for Water
UNICEF	United Nations Children's Fund
US$	United States Dollar
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
VES	Vertical Electric Sounding
WAB	Water Apportionment Board
WC	Water Closet
WHO	World Health Organization
WID	Women In Development
WQPCL	Water Quality and Pollution Control Laboratory
WRAP	Water Resources Assessment Project
WTP	Water Treatment Plant

THE STUDY ON WATER SUPPLY FOR
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APPENDIX A

WATER RESOURCES

APPENDIX A WATER RESOURCES

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1. GENERAL CONDITIONS

1.1 Topography

The Study Area is located in the south-western part of the Eastern Province of Kenya. Mt. Kenya, the second highest mountain in the continent of Africa, rises to a height of 5,199 m. The Nyambene Hills with the height of 2,514 m ranges from the eastern slope of Mt. Kenya to the north-east. The slopes of these mountains contain a number of pyroclastic cones formed by the eruption of parasitic volcanoes. The volcanic plain spreads out in the surrounding lowlands. The locations of the seven towns concerned in the Study Area and the topography of the surrounding areas are shown in ***Figure A-1***.

The towns of Meru and Nkubu in Meru District and Chuka and Chogoria in Tharaka Nithi District are located on the eastern slopes of Mt. Kenya. These four towns are situated at an elevation between 1,400 and 1,600 m. Owing to relatively abundant rainfall, the eastern slopes of Mt. Kenya are deeply forested and numerous streams run in an easterly direction through the Study Area. These streams subsequently flow south-eastward before their eventual confluence with the Tana river. The terrain around the towns concerned shows a high relief comprising V-shaped deep gorges formed by streams and steep mountain ridges.

The town of Maua and the Tigania region in Nyambene District are located around the Nyambene Hills. The town of Maua and the Tigania region are located at the foot of the mountain range where the terrain changes from steep mountain to flat plain. The elevations of Maua and Tigania vary from 1,600 to 1,800 m. Water resources are more abundant along the southern slopes of the Nyambene Hills where perennial streams collect an abundant rainfall through deeply forested mountains. However, resources are more scarce along the northern slopes which adjoin the semi-arid zone to the north.

The terrain around the town of Isiolo is quite different from the other six towns. The Isiolo town is situated on the volcanic flat plain gently sloping towards the Ewaso Ngiro river in the north. The elevation around the town of Isiolo is approximately 1,100 m. This area is classified as a semi-arid zone and where surface water courses tend to be dry for much of the year.

1.2 Climate

The climate in Kenya is generally controlled by the Intertropical Convergence Zone (ITCZ) moving across the equator seasonally northward and southward, bringing two rainy and dry seasons in a year. The rainy seasons occur during middle March to May and early October to November, and called the long rains and the short rains, respectively. The seasonal change of wind direction appears in the beginning of each rainy and dry season. The north-west monsoon is dominant from January to March forming a dry season. The long rains is brought by the south-east monsoon prevailing in April. In May, the south monsoon is dominant and gives the maximum monthly rainfall in a year. The south monsoon also prevails from June to September, but brings less rainfall resulting in dry season. The monsoon changes its direction gradually through October. In November, the north-east monsoon is dominant and brings a peak monthly rainfall in the short rains. The north-east monsoon maintains its strength but brings dry and clear weather in December. The seasonal variation of monthly rainfall is given in ***Figure A-2***.

The Study Area varies from humid to semi-arid zones depending on altitude. The humid zone with an average annual rainfall of more than 1,500 mm extends from the eastern slope of the Mt. Kenya to the southern slope of the Nyambene Hills where the elevation exceeds 1,500 meters. The towns in the Study Area, except Isiolo are situated in the humid or sub-humid zones. Whereas, the volcanic plain extending northward is a semi-arid zone with an annual average rainfall ranging from 450 to 900 mm. The elevation of the volcanic plain is less than 1,200 meters and the town of Isiolo is located in this zone. The isohyetal map of the average annual rainfall is shown in ***Figure A-3***.

The meteorological summary shown in ***Figure A-4*** and ***Table A-1*** indicates a clear climatic contrast between Meru and Isiolo. Compared with Meru, rainfall is much less in Isiolo but an evaporation rate is extremely higher. The annual rainfall and evaporation are 1,259 mm and 1,439 mm in Meru, whereas 619 mm and 2,682 mm in Isiolo, respectively. The temperature varies less through a year. The annual average daily maximum and minimum temperatures are 24 °C and 13 °C in Meru, whereas 30 °C and 17 °C in Isiolo, respectively.

1.3 Regional Geology

The Study Area is located to the east of the East African Rift Valley. The surrounding region is wholly underlain by the Precambrian Basement System and mostly covered by volcanic rocks and sediments from the major eruption centers of Mt. Kenya and the Nyambene Hills, and the associated parasitic cones. The rock formations are generally classified into the following three groups. The lithostratigraphic classification is given in ***Table A-2***.

(1) Precambrian Basement Rocks

The Precambrian Basement Rocks form the oldest basement system underlying all the other rock units in this area. They are metamorphic rocks composed of gneisses, schists and quarizites. The basement rocks outcrop mainly around the southern part of Meru National Park and Tharaka, which are in the east and south of the low lying areas. Isolated outcrops are also observed on hilltops in the west of the Isiolo town.

(2) Tertiary Volcanic Rocks

The volcanic rocks were produced by eruption activities from the Miocene to the Middle Pliocene. The Mt. Kenya Volcanic Series outcrop on the higher part. From the summit south-eastward, the rocks comprise phonolite, kenyte lavas, tuffs and aggromerates. The middle eastern slope is mainly covered with basalt. The rocks in the higher part of the northern slope include trachytes tuffs and aggromerates. The Nyambene Series distributes on the Nyambene Hills and their surrounding slope, and the Northern Grazing Area extending out in the east of the Isiolo town. The rocks outcropping in the low lying volcanic plains are mainly composed of basalt. The rocks in the mountainous areas in the north-east include phonolite and tephrite around the summit, and olivine basalt.

(3) Quaternary Volcanic Rocks and Sediments

The upper basalt of Nyambene composed of the basaltic phyrocastic deposits and lavas are products of parasitic eruptions in the Pleistocene. The superficial sediments belong to the Pleistocene and Recent deposits. Alluvium deposits of silt, sand and gravel exist locally along streams. Colluvium deposits of mixtures of clay, silt and rock fragment are observed on the slope of rock hills around Isiolo. Lacustrine sediments with carcrete limestones are also found along water courses in the low lying areas.

2. SURFACE WATER RESOURCES

2.1 Hydrology

The rivers in and around the Study Area originate in the Mt. Kenya and the Nyambene Hills which run from south-west to north-east demarcating the watershed between the Ewaso Ngiro river system in the north and the Tana river system in the south. In Kenya, the major drainage areas are largely classified into five groups. The Tana and Ewaso Ngiro river systems correspond to the drainage area 4 and 5, respectively. These river systems are divided into several sub-basins as seen in ***Figure A-5***. Descriptions of the sub-basins concerned with the Study Area are presented below. The figures for drainage area, average annual flow and basin mean rainfall in the descriptions are referred to figures indicated in NWMP.

(1) Drainage Area 4FA

The Kathita river in the Tana river system originates in the upper north-eastern slopes of Mt. Kenya and runs from west to east passing through the town of Meru. In the south of this drainage area, the Thingithu river runs in the vicinity of Nkubu. These two rivers subsequently run in a south-easterly direction through the low lying plain around Tharaka, flowing finally into the Tana river. The drainage area of this sub-basin amounts to 2,181 km^2. The average annual flow amounts to 10.54 m^3/sec or 332 million m^3 which is equivalent to a runoff depth of 152 mm, while the basin mean annual rainfall is 829 mm. The annual rainfall-runoff rate becomes 0.18.

(2) Drainage Area 4FB

The major rivers such as the Thangatha, Ura and Rojewero originate in the Nyambene Hills. These rivers flow down to the low lying plain around Tharaka in the south-east and finally join with the Tana river. The total drainage area is 3,950 km^2. The basin mean annual rainfall is 650.

(3) Drainage Area 4EA

The main stream is the Mutonga river originating near the summit of Mt. Kenya. The river flows down collecting water from Mt. Kenya forest on the eastern slope together with the Irau and the Kithenu rivers. These three rivers join together further downstream before joining the Tana River. This sub-basin has a drainage area of 743 km^2 with its average annual flow of 5.73 m^3/sec or 181 million m^3. From the annual runoff depth of 243 mm and the basin mean annual rainfall of 857 mm, the annual rainfall-runoff rate is obtained at 0.28.

(4) Drainage Area 4EB

Several rivers flow in a south-easterly direction on the eastern slopes of Mt. Kenya. The North Mara river and the South Mara river originate in the upper forest near Chogoria. The Nithi river originating around the summit of Mt. Kenya drains a narrow catchment area along its water course. The Tungu and the Ruguti rivers run in parallel with the Nithi river and pass in the vicinity of Chuka. These rivers join together further downstream and then flow into the Tana river. The Thuchi river occupies the catchment area along the southern boundary of this sub-basin. The total drainage area is 1,193 km^2. The average annual flow amounts to 9.26 m^3/sec corresponding to the annual runoff depth of 245 mm. The basin mean annual rainfall is 1,048 mm. The annual rainfall-runoff rate is 0.23.

(5) Drainage Area 5DA

The rivers Engare Ondare, Western Marania and Eastern Marania originate on the northern slopes of Mt. Kenya and flow down to the Ewaso Ngiro river in the north. The Eastern Marania river is also called the Isiolo river which runs in the vicinity of Isiolo town. These rivers are perennial but their flows decrease during the dry season, because most of the drainage area is contained in the semi-arid zone. In the dry season, rain water which runs on the ground surface is rarely expected and river flow is sustained by springs located along the water course. The drainage area is 2,237 km^2 in total. The average annual flow amounts to 3.45 m^3/sec or 112 million m^3 which is equivalent to a runoff depth of 50 mm, while the basin mean annual rainfall is 794 mm. The annual rainfall-runoff rate becomes 0.06.

2.2 Surface Water Sources in the Study Area

The eastern slopes of Mt. Kenya and the southern slopes of the Nyambene Hills provide the major water sources for both surface water and groundwater. These areas have a high potential for water resources due to an abundant rainfall and to a subsoil strata suitable for infiltration and retention in the widespread forests. Many springs yield water in these areas and sustain perennial flows of rivers.

The north-west side of Mt. Kenya and the Nyambene Hills is, however, a low potential area for surface water. Seepage loss is significant due to the subsoil composed of coarse pyroclasitic deposits which exist to a shallow depth. The lower altitude area to the north, is mostly within a semi-arid to arid zone which suffers from high rates of evaporation loss.

2.3 Present Conditions of Surface Water Development

(1) Mt. Kenya Slopes (Meru-Chuka Area)

On the eastern slopes of Mt. Kenya, the quantity of surface water is abundant in combination with numerous springs. No restrictions are presently reported on water use of the rivers in the sub-basins 4FA, 4EA and 4EB pertinent to the Study Area, and a large number of water projects are currently being implemented and proposed. Further water development projects, however, should be executed on the basis of comprehensive water resources study and water management of the rivers.

(2) Nyambene Hills (Tigania, Maua Area)

There are also numerous perennial springs around the Nyambene Hills. In this area, unlike the slopes of Mt. Kenya, there are few major streams, and these are not found in the vicinity of population centers. Thus, the water supply for inhabitants is mostly dependent upon nearby springs. Spring yields are assessed to be sufficient for the current water demand but not assured for future increase of water demand. In order to successfully meet the future water demand, the combination of river water and groundwater as well as springs shall be taken into account in establishing the future water supply plan.

(3) Isiolo

There are few perennial streams in the northern side of Mt. Kenya. One of these is the Isiolo river. However, due to the absence of alternative water sources, water from the river is abstracted intensively by unregistered users as well as legally registered users. As a result, the river flow decreases drastically and almost no water reaches downstream of the Isiolo water intake in the dry season.

The Isiolo town currently experiences quite serious domestic water shortages, while surface water is extracted extensively for mainly irrigation purposes. Coordination of water use between the domestic and irrigation purposes should therefore be undertaken urgently for improving the water shortages. For this purpose, a comprehensive investigation for clarification of the actual flow rate of the Isiolo river and present water abstraction for irrigation need to be conducted.

3. GROUNDWATER RESOURCES

3.1 Hydrogeology

Recent hydrologeological studies covering the districts in the Study Area have been carried out by WRAP. Extensive investigations and analyses were elaborated in order to clarify the regional hydrogeological characteristics and groundwater resources potential. The study results and data accumulated will contribute to further water resources development in the Study Area as well as the districts. The following gives the general hydrogeological conditions by region, which were revealed by the above study.

(1) Mt. Kenya (Meru-Chuka Area)

Mt. Kenya constitutes a major hydrogeological system with the water bearing layers composed of fissured and weathered volcanic deposits in the Tertiary period. These water bearing layers form the interconnected aquifer system with groundwater flow radiating from the slopes of Mt. Kenya. It is also characterised as 'perched aquifers' showing that groundwater accumulation appears on impervious layers which are locally formed by lava flows.

The summit area is generally occupied by steep terrain with low recharging zone because of the freezing climate and the impervious layers which predominate on the ground surface. With an abundant rainfall and a high infiltration capacity of soil which cover in the Mt. Kenya Forest, the middle slope is considered as the major recharging zone. Thickness of the aquifer decreases gradually in a downstream direction and many springs rise on the lower eastern slope.

In addition, the aquifers may be situated at greater depth on the north-eastern slope. Perched aquifers are not formed in this area due to absence of impervious lava layers at shallow depth. The parasitic cones formed in the latest volcanic activity are seen in this area. These parasitic cones mainly consist of coarse pyroclastics with a high infiltration capacity. This area is therefore considered as the recharging zone for the aquifer underlying the northern volcanic plain .

(2) Nyambene Hills (Tigania-Maua Area)

The hydrogeological features of the Nyambene Hills are similar to those of Mt. Kenya. The subsoil consists of Tertiary volcanic deposits with massive lava flows. Perched aquifers are formed mainly at shallow depth. The southern slope is a spring yielding area because of an abundant rainfall and a high infiltration capacity of the ground surface. The spring water is considered as overflow of groundwater accumulated on the perched aquifers.

On the northern slopes, only a few springs are observed. The upper layers are covered by the recent coarse pyroclasitic deposits with a high infiltration capacity. The rain water may percolate to greater depth and recharge an aquifer possibly underlying the Northern Grazing Area. The existence of this aquifer can be explained by the occurrence of the springs along the Ewaso Ngiro river. The same hydrogeological features are foreseen in the low-lying plain to the north-east, suggested by the major springs along the eastern boundary between the volcanic plain and the basement area.

(3) Volcanic Plains (Isiolo Area)

The volcanic plain covers the Northern Grazing Area in the north and the Nyambene Plain in the south-east. These areas are mainly covered by basaltic rocks of the Lower Nyambene Series. The recharge from rainfall is limited because the areas generally belong to the semi-arid zone. According to geophysical surveys and exploratory drillings carried out by WRAP, the existence of productive aquifers recharged from the Nyambene Hills is expected in the volcanic plains.

(4) Basement Area

The basement area is located further south to east from the watershed. The area is composed of the metamorphic rocks of the Precambrian Basement System. The major part of this area is covered by impervious rocks. Consequently, the aquifer is formed locally by fractured or weathered deposits and alluvial deposits along the streams. Recharge from rainfall in this area is expected to be limited due to the semi-arid climate. Due to these hydrogeological conditions, the groundwater is generally shallow and its yield is low.

3.2 Groundwater Potential Zones

According to the hydrogeological evaluation by WRAP, the following high potential groundwater zones were identified. A summary of these hydrological zones is given in ***Table A-3***. Groundwater level contours and flow directions estimated by WRAP are shown in ***Figure A-6***.

(1) Volcanic Plains (Isiolo Area)

This zone covers the Northern Grazing Area and the southern and eastern foot of the Nyambene Hills. Of 75 boreholes, approximately 85% were successfully drilled with an average depth of 66 m. An average yield was reported of 10.5 m^3/hour, or 2.9 liter/sec. The average groundwater struck and rest levels were at a depth of 40 and 30 m from the ground surface. Groundwater quality in the volcanic deposits was generally good, however, saline water was identified in some boreholes in the Northern Grazing Area. Approximate transmissivity and groundwater flows have been estimated as follows.

Table A-4 Approximate Groundwater Flow Amount

Area	Transmissivity (m^2/day)	Groundwater flow (m^3/day)
Northern foot hills	1,000	542,000
Lower south-eastern slope	500	420,000
Lower southern slope	200	77,000

Source : WRAP

45 springs were identified during the inventory survey. The average yield was found to be 9.4 liter/sec.

(2) The Lower Slopes of Mt. Kenya (Meru-Chuka Area)

There are only 11 boreholes listed in this area. This low number can be explained by the abundant perennial streams and springs which have provided satisfactory water supplies to this area. On average, the depth of the boreholes was 129 m with a yield of 9.6 m^3/hour or 2.7 liter/sec. The average groundwater struck and rest levels were almost same at a depth of 53 m from the ground surface. Groundwater quality was reported to be excellent. There are 307 springs and the average yield was 7.4 liter/sec.

(3) Nyambene Hills (Tigania, Maua Area)

The prevalence of groundwater is similar to that of the above, namely, many springs and small number of boreholes listed in the high relief terrain. Out of 13 boreholes, 69% were successfully drilled with an average depth of 55 m. The groundwater struck and rest levels for the aquifer were 40 m and 30 m from the ground surface, respectively. An average yield of 5.1 m^3/hour or 1.4 liter/sec was recorded with an excellent quality. 125 springs were identified with and average yield of 11.3 liter/sec.

3.3 Borehole Yield and Water Quality

Groundwater potential is generally high in the south-east flanks of Mt. Kenya and the Nyambene Hills. However, exploitation of groundwater is not a common method to acquire water due to abundant supplies of water from the rivers and springs in these areas. Boreholes drilled around Isiolo town belong to private users and their water quality is reported to be comparatively good.

The results of the preliminary quantitative hydrogeological analysis, indicate that the potential of surface water development is limited due to climatic conditions in the area around Isiolo town. In this regard, development of groundwater sources may be a mere short-term alternative to meet the projected water demands for the near future.

A number of boreholes have been constructed by the private sector and organizations since the 1940s, according to the monitoring made by WRAP. The available borehole data around Isiolo town is shown in ***Table A-5***. The depth of these boreholes vary from 37 m to 213 m depending on the topographic configuration and the extraction. The practical yields vary from 30 to 100 m^3/hour.

The groundwater quality data for these boreholes are summarized in ***Table A-6***. From this table it can be seen that the parameters obtained in the Northern Grazing Area reveals good and satisfactory results compared to the potable water standards in Kenya. Some of the boreholes monitored, however, contain comparatively high contents of chloride, and electric conductivity is very high as a whole. This suggests that the groundwater in these areas is saline.

Consequent to the above results described, groundwater development will be possible around Isiolo town from a quantitative view point. For evaluating safe yield for the water supply for Isiolo township, more detail investigations and analysis are recommended. According to the future water demand estimation, the use of groundwater will be in the order of 1,000 m^3/day, depending on surface water availability. This amount of groundwater extraction is much larger than that at present. Such extraction should be managed based on a detail evaluation of the groundwater potential and the calculated safe development yield of boreholes.

4. EXISTING AND ONGOING DEVELOPMENT PLAN

4.1 National Water Master Plan (NWMP)

NWMP Study was carried out from 1990 to 1992. Its planning horizon was established for the year 2010 in the basic framework planning. The national action plan was subsequently provided in compliance with NWMP aimed for the target year of 2000 for implementation of regional water resources development programs providing the necessary information and guidelines for specific development plans for each district.

4.2 Water Resources Assessment Project (WRAP)

The project was carried out by the former Ministry of Water Development in cooperation with the TNO-DGV Institute of Applied Geoscience of the Netherlands. WRAP comprised water resources assessment and water development studies for a number of districts in Kenya. The water resources assessment study provides an evaluation of water resources potential on a district basis, and the results of this study contributed in formulation and preparation of guidelines and recommendations for investment packages in district water development plans. WRAP covering these studies for Meru and Isiolo was completed with the study period from 1987 to 1991.

5. INVESTIGATION FOR INTAKE SITES

5.1 Intake Site Proposed by MLRRWD

For establishment of the future water supplies in the seven towns, the following new intake sites were originally proposed by MLRRWD. Locations of the proposed sites are shown in ***Figures A-7 to A-13.*** The Study Team carried out the investigations for these site during the first field work from July to November, 1996. General topographic and hydrologic conditions at these sites were confirmed in the course of the field reconnaissance. In addition, topographic surveys, flow measurements, initial environmental examinations and water quality tests were also elaborated. Applicability for construction of intake at the proposed sites were initially evaluated on the basis of these investigations.

The followings are the brief description of each intake site proposed.

(1) Kathita Munyi River - Meru

The proposed intake site is located in Mt. Kenya Forest about 15 km west from Meru town. Approximate elevation of the site is 2,340 m. The river channel runs through the bottom of a U-shaped deep rocky gorge. The bottom width of the gorge is approximately 25 m. The sides of the gorge are nearly vertical in place. The riverbed material is mainly composed of gravel and boulders. The width of water surface was 4.5 m with a depth of 0.75 m in the dry season on 13th September, 1996 when flow measurements were conducted. The measured flow velocity and discharge were 0.52 m/sec and 1.219 m^3/sec, respectively.

(2) Kiguandegwa River - Nkubu

The Kiguandegwa river is a tributary of the Thingithu river which is the present source of the Nkubu water supply. The proposed intake site is located 4 km west of Nkubu town, at an elevation of approximately 1,660 m. Cultivated lands for coffee farming are observed along the river bank. The riverbed consists of a mixture of silt, gravel and boulder. Water flows through a narrow U-shaped channel. On 11th September, 1996, the width of water surface was 3.5 m with a depth of 0.71 m. Flow velocity and discharge were measured at 0.15 m/sec and 0.216 m^3/sec, respectively.

(3) Ruguti River - Chuka

The intake site is proposed on the Ruguti river in Mt. Kenya Forest and located 15 km north-west from the town of Chuka. Approximate elevation at the site is 1,580 m. The site is surrounded by forest. Riverbed material is mostly composed of gravel, boulders and silty soil. The water course follows the bottom of a deep V-shaped gorge. The water surface width was 6.2 m with a depth of 0.46 m. Flow measurements conducted on 19th September, 1996 indicate a flow velocity of 0.23 m/sec and discharge of 0.383 m^3/sec.

(4) Mara Manyi Stream - Chogoria

The proposed water source for Chogoria town is the Mara Manyi stream which is a tributary of the North Mara river. The proposed intake site is located 5 km to the north-west of Chogoria at an elevation of approximately 1,780 m. The location of the site is deep in the forest and is close to the origin of the river. The stream flows through the bottom of a V-shaped gorge. The river bed material is composed of a mixture of silt, gravel and boulders. Flow measurements carried out at the end of dry season on 20th September, 1996, resulted in a water surface width and depth of 3.8 m and 0.30 m, respectively. The flow velocity was found to be 0.14 m/sec with a discharge of 0.153 m^3/sec.

(5) Mboone Stream - Maua

The proposed intake site is located upstream of the existing water supply intake on the Mboone stream, approximately 1.5 km north-west of the town center. The stream collects water from upstream springs and waterfalls. The intake site is at an approximate elevation of 1,800 m, where the stream descends on a steep escarpment. Bed materials consist of a mixture of silt, gravel and boulders. According to flow measurements conducted on 16th September 1996, the width of the water surface was 1.4 m with a depth of 0.27 m. Flow velocity and discharge were 0.08 m/sec and 0.022 m^3/sec, respectively.

(6) Thangatha Stream - Tigania

The propsed intake site is located on the Thangatha stream originating from the Nyambene Forest. Location of the site is about 10 km east from Tigania, at an elevation of approximately 1,770 m. The stream flows through the foot of steep mountain slopes. The river bed material is composed of a mixture of gravel and boulders. Flow measurements carried out at one spring only on 16th September, 1996, indicate a water surface width of 1.4 m with a depth of 0.15 m. Flow velocity and discharge were 0.11 m/sec and 0.017 m^3/sec, respectively.

(7) Eastern Marania (Isiolo) River - Isiolo

Two intake sites are proposed. One is located on the Isiolo river 6 km south of the Isiolo town, at approximate elevation of 1,240 m. The surrounding area is gently sloping volcanic plain. Vegetation is poor because of the semi-arid climate. The river runs through a shallow valley formed by water flow erosion through the volcanic plain. The width of the valley is between 100 and 200 m wide while the bottom of water channel width is only about 10 m. Ground surface in the valley is covered by fine fluvial deposits underlain by volcanic deposits. Riverbed materials include silt, sand, gravel and boulders. In the dry season, the Isiolo river is only fed by upstream springs. There are however existing water extraction points between the springs and the proposed intake site. Therefore flow measurements at the proposed intake site does not represent the natural flow rate. Measurements were carried out on 12th

September, 1996, indicating a water surface width of 3.0 m with a depth of 0.29 m. Flow velocity and discharge were 0.10 m/sec and 0.061 m^3/sec, respectively.

The other proposed intake site is the Kithima springs located 10 km south of the Isiolo town at an approximate elevation of 1,340 m. Several springs originate in this area issuing water from the outcrops of weathered volcanic deposit. Water from these springs come together forming a tributary of the Isiolo river. Flow measurements were also conducted on the stream coming out from the Kithima springs. On 12th September, 1996, the measurement concluded that water surface width was 1.5 m with a depth of 0.29 m. Flow velocity and discharge were measured at 0.19 m/sec and 0.059 m^3/sec, respectively.

5.2 Alternatives

In the course of the initial evaluation, the following alternatives were identified on preliminary basis. Locations of the alternative sites / water sources are shown in ***Figures A-7 to A-13***.

(1) Kathita Munyi River - Meru

Because of difficult terrain for water conveyance from the proposed intake site, it is necessary to consider shifting the new intake site further upstream. An alternative site is identified around 2 km upstream from the proposed intake site

(2) Kiguandegwa River - Nkubu

Since almost half of the catchment area of the proposed intake site is covered by agricultural land, water pollution at the site is anticipated due to soil erosion, agricultural chemicals or fertilizer. An alternative site is therefore identified on the Kiguandegwa river further 8 km upstream in the forest.

(3) Ura River - Maua

NWMP proposed the Ura river as a source of water supply for Maua town. An intake site was proposed 4 km south from the town.

(4) Thangatha Stream - Tigania

It is found that flow rate in the vicinity downstream is much larger than the proposed site. Although flow measurements are not available, the downstream seems to be preferable for the proposed Tigania water supply.

(5) Rugusu Spring - Isiolo

The Rugusu spring is located on the Eastern Marania (Isiolo) river 10 km south from Isiolo town. Flow of the Isiolo river is sustained mainly by water from the Rugusu and the Kathima springs during the dry season.

(6) Groundwater - Isiolo

The Northern Grazing Area is identified as a groundwater potential zone. Referring to the borehole data around Isiolo town, an average yield is 10.5 m^3/hour and the successful boreholes recently drilled by WRAP gave the yields ranging from 30 to 100 m^3/hour.

The alternatives were also incorporated with the initial evaluation. As a result, the following alternatives appears to be more advantageous than the originally proposed intake sites or water sources.

(1) Kathita River Intake Site (Meru)

Concerning the Kathita river intake site originally proposed by MLRRWD, the topographic survey of the raw water pipeline revealed problems with difficult terrain for water transmission by gravity. Whereas, an alternative site with a sufficient elevation was identified upstream of the tributary confluence. From vegetation and hydrology in the upstream, it is expected that this site also provides a sufficient quantity and good quality of water. Confirmation of suitability for locating the intake in the upstream is therefore decided to be investigated.

(2) Thangatha Stream Intake Site (Tigania)

The originally proposed intake site gauged during the initial stage of this Study did not have sufficient yield for the Tigania supply area. In the course of the site reconnaissance, it was found that the Thangatha stream has a much larger flow rate about 1 km downstream of the original site after joining with some tributaries.

Taking an advantage of flow rate into account, the intake site is recommended to be shifted downstream at a sufficient elevation for raw water transmission by gravity.

(3) Groundwater Development in Isiolo

The hydrological assessment for the Isiolo river concluded that further surface water development is not expected under the current conditions. Whereas, groundwater appears to be a short term solution for the water shortage in Isiolo town according to the hydrogeological assessment. Detail groundwater investigations by exploratory drilling were therefore decided to be carried out.

The others were not expected to be most possible alternatives due to the results of the initial evaluation described below.

(1) Kiguandegwa River Intake Site (Nkubu)

Better water quality is expected, but much longer raw water pipelines will result in a significant increase of construction costs.

(2) Ura River Intake Site (Maua)

Quantity of water seems to be sufficient, but pumping will be required for water transmission to the Maua supply area.

(3) Rugusu Spring (Isiolo)

Constrains remain on water rights.

5.3 Additional Investigations for Intake Sites

In compliance with the initial evaluation of water sources, the additional investigations were carried out during the second field work from January to March, 1997. The groundwater investigations in Isiolo are described in ***Chapter*** *7*. The investigations conducted on the alternative surface water intakes for Meru and Tigania are summarized below.

(1) Field Reconnaissance Surveys

1) Kathita River Intake Site (Meru)

The alternative site is located approximately 5 km upstream of the site originally proposed. Approximate elevation of this site is 2,450 m. The river flows through the bottom of a U-shaped deep rocky gorge in the Mt. Kenya Forest. The bottom width of the gorge is about 25 m. The riverbed material is mainly composed of gravel and boulders.

Around this site, the Italian NGO group named CEFA has been implementing the Kathita-Kirua Water Project and has constructed an intake weir on the river. A small intake for two community water supplies is also found about 100 m upstream of the CEFA's intake, but these community water supplies are not in operation.

2) Thangatha Stream Intake Site (Tigania)

The alternative site is located about 1 km downstream of the site originally proposed. Approximate elevation of this site is 1,760 m which is about 40 m lower than the original site but is still sufficient for supplying water by gravity. One major tributary flows into the mainstream just upstream of this site so that a flow rate is much larger than the original site.

(2) Flow Measurements

Flow measurements were carried out during dry season in February,1997.

Table A-7 Flow Measurements

Town	Water Source	Flow Rate
Meru	Kathita River	0.906 m^3/sec
Tigania	Thangatha Stream	0.053 m^3/sec

6. HYDROLOGICAL STUDY ON WATER SOURCES

6.1 Rainfall and Runoff Analysis

(1) Runoff Record

Numbers of gauging stations have been installed on the river basins in and around the Study Area, namely, the catchment areas of the Tana and the Ewaso Ngiro river tributaries. The number of river gauging stations in each sub-basin is listed below. The figures include the number of river gauging stations both currently operating and already closed.

Table A-8 Number of River Gauging Stations

Sub-basin No.	Major Streams	Number of RGS
4EA	Mutonga, Kithenu	7
4EB	Nithi, Mara, Ruguti, Thuchi	16
4FA / 4FB	Kathita, Thingithu, Thanantu, Thangatha, Ura, Rojiwero	37
5D	Isiolo, Ngare Ndare, Ngare Nything	14

Source : NWMP

The results of flow analyses based on these gauging stations carried out by WRAP and NWMP are appropriate to this Study. The analyses provide 1) average flow, 2) daily low flow with 95 % probability 3) minimum monthly flow, and 4) minimum daily flow as given in ***Table A-9***.

(2) Basin Mean Rainfall

Basin mean annual rainfall was estimated from the annual rainfall isohyetal map shown in ***Figure A-3***. The estimation was carried out for the catchement areas of the existing and proposed intake sites as well as for the river gauging stations in the vicinity of the intake sites. Locations of the river gauging stations and the intake sites are shown in ***Figure A-14***. The estimated basin mean annual rainfall is tabulated on ***Table A-10***.

(3) Runoff Rate

The annual runoff rate for the river gauging stations most appropriate for the intake sites were calculated from basin mean annual rainfall and annual runoff. As seen from ***Table A-11***, the RGS 4EA01, 4EB04 and 4EB16 indicate higher runoff rates than normally expected in the sub-basins in which these three RGSs are located. The values for the other RGSs in the drainage areas 4FA and 4EB stand within an acceptable range. Due to the semi-arid climate in the basin, the runoff rate for the Isiolo river at RGS 5D08 was quite small. However, it should be noted that the accuracy of the runoff records of 5D08 is not high due to many gaps that exist in the records. In addition, the amount of water extraction upstream of the RGS is uncertain, and may not be negligible in comparison with the actual flow rate of the Isiolo river.

6.2 Low Flow Analysis

(1) River Intake

Intake sites located on mainstream of river with comparatively wide catchment area have been defined here as 'river intake'. Low flows at river intake sites were estimated using the data for existing gauging station in the vicinity.

For the river gauging stations (RGS) concerned with the Study Area, a hydrological study was carried out by WRAP and its results are shown in ***Table A-9***. The table indicates the average flow, the 95% daily low flow, the minimum monthly flow and the minimum daily flow. These values at the intake sites were estimated from the corresponding data at the gauging stations nearby. The values at an intake site can be approximated by the following equation. The estimated values are shown in ***Table A-12***.

$$Q_{site} = Q_{RGS} \times (A_{site}/A_{RGS}) \times (R_{site}/R_{RGS})$$

where Q_{site}, Q_{RGS} : Discharge (m^3/sec), at intake site and RGS
A_{site}, A_{RGS} : Catchment area (km^2), at intake site and RGS
R_{site}, A_{RGS} : Basin mean annual rainfall (mm), at intake site and RGS

The accuracy of the available runoff records for the RGS 5D08 is poor due to many gaps that exist in the records. In addition, there are a number of water abstraction points upstream of the RGS. The quantity of water abstraction is uncertain but it may not be negligible in comparison with the actual flow rate of the Isiolo river. According to WRAP, the 95 % daily low flow was estimated at 0.025 m^3/sec which was derived from the available records in spite of the said difficulties in estimation of the actual flow rate.

(2) Stream/Spring Intake

Proposed intake sites located close to the origin of streams have been defined here as 'stream intakes' or 'spring intakes'. Due to the small size of catchments, it is generally more difficult to accurately correlate spring flows with these from the larger RGS catchments. It is therefore used to use periodic flow measurements in order to 'calibrate' the correlations. However in this case only single measurements carried out during the September dry season of 1996 , as given below, are available. More measurements are therefore required in order to confirm the safe yields of the proposed intake sites.

Table A-13 Flow Measurements at Stream/Spring Intakes

Site	Measured Flow	Date
Chogoria	0.153 m^3/sec (13,219 m^3/day)	20 September, 1996
Tigania	0.053 m^3/sec (4,579 m^3/day)	18 February, 1997
Maua	0.022 m^3/sec (1,901 m^3/day)	16 September, 1996

There are two springs which are major water sources of the Isiolo river in the dry seaon. One is the Kithima spring which is one of the currently proposed water sources for Isiolo water supply. The other spring is the Rugusu spring on the main tributary called the Western Marania river. The streams formed by the respective springs join together before discharging into the Isiolo river. Some flow measurements have been undertaken at both springs by the Isiolo District Water Office. According to these flow measurements, the minimum flows measured at the respective springs were given as follows.

Table A-14 Measured Minimum Flows at Kithma and Rugusu Springs

Spring	Measured Minimum Flow	Date
Kithima	0.035 m^3/sec	9 July, 1992
Rugusu	0.045 m^3/sec	26 February, 1987

6.3 Flow Rates of Intake Sites

(1) Reliability

The safe yield at each intake site was estimated on the basis of the 95 % daily low flow at existing gauging stations in the vicinity correlation of catchment characteristics supported by flow measurement at the intake sites.

(2) River Maintenance Flow

Minimum maintenance flow in perennial rivers is not mentioned in the Design Manual for Water Supply in Kenya. However, it is necessary to maintain a certain amount of water for conservation of the natural river environment as recommended by NWMP. The same concept of river maintenance flow is therefore proposed for the estimation of safe yield for this Study.

NWMP recommended that the river maintenance flow is assumed to be equivalent to the minimum daily flow. NWMP applied a ratio of the minimum daily flow to the average flow which was estimated at 6.2 % on average for the representative 15 rivers in the whole country. Whereas, the ratio was obtained at 14.8 % on average based on the runoff records in the sub-basins concerned with the Study Area. It is understood that this higher ratio results from the hydrologic characteristics with abundant water resources in the eastern slope of Mt. Kenya. The value of 14.8 % was applied as a regional factor for estimating river maintenance flow in the Study Area.

(3) Safe Yield for River Intakes

The safe yield of surface water sources were obtained from the balance between the 95 % daily low flow and the river maintenance flow. The estimated safe yields are shown in ***Table A-15***.

(4) Safe Yield for Stream/Spring Intakes

Periodical flow measurements are the practical way to determine the safe yield at small streams or springs. However, flow measurements at the stream/spring intakes are not available sufficiently. For the purpose of this Study, the safe yield for stream/spring intakes was provided referring to the minimum flow obtained from the available results of flow measurements.

6.4 Preliminary Study for Isiolo Dam Alternative

(1) General

Construction of a storage dam has been expected to be a principal solution of the water shortage in Isiolo town and surrounding areas. A preliminary study for this dam alternative was therefore carried out based on the topographic survey, the available runoff records, prevailing water rights and water demand projections

(2) Reservoir Storage from Topographic Condition

The proposed dam site is located about 0.5 km upstream of the existing intake. The topographic map showing the proposed dam site and upstream is given in ***Figure A-15***. A relationship between elevation and reservoir storage was derived from this map as shown in ***Figure A-16***. An elevation of dam crest will be EL. 1,218 m approximately from the topographic constrains around the dam site. The high water level of reservoir will be EL. 1,216 m providing 2 m freeboard from the crest level. The low water level will be EL. 1,210 m approximately in consideration of possible location for construction of a raw water intake. An approximate effective storage of reservoir will be 400,000 m^3 as a storage between EL. 1,210 and EL. 1,216 m.

(3) Review of Runoff Record

The runoff records of the Isiolo river at RGS 5D08 are available for the period from 1978 to 1988. These records were reviewed using a double mass curve as given in ***Figure A-17***. A relationship between the accumulated runoff depth at RGS 5D08 and the accumulated rainfall at the rainfall station 8937003 shows that the years 1980 to 1982 show the much larger runoff depth than the other years. A graph of monthly runoff and rainfall (***Figure A-18***) also indicates that runoff during the rainy season from the late 1979 to the end of 1982 season are quite large compared with the other periods. The runoff records at RGS 5D08 for these years were therefore suspected.

Reviewing the daily gauge height records and the stage-discharge rating equations for RGS 5D08, the followings were detected concerning with the suspected runoff records.

1) From the hydrograph of the daily gauge height, the gauge height records in 1982 are found to be doubtful.

2) ***Figure A-19*** shows the stage-discharge rating equations for RGS 5D08. As seen in the Figure, it is likely that discharge is overestimated by the rating equation for the period from November 1979 to June 1982.

As a conclusion, the runoff records for the period from November 1979 to December 1982 are so doubtful that these records are excluded for estimating long term runoff discussed later. ***Figure A-20*** shows the double mass curve excluding the doubtful records. This double mass curve indicates an acceptable relationship between runoff and rainfall. Accuracy of the records for the rest of periods is therefore acceptable.

(4) Estimation of Long Term Runoff

Long term runoff at RGS 5D08 was estimated using a rainfall-runoff simulation model. The tank model which is a serial storage type model was applied. The tank model is composed of a number of containers which indicate the river basin (hereinafter the container is called a 'tank').

A tank has several holes on their sides and bottoms. Rain enters the top tank first then passes into the lower tank through holes on the bottom of the upper tank. Water also passes through holes on the sides of the respective tanks. Water moving through the bottom holes indicates infiltration, while runoff moving through the side holes of all the tanks indicates river discharge.

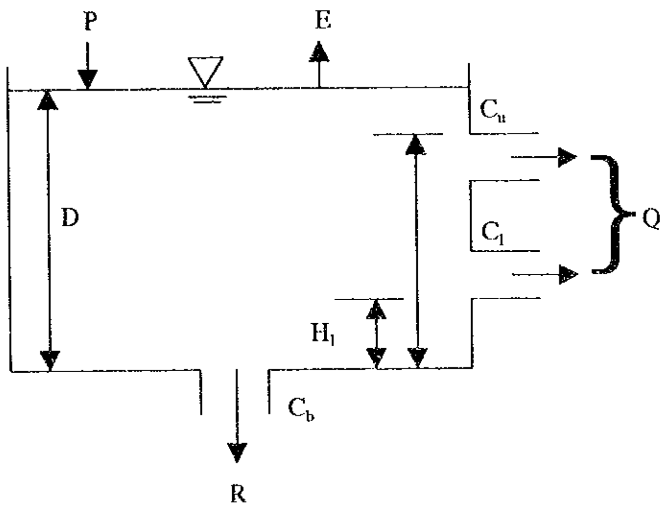

Figure A-21 Conceptual Diagram of Tank Model

Q = (D - Hu) x Cu + (D - Hl) x Cl	(D > Hu)
Q = (D - Hl) x Cl	(Hl < D < Hu)
Q = 0	(D < Hl)
R = D x Cb	

Where,		
	P	: Precipitation or infiltration from the upper tank
	Q	: Runoff
	R	: Infiltration to the lower tank
	E	: Evapotranspiration
	Cu	: Coefficient of the upper hole on the side
	Cl	: Coefficient of the lower hole on the side
	Cb	: Coefficient of the bottom hole
	Hu	: Height of the upper hole from the bottom
	Hl	: Height of the lower hole from the bottom
	D	: Depth of water (storage of tank)

Note: All variables are in mm.

Calculations are made for all tanks from the upper to the lower tanks. The sum of runoff from the side holes of all the tanks indicates river runoff. The remaining depth of each tank constitutes the initial depth for the next step, and the calculations are repeated using the same process.

To establish a tank model, precipitation and potential evapotranspiration are given as input for calculating runoff. The coefficients, such as Hu, Cu, Hl, Cl and Cb, are analyzed by comparing the computed runoff with the observed runoff. Model calibration is carried out by trial and error for adjusting the coefficients until the computed hydrograph fits in with the observed one.

The amount of water extraction upstream of RGS 5D08 may not be negligible in comparison with the actual flow rate. Although the amount of water abstraction from the Isiolo river is uncertain, a rate of water abstraction upstream of the dam site was estimated at 0.046 m^3/sec (4,017 m^3/day) referring to the existing water permit data as given in ***Table A-16***. The 'naturalized runoff' used for the simulation model was therefore considered as the sum of the recorded runoff and the estimated water abstraction. The comparison between naturalized and simulated runoff is shown in ***Figure A-22***.

Using the calibrated model, the long term runoff was simulated for the period of 20 years (1969-1988). ***Figure A-23*** shows the flow duration curve using the simulated monthly runoff. The average flow, the 95% low flow and the minimum flow for the 20 years were obtained at 0.143 m^3/sec, 0.080 m^3/sec and 0.075 m^3/sec, respectively.

(5) Development Yield and Required Storage

Required reservoir storage was analyzed based on the simulated long term runoff. The mass curve analysis was applied for estimating a required reservoir storage to maintain a constantly regulated reservoir outflow for downstream use. The analysis was carried out using several different reservoir outflow rates in order to establish a draft-storage curve indicating a relationship between reservoir outflow and required storage.

Reservoir inflow was defined to be a balance between the simulated runoff and the amount of upstream water requirements. The amount of upstream water requirements was estimated based on the following assumptions.

1) Domestic

The amount of domestic water requirements upstream of the dam site was estimated at 245 m^3/day from the existing water permit data. The domestic water requirements in 2010 was estimated at 417 m3/day, providing the same growth rate for the water demand projections in Isiolo (rural).

2) Irrigation

The amount of irrigation water requirements upstream of the dam site was estimated at 3,772 m^3/day from the existing water permit data. Alternative cases were also provided for irrigation water requirements decreasing in 75, 50 and 25%, respectively.

The assumed cases for upstream water requirements are summarized as follows.

Table A-17 Assumptions of Upstream Water Requirements

(Unit : m^3/day)

Case	Domestic	Irrigation	Total
1	417	3,772	4,189
2 (Irrigation decreasing in 75%)	417	2,829	3,246
3 (Irrigation decreasing in 50%)	417	1,886	2,303
4 (Irrigation decreasing in 25%)	417	943	1,360

When the effective reservoir storage of 400,000 m^3 is provided, possible development yield (regulated outflow) for downstream water requirements can be derived from the draft-storage curves shown in ***Figure A-24***.

Table A-18 Possible Development Yield

Case	Development Yield
1	0.065 m^3/sec (5,616 m^3/day)
2 (Irrigation decreasing in 75%)	0.076 m^3/sec (6,566 m^3/day)
3 (Irrigation decreasing in 50%)	0.087 m^3/sec (7,517 m^3/day)
4 (Irrigation decreasing in 25%)	0.098 m^3/sec (8,467 m^3/day)

(6) Water Balance

The amount of downstream water requirements were estimated based on the following assumptions.

1) Domestic

For the downstream of the dam site, the amount of domestic water requirements other than the Isiolo water supply was estimated at 179 m^3/day from the existing water permit data. The domestic water requirements in 2010 was estimated at 242 m3/day, providing the same growth rate for the water demand projections in Isiolo (rural). Whereas, the raw water demand for the Isiolo water supply in 2010 was estimated at 10,671 m^3/day. The total amount of domestic water requirements downstream of the dam site therefore becomes 10,913 m^3/day.

2) Irrigation

The amount of irrigation water requirements was estimated at 4,557 m^3/day from the existing water permit data. Alternative cases were also provided for irrigation water requirements decreasing in 75, 50 and 25%, respectively.

The assumed cases for upstream water requirements are summarized as follows.

Table A-19 Assumptions of Downstream Water Requirements

(Unit : m^3/day)

Case	Domestic	Irrigation	Total
1	10,913	4,557	15,470
2 (Irrigation decreasing in 75%)	10,913	3,418	14,331
3 (Irrigation decreasing in 50%)	10,913	2,779	13,692
4 (Irrigation decreasing in 25%)	10,913	1,139	12,052

Water balance between possible development yield and downstream water requirements is shown below.

Table A-20 Water Balance

(Unit : m^3/day)

Case	Development Yield	Downstream Water Use	Balance
1	5,616	15,470	-9,854
2 (Irrigation 25% Saved)	6,566	14,331	-7,765
3 (Irrigation 50% Saved)	7,517	13,692	-6,175
4 (Irrigation 75% Saved)	8,467	12,052	-3,585

(7) Sediment

Sediment inflow to the Isiolo dam site with a catchment area of 230 km^2 was estimated at 80,500 m^3/year referring to the regional denudation rate of 350 m^3/km^2/year as given by NWMP. When the low water level is set at EL. 1,210 m, the corresponding dead storage of reservoir is 135,000 m^3 only which is less than the amount of sediment inflow for two years. Such dead storage is so small that measures for preventing from sediment inflow in combination with removal of sediment deposit in reservoir should be necessary. The following measures should therefore be taken into account for the dam construction.

1) Installation of sediment flushing gate
2) Construction of check dam(s) in upstream
3) Introduction of dredging facilities

7. GROUNDWATER INVESTIGATION IN ISIOLO

7.1 Preliminary Groundwater Assessment

The results of the preliminary quantitative hydrological analysis, indicate that the potential of surface water development is limited due to climatic conditions in the area around the Isiolo town. In this regard, development of groundwater sources may be a mere short-term alternative to meet the projected water demands for the near future.

A number of boreholes have been constructed by the private sector and organizations since the 1940s, according to the monitoring made by WRAP. The available borehole data around Isiolo town is shown in ***Table A-21***. The depth of these boreholes vary from 37 m to 213 m depending on the topographic configuration and the extraction. The practical yields vary from 10 to 30 m^3/hour.

The groundwater quality data for these boreholes are summarized in ***Table A-22***. From this table it can be seen that the parameters obtained in the Northern Grazing Area reveals good and satisfactory results compared to the potable water standards in Kenya. Some of the boreholes monitored, however, contain comparatively high contents of chloride, and electric conductivity is very high as a whole. This suggests that the groundwater in these areas is saline.

Consequent to the above results described, groundwater development will be possible around Isiolo town from a quantitative view point. For evaluating safe yield for the water supply for Isiolo township, more detail investigations and analysis are recommended. According to the future water demand estimation, the use of groundwater will be in the order of 1,000 m^3/day or more, depending on surface water availability. This amount of groundwater extraction is much larger than that at present. Such extraction should be managed based on a detail evaluation of the groundwater potential and the calculated safe development yield of boreholes.

7.2 Geophysical Prospecting

The location for electric inspecting was selected in the southern area of Isiolo town, since water quality of the immediate vicinity and the northern area, where the alluvial plain prevails, are mainly saline water. VES points are mainly established along the existing roads due to ease of accessibility. The location of VES points are shown in ***Figure A - 25***. According to the analysis of the p-a curves obtained from the surveys, the under ground strata on each VES point was identified to constitute three to four layers. The apparent resistivity on the VES points is tabulated for each profile line as given in the ***Table A-23.*** The third layer is interpreted as an aquifer extending over the fourth layer which is identified as an impermeable layer. This aquifer tends to decrease its thickness towards Isiolo.

Table A-23 Apparent Resistivity on the Profile Line

Profile Line	Apparent Resistivity $(\Omega - m)$			
	1st Layer	2nd Layer	3rd layer	4th Layer
No. 1 - No. 22	4 ~ 460	162 ~1360	90 ~ 390	11 ~ 83
No. 24 - No. 13	3 ~ 690	200 ~ 1380	100 ~ 630	18 ~ 190
No. 25- No. 20	4 ~ 310	75 ~ 900	54 ~ 300	30 ~ 190

7.3 Exploratory Drilling and Pumping Test

Exploratory drilling sites were selected in area as shown in ***Figure A-26***. The detail of the drilling works is as shown in ***Table A-24.***

Table A-24 List of Test Wells

Well No.	Unit	TW1	TW2	TE3
Location		Ruisi Meru	Ruisi Meru	Ruisi Meru
Elevation	m	1254.74	1280.00	1262.51
Well Completed Date		7-Mar-93	16-Mar-97	23-Mar-97
Drilling Rig		Drill TECH	Drill TECH	Drill TECH
Diameter	mm	155	155	155
Depth	m	109.70	96.00 (122.00)	83.00 (120.00)
Screen Position	m	67.00 – 79.00 85.00 – 109.00	82.00 – 94.00 (100.00) – (118.00)	30.00 – 36.00 42.00 – 54.00 60.00 – 78.00
Screen Length	m	12.00 24.00	12.00 18.00	6.00 12.00 18.00
Static Length	m	24.71	0.90	2.53
Pumping Water Level	m	38.17	13.33	6.25
Pumping Test Yield	l/sec	5.28	4.90	5.38

Three types of tests were involved in a pumping test: 1) the step drawdown test, 2) the time drawdown test, and 3) recovery test. The results are summarized in ***Table A-25***.

8. WATER QUALITY

8.1 Surface Water Quality

Water quality standards for drinking water in Kenya follow those established by the World Health Organization (WHO). The Design Manual for Water Supplies in Kenya stipulates of bacteriorological and chemical water quality requirements. Water quality analysis is performed by the Water Quality and Pollution Control Laboratory. Chemical quality testing is performed on approximately 27 constituents, in addition to bacteriological examination.

A water quality survey for the proposed water resources was conducted during September 1996 and March 1997. Twenty seven (27) chemical quality parameters and two bacteriological quality parameters were assessed. The water quality results are attached in ***Table A-26***, and selected parameters are summarized below. Although high coliform counts were recorded in Nkubu, and Isiolo, the raw water quality results at the intake sites show suitability for the purpose of water supply.

Table A-27 Water Quality Summary at Intake Site

Parameters	Meru	Nkubu	Isiolo	Chuka	Chogoria	Maua	Tigania
Turbidity (FTU)	0.3	1.4	1.3	1.2	0.5	0.6	0.2
BOD (mg/l)	2	5	3	2	10	6	2
Coliform (/100ml)	60	300	50	20	10	25	270

8.2 Groundwater Quality

Water quality was analyzed for TW1, TW2 and sample close to TW3 well. These results are similar with the existing water quality data and they contain high rate of Total Dissolved Solids (TDS). Water treatment plant is necessary to apply for the groundwater as a water resource.

9. SELECTION OF WATER SOURCES

9.1 Evaluation of Water Sources

Selection of water sources were carried out to formulate the water supply master plans for the respective seven towns. Water sources were evaluated based on the following engineering viewpoints.

1) Quantity of water is sufficiently reliable for satisfying raw water requirements.

2) Water transmission by gravity is applicable in principle.

3) Work quantities of construction are appropriate in view of cost effectiveness.

4) Water quality is acceptable for the purpose of water supply.

Main points of the evaluation of water sources are described below.

(1) Meru

As discussed above, problems with difficult terrain for water transmission by gravity were detected on the Kathita river intake site proposed by MLRRWD. Relocation of the intake site was therefore taken into account. At the alternative site located 5 km upstream of the originally proposed site, the safe yield was estimated at 0.409 m^3/sec (35,300 m^3/day). Whereas, the raw water requirements for Meru town in 2010 are estimated at 22,000 m^3/day. In addition, there are the other three projects having their water permits on the Kathita river in the vicinity of the alternative site. Water requirements for Meru town, the CEFA's project and the two community water supplies are given below. The safe yield is still sufficient for the total water requirements for all the projects concerned.

Table A-28 Water Requirements for Projects Concerned

Scheme	Water Permit Authorization No.	Water Requirements
Meru Town	-	22,000 m^3/day
Kathita-Kirua Water Project (CEFA)	P26616	4,109 m^3/day
Kiamigo Water Project (Community Water Supply)	P25596	472 m^3/day
Kimuri Water Project (Community Water Supply)	P24999	63 m^3/day
Total		26,644 m^3/day

(2) Nkubu

The intake site proposed by MLRRWD on the Kiguandegwa river has ample capacity to supply water for Nkubu town in 2010. The safe yield is estimated at 0.163 m^3/sec (14,100 m^3/day), whereas the estimated raw water requirements are 2,200 m^3/day.

(3) Chuka

The intake site proposed by MLRRWD on the Ruguti river has ample capacity to provide the raw water for Chuka town in 2010. The safe yield is estimated at 0.149 m^3/sec (12,800 m^3/day), whereas the estimated raw water requirements are 4,400 m^3/day.

(4) Chogoria

The intake site proposed by MLRRWD on the Mara Manyi river which is a tributary of the North Mara river. Flow measurements carried out at the end of dry season in 1996 resulted in 0.153 m^3/sec (13,200 m^3/sec). Whereas the raw water requirements for Chogoria town in 2010 are estimated at 3,300 m^3/day. The raw water requirements represent about 25 % of the measured yield during the dry season, which should therefore prove adequate.

(5) Maua

The intake site is proposed on the Mboone stream by MLRRWD. The yield of the site, however, measured during the dry season of 1996 came to only 0.022 m^3/sec (1,900 m^3/day), which is below the requirements of the originally identified supply area

There are no other sources of comparable size in the area except the Ura river to the south of Maua, pumping will be required for water transmission to the supply area. It is therefore suggested that northern areas including the town center will be supplied from the Mboone stream and southern areas will be supplied from the Ura river.

(6) Tigania

As discussed above, flow measurements conducted during the dry season in 1996 revealed that flow rate at the intake site proposed by MLRRWD on the Thangatha stream was not sufficient for the Tigania supply area. Relocation of the intake site was therefore taken into account. At the alternative site located about 1 km downstream of the originally proposed site, flow measurements carried out during the dry season in February 1997 resulted in 0.053 m^3/sec (4,500 m^3/day). The measured flow rate is still critical to satisfy the estimated raw water requirements of 4,400 m^3/day.

(7) Isiolo

Taking the limited water resources in Isiolo into account, the following alternative water development plans were provided for the purpose of the water supply master plan for Isiolo town. The evaluations of the respective alternative plans were summarized below.

1) Dam Construction on the Isiolo River

As a conclusion of the preliminary study, it was concluded that the construction of a storage dam is not affordable for water development of the Isiolo river due to the following reasons.

a) An effective storage capacity at the proposed site is not sufficient for flow regulation. In general, a storage capacity required for regulating seasonal fluctuation of river flow shall be more than 30 % of average annual flow amount. In compliance with this condition, a required effective storage is at least 1,350,000 m^3 resulting from the estimated average annual flow amount of 4,500,000 m^3 at the dam site. Whereas, the computed effective storage capacity is only 400,000 m^3 which is derived from the topographic configuration at the dam site.

b) Providing the effective storage of 400,000 m3, a dead storage is about 135,000 m3. Such dead storage is too small to overcome the sediment yield estimated at 80,500 m3/year (equivalent to 0.35 mm/km2/year). Sedimentation in the reservoir should therefore be minimized in order to secure the effective storage. For this purpose, countermeasures such as provision of sediment flushing gates, dredging facilities and upstream check dams will be inevitably necessary. However, provision of these countermeasures will not be realistic due to various technical constraints and financial cost overrun.

c) The Isiolo river is a limited surface water source for Isiolo town and the surrounding area. Water development by dam construction should therefore be beneficial not only for Isiolo water supply but also other users. However, the water balance study revealed that the estimated flow rate to be developed by the storage dam will not be sufficient to meet water requirements in the downstream of the dam site.

2) Springs on the Isiolo River

There are two springs along the Isiolo river, from which water is flowing into the Isiolo river. These are the Kithma and the Rugsu springs which are major water sources of the Isiolo river in the dry season. Water development of these springs is expected to be a possible alternative for supplying water to Isiolo town.

An advantage of this alternative is that the present loss of water between the springs and the existing intake is minimized by direct introduction of water from the sources. As far as the measured minimum flow rates, an order of 6,800 m^3/day of water in total may be utilized from these springs. However, this alternative should be realized under a trade-off with the existing water rights mainly consisting of irrigation in the downstream of the springs. This alternative is not recommendable without coordinating water use between the Isiolo water supply and the other water rights in the downstream of the sprigs under a more strengthened water management for the Isiolo river.

9.2 Conclusions

As a result of the evaluations above, the resultant raw water requirements and the safe yields for the selected water sources for the different schemes are given below:

Table A-29 Source Requirements and Flow Rates

Scheme	Raw Water Requirement (m^3/day)	Selected Source	Flow Rate applied as Safe Yield (m^3/day)
Meru	22,000	Kathita River	35,300
Nkubu	2,200	Kiguandegwa River	14,100
Chuka	4,400	Ruguti River	12,900
Chogoria	3,300	Mara Manyi Stream	13,200
Maua	1,650 [1]	Mboone Stream	1,900
Tigania	4,400	Thangatha Stream	4,500
Isiolo	8,800	Groundwater	-

Note : Northern supply area only.

TABLES

Table A-1 Meteorological Records

Rainfall (mm)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1930-1986	35	37	84	122	33	5	5	5	7	64	148	76	619
8937065	Meru Meteorological Station	1555	1975-1980	80	39	126	282	86	5	10	8	16	140	328	139	1259

Daily Maximum Temperature (degree)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1941-1962	30.8	32.3	31.7	30.1	29.9	29.5	28.9	29.4	30.8	30.9	28.6	29.0	30.2
8937065	Meru Meteorological Station	1555	1975-1980	23.4	24.7	25.7	24.1	22.8	22.1	21.5	22.1	24.4	25.1	22.8	22.7	23.5

Daily Minimum Temperature (degree)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1941-1962	15.7	16.3	17.6	17.8	17.8	16.9	16.3	16.5	16.9	17.6	16.6	15.5	16.8
8937065	Meru Meteorological Station	1555	1975-1980	11.4	11.9	13.0	14.3	13.7	12.0	11.9	12.0	12.3	13.5	13.1	12.0	12.6

Evaporation (mm)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1946-1988	200	210	218	181	216	245	261	286	277	249	165	173	2682
8937065	Meru Meteorological Station	1555	1976-1989	119	124	144	116	114	98	101	119	137	154	109	105	1439

Daily Maximum Relative Humidity (%)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1941-1962	57	54	59	66	65	61	64	61	60	61	67	66	62
8937065	Meru Meteorological Station	1555	1975-1980	79	78	78	81	83	81	84	83	78	79	83	81	81

Daily Minimum Relative Humidity (%)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1941-1962	39	35	40	48	47	44	44	42	38	40	52	52	43
8937065	Meru Meteorological Station	1555	1975-1980	67	50	55	67	71	63	56	49	49	49	71	73	60

Daily Sunshine Hours (hours)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1941-1962	-	-	-	-	-	-	-	-	-	-	-	-	-
8937065	Meru Meteorological Station	1555	1975-1980	8.1	8.6	8.3	7.5	8.1	7.5	6.1	6.5	7.7	7.9	6.4	7.0	7.5

Daily Wind Run (km)

No.	Name of Station	Elevation (m)	Period	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
8937003	Isiolo District Office	1104	1941-1962	-	-	-	-	-	-	-	-	-	-	-	-	-
8937065	Meru Meteorological Station	1555	1975-1980	66.8	67.7	63.5	53.6	62.9	58.1	62.1	75.2	82.7	75.3	50.9	50.8	64.1

Table A-2 Summary of Lithostratigraphy

Mount Kenya

Period	Epoch	Formation			Lithology	Maximum Thickness (meters)
Quaternary	Recent	Superficial Deposit			Loam, Silt, Clay, Laterites, Gravel, Ashes, Moraines	
		Mont Kenya Volcanic Series	Upper :	Parasitic Vents	Basaltic Pumice, Scoriaceous Lavas	200 - 300
	Pleistocene		Middle :	Parasitic Fissure Eruptions	Trachytes, Olivine Basalts, Mugurites, Olivine Trachytes	> 500
			Lower :	Main Eruptive Episode	Nepheline Syenite of the Plug	
					Kenytes, Phonolites	600
Tertiary	Pliocene				Phonolites and Trachytes	> 500
					Unexposed Volcanics	3000
		(End-Tertiary Peneplain)				
Pre-Cambrian		Basement System			Pelitic to Semi-Pelitic Gneisses, Granitoid Gneisses, Pegmatites, Schists	
					Mt. Kenya Charnokitic Rock (Dioritic) interbedded with Semi-Pelitic Gnesses	
		Intrusives			Gabbros, Olivie Doierites, Perknites	

Nyambene Hills

Period	Epoch	Formation		Lithology	Maximum Thickness (meters)
Quaternary	Recent	Superficial Deposit		Loam, Silt, Clay, Laterites, Gravel, Ashes, Calcretes	
		Nyambene Volcanic Series	Parasitic Vents	Basaltic Pumice, Scoriaceous Lavas	60 - 100
	Pleistocene		Upper :	Basalts, Phonolites, Tephrites, Scoriaceous Lavas, Tuffs	1070
			Lower :	Porphiric Olivine Basalts	30 - 300
			Lakebeds	Friable Limestone	
		(End-Tertiary Peneplain)			
Pre-Cambrian		Basement System		Pelitic to Semi-Pelitic Gneisses, Granitoid Gneisses, Pegmatites, Schists	
		Intrusives		Perknites	

Source : WRAP

Table A-3 Summary of Hydrogeological Zones

Zone		Area (km2)	Lithology	Aquifers	Springs No.	Springs Average Yield (L/sec)	Boreholes No.	Rate Successful	Depth Average	Depth Range	Struck Level Average	Struck Level Range	Rest Level Average	Rest Level Range	Yield Average (m3/hr)	Yield Max. (m3/hr)	Water Quality	Groundwater Potential
									(meters below ground surface)									
Mount Kenya	Upper and Middle Slopes	1,246	Phonolites, Trachytes, Kenyte Lavas, Agglomerates	Regional : Cinder Layers Old Land Surfaces	(Many)	(high)	(No Boreholes)		-	-	-	-	-	-	-	-	Very Good	(Inaccessible)
Mount Kenya	Widnward Lower Slopes	987	Phonolites, Kenyte Lavas, Tuffs, Agglomerates	Regional : Cinder Layers Old Land Surfaces	307	7.4	11	100%	129	21 - 201	53	12 - 170	53	8.5 - 150	9.6	70	Very Good	High
Mount Kenya	Leeward Lower Slopes	651	Trachytes, Tuffs, Agglomerates	Regional : Cinder Layers Old Land Surfaces	24	5.6	12	82%	93	50 - 157	76	34 - 157	60	16 - 151	4.6	13.7	Very Good	Medium
Mount Kenya	Deep Aquifer Zone	200	Coarse Pyroclasts	Very Good Extensive Aquifers at Greater Depth	6	0.19	4	25%	190	136 - 239	62	-	-	-	0.13	-	Probably Good (No Data)	Uncertain
Mount Kenya	Compact Tuff Area	137	Compact Tuffs	Very Poor	0	0	(No Boreholes)		-	-	-	-	-	-	-	-	(No Data)	Low
Nyambene Hills		457	Phonolites Tephrites	Regional : Cinder Layers Old Land Surfaces	125	11.3	13	69%	55	18 - 120	40	4.5 - 116	30	1.6 - 101	5.1	10.3	Probably Good (No Date)	High
Nyambene Deep Aquifer Zone		394	Coarse Pyroclasts, Basaltic Lavas, Phonolites, Tuffs	Very Good Extensive Aquifers at Greater Depth	2	5	13	15%	78	49 - 104	45	28 - 76	61	39 - 84	2.7	-	Very Good	High
Volcanic Plains		2,565	Basalts, Pyroclasts	Regional : Cinder Layers Old Land Surfaces	45	9.4	75	65%	66	11 - 213	40	5 - 115	30	0 - 100	10.5	100	Good	Uncertain
Basement Area		2,546	Metamorphic Rocks, Alluvium, Colluvium	Local : Weathered Zones, Faults, Fractures, Alluvium	0	0	33	55%	29.1	9 - 57	13.8	2 - 40	6.1	1.5 - 24	3.1	10	Poor to Fair	Low

Source : WRAP

Table A-5 Borehole Data around Isiolo Town

Borehole No	Location	Coordinates X	Coordinates Y	Ground Elevation (m)	Total Depth (m)	Completion Date	Water Struck Level Depth (m)	Water Struck Level Elevation (m)	Water Rest Level Depth (m)	Water Rest Level Elevation (m)	Yield (m3/hour)
C2114	Isiolo				136.8	08/12/53	54.8		64.0		0.60
C2212	Isiolo				97.5	07/06/54	47.2		36.0		10.90
C2502	Isiolo				213.4	30/04/56	65.5		52.0		18.20
C3129	Mlango				83.8	08/07/61	68.0		62.5		5.18
C6877	(no data)										
C7344	(no data)										
C7406	(no data)										
C7409	Maliala	0 23' 16" N	37 47' 20" E	1143.0	127.0	11/07/87	112.0	1031.0	79.0	1064.0	8.00
C7631	(no data)										
C7734	(no data)										
C7924	Isiolo Air Strip	0 20' 18" N	37 35' 49" E	1040.0	184.0	31/07/89	112.0	928.0	18.0	1022.0	
C7925	Ngare Mara River	0 23' 35" N	37 40 '06" E	1025.0	48.0	26/10/89	28.0	997.0	19.0	1006.0	25.00
C7926	Near Bule Shime Rive	0 25' 57" N	37 45' 55" E	1057.0	138.0	25/08/89	52.0	1005.0	41.0	1016.0	100.00
C7927	Near 78 Barracks	0 21 '42" N	37 36' 39" E	1080.0	78.0	25/09/89	22.0	1058.0	15.0	1065.0	30.00
C7969	(no data)										
C87	Isiolo				64.0	10/02/40	26.2		13.4		4.60
C8976	Ngare Mara Village	0 29' 34" N	37 38' 20" E	950.0	45.7	10/01/90	31.0	919.0	21.0	929.0	30.00
C90	Isiolo				54.8	08/04/40	37.5		29.0		4.80
C9385	(no data)										
C97	Isiolo				36.6	25/04/40	24.4		14.6		14.00
C98	Isiolo				62.0	01/06/40	30.5		24.4		15.90
SA6	Isiolo	0 20' 15" N	37 48' 15" E	1082.0	39.3	29/09/40	28.0	1054.0	12.2	1069.8	4.53

Source : WRAP

Table A-6 Chemical Data for Boreholes around Isiolo Town

Borehole Nc	Date	pH	EC	Fe	Mn	Ca	Mg	Na	K	Total Hardness	Total Alkatinity	Cl	F	HCO3	NO2	SO4	Free CO2	TDS
			(microS/cm	(mg/l)														
C7344	30/09/88	7.8	1560	< 0.1	< 0.1	9.6	122	91	12	524	-	44	0.6	186	-	7	-	936
C7409	16/06/88	7.3	910	2.6	< 0.1	27	20	92	25	148	360	21	1.5	438.8	< 0.01	30	22	546
C7631	05/01/88	8.6	1100	0.8	0.15	86	53	137	11.5	440	-	26	-	652	-	6	-	800
C7924	28/07/89	7.4	7278	0.2	< 0.1	-	-	1323	82	468	442	176	0.1	538.8	< 0.01	288	460	4367
C7926	30/08/89	7.6	855	< 0.1	< 0.1	25	80	116	27	392	352	22	1.2	429.1	< 0.01	11	22	513
C7927	07/11/89	7.1	1696	0.7	< 0.1	90	81	168	13	558	860	22	0.4	1048	< 0.01	17	398	1017
C8976	19/01/90	7.1	1700	< 0.1	< 0.1	205	33	126	15	650	-	38	0.8	834	-	15	-	650
C90		6.9	-	0.3	-	-	-	-	-	100	-	1.2	0.3	453	-	-	-	585
C10557	27/11/96	6.9	1660	0.1	< 0.1	62	90	125	13	526	698	47	0.2	-	< 0.01	37	232	1225
C11340	15/05/96	6.8	1500	< 0.1	< 0.1	80	87	125	13	560	800	61	0.8	-	< 0.01	27	100	1370

Source : WRAP, NWMP, Isiolo District Water Office

Table A-9 Summary of Runoff Data at Existing River Gauging Stations

Sub-basin	No. of RGS	River	Period Recorded (year)	Catchment Area (km2)	Mean Monthly Flow (m3/sec)	95 % Daily Flow (m3/sec)	Minimum Monthly Flow (m3/sec)	Minimum Daily Flow (m3/sec)
4EA	4EA01	Mutonga	1953-1988	124	5.22	1.72	1.55	1.26
	4EA03	Kithenu	1952-1969 1975-1989	44	1.98	0.58	0.41	0.26
	4EA06	Mutonga	1964-1988	613	11.73	3.20	2.49	1.39
4EB	4EB01	Nithi	1953-1988	120	3.17	0.94	0.80	0.52
	4EB02	South Mara	1953-1962 1966-1971	83	2.49	0.58	0.41	0.12
	4EB03	North Mara	1952-1969	44	1.73	0.34	0.23	0.17
	4EB04	Thuchi	1956-1988	111	4.34	0.68	0.45	0.44
	4EB06A	Ruguti	1962-1988	368	4.84	0.79	0.52	0.26
	4EB07	Thuchi	1960-1988	495	5.13	0.76	0.51	0.35
	4EB09	Tungu	1959-1988	80	1.61	0.15	0.04	0.03
	4EB11	Mara	1967-1988	534	10.41	2.51	2.33	1.85
	4EB12	South Mara	1981-1988	84	2.30	0.63	0.43	0.38
	4EB16	North Mara	1985-1989	44	1.98	0.42	0.41	0.28
4FA	4F03	Kathita	1952-1961	246	2.45	1.25	1.09	1.04
	4F04	Thingithu	1953-1988	91	2.32	0.96	0.89	0.79
	4F05	Mariara	1956-1974 1980-1988	42	1.44	0.56	0.38	0.36
	4F10	Kathita	1960-1987	878	13.43	2.63	1.78	1.28
	4F17	Thingithu	1965-1987	303	4.16	0.57	0.55	0.14
4FB	4F08	Thangatha	1958-1988	210	5.07	0.33	0.32	0.06
	4F09	Ura	1958-1988	198	5.36	0.48	0.45	0.07
5DA	5D08	Isiolo	1976-1988	230	0.18	0.025	0.014	-

Source : WRAP, NWMP

Table A-10 Basin Mean Annual Rainfall

Basin Mean Rainfall for Gauging Station

No. of RGS	River	Catchment Area (km2)	Basin Mean Annual Rainfall (mm)
4EA01	Mutonga	124	1,240
4EB01	Nithi	120	1,120
4EB02	Sounth Mara	83	1,540
4EB03	North Mara	44	1,670
4EB04	Thuci	111	1,340
4EB09	Tungu	45	1,640
4EB12	Sounth Mara	44	1,670
4EB16	North Mara	84	1,540
4F03	Kathita	246	1,120
4F04	Thingithu	91	1,620
4F09	Ura	198	1,900
5D08	Isiolo	230	750

Basin Mean Rainfall for River Intake Site

Intake Site	River	Catchment Area (km2)	Basin Mean Annual Rainfall (mm)
Meru (existing)	Kathita	192	1,070
Meru (proposed by MLRRWD)	Kathita	167	930
Meru (alternative)	Kathita	149	1,000
Nkubu (existing)	Thingithu	91	1,620
Nkubu (proposed by MLRRWD)	Kiguadegwa	22	1,770
Nkubu (alternative)	Kiguadegwa	10	1,500
Chuka (existing, Karingani W/S)	Tungu	25	1,550
Chuka (proposed by MLRRWD)	Ruguti	35	1,220
Chogoria (existing, Mwimbi W/S)	Mutonga	96	1,070
Maua (alternative)	Ura	31	2,300
Isiolo (existing/proposed by MLRRWD)	Isiolo	230	750

Table A-11 Annual Rainfall-Runoff Rate

No. of RGS	River	Catchment Area (km2)	Basin Mean Annual Rainfall (mm)	Mean Annual Runoff		Runoff Rate
				(m3/sec)	(mm)	
4EA01	Mutonga	124	1,240	5.22	1328	1.07
4EB01	Nithi	120	1,120	3.17	833	0.74
4EB02	Sounth Mara	83	1,540	2.49	946	0.61
4EB03	North Mara	44	1,670	1.73	1240	0.74
4EB04	Thuci	111	1,340	4.34	1233	0.92
4EB09	Tungu	45	1,640	1.61	1128	0.69
4EB12	Sounth Mara	84	1,670	2.30	863	0.52
4EB16	North Mara	44	1,540	1.98	1419	0.92
4F03	Kathita	246	1,120	2.45	314	0.28
4F04	Thingithu	91	1,620	2.32	804	0.50
4F09	Ura	198	1,900	5.36	854	0.45
5D08	Isiolo	230	750	0.18	25	0.03

Table A-12 Estimated Low Flow at River Intake Sites

Intake Site	Catchment Area (km2)	Average Flow (m3/sec)	95% Daily Flow (m3/sec)	Minimum Monthly Flow (m3/sec)	Minimum Daily Flow (m3/sec)
Meru (existing)	192	1.827	0.932	0.813	0.775
Nkubu (existing)	91	2.320	0.960	0.890	0.790
Chuka (existing)	25	0.914	0.271	0.231	0.150
Chogoria (existing)	96	2.423	0.718	0.611	0.397
Meru (proposed by MLRRWD)	167	1.381	0.705	0.614	0.586
Meru (alternative)	127	1.129	0.576	0.502	0.479
Nkubu (proposed by MLRRWD)	22	0.613	0.254	0.235	0.209
Nkubu (alternative)	10	0.236	0.098	0.091	0.080
Chuka (proposed by MLRRWD)	35	1.007	0.299	0.254	0.165
Maua (alternative)	31	1.016	0.091	0.085	0.01[illegible]

Table A-15 Water Sources

Unit : m3/day

Town	Water Sources	Flow rate given by DWO	Estimated 95% daily low flow	Flow rate measured	Flow rate applied as safe yield 1)	Remarks
1 Meru	(1) Kathita River (existing)	97,600	80,520		57,100	
	(2) Gatabora Spring (existing)	1,500			1,500	
	(3) Kathita River (proposed by MLRRWD)		60,900	(105,300)	43,200	
	(4) Kathita River (alternative)		49,700	(78,200)	35,300	Selected
2 Nkubu	(1) Thinghthu River (existing)		82,900		53,200	
	(2) Kiguandegwa River (proposed by MLRRWD)		21,900	(18,600)	14,100	Selected
	(3) Kiguandegwa River (alternative)		8,400		5,400	
3 Chuka	(1) Tungu River (existing)		23,400		11,700	
	(2) Ruguti River (proposed by MLRRWD)		25,800		12,900	Selected
4 Chogoria	(1) Mutonga River (existing)		62,000		31,000	
	(2) Mara Manyi Stream (proposed by MLRRWD)			(13,200)	(13,200) 2)	Selected
5 Maua	(1) Mboone Stream (existing)	2,700			2,700	
	(2) Mboone Stream (proposed by MLRRWD)			(1,900)	(1,900) 2)	Selected
	(3) Ura River (alternative)		7,800		6,700	
6 Tigania	(1) Mikrowe Spring (existing)	2,100			2,100	
	(2) Michi Mikuru Spring (existing)	1,800			1,800	
	(3) Thangatha Stream (proposed by MLRRWD)			(1,400)	(1,400) 2)	
	(4) Thangatha Stream (alternative)			(4,500)	(4,500) 2)	Selected
7 Isiolo	(1) Isiolo River (existing)	2,800	2,000	4,500	2,000	
	(2) Isolo River (proposed Dam by MLRRWD)			4,500	5,500 3)	
	(3) Kithima Spring (proposed by MLRRWD)			3,000	3,000	
	(4) Rugusu Spring (alternative)			3,800	3,800	
	(5) Groundwater (alternative)				8,800	Selected

Note : 1) River maintenance flow is taken into account for intakes on major rivers.
2) ( ) denotes flow measurements only available during the dry seasons in 1996 and 1997.
3) Requirements for downstream water rights can not be satisfied.

Table A-16 Isiolo River Water Permits

Dam Site Upstream

(Unit : m3/day)

No.	River	Name	Domestic	Irrigation	Total
18037	Isiolo	Child Welfare Society (Isiolo Branch)		36.30	36.30
18707	Isiolo	Nkando Water Association		363.40	363.40
25597	Isiolo	Samuel Mugaa M'maita	1.25		1.25
26696	Isiolo	Jeremiah Mungania Ayub	2.45		2.45
21494	Isiolo	Simon M. Murungi	2.38		2.38
13700	Isiolo	Diocese of Meru (Isiolo Catholic Misson)	4.90	99.00	103.90
16845	Isiolo	Commissioner of Prison (G. K. Prison Isiolo)		243.00	243.00
18718	Isiolo	Islamic Foundation		22.50	22.50
21537	Isiolo	Mutunyi Water Association	37.35	2072.60	2109.95
26513	Isiolo	Kambogo Water Association	8.70		8.70
14161	Eastern Marania	Maturu Water Association	9.36	27.00	36.36
25493	Kithima Spring	Gideon Kaburuki Kirera	13.36		13.36
15704	Kithima Spring	Erastus Phares Rutere	77.45	908.70	986.15
24449	Kithima Spring	Justus Murerwa	87.55		87.55
		Total	244.75	3772.50	4017.25

Dam Site Downstream

(Unit : m3/day)

No.	River	Name	Domestic	Irrigation	Total
21537	Isiolo	Mutunyi Water Association	37.35	2072.64	2109.99
17838	Isiolo	Child Welfare Society (Maendeleo Farm)	32.50	54.50	87.00
20869	Isiolo	Maisha Bora Water Association		1345.45	1345.45
21802	Isiolo	Islamic Foundation (Baraka Farm)	25.00	27.27	52.27
18707	Isiolo	Nkando Water Association		363.40	363.40
17971	Isiolo	Isiolo Central Water Association		233.18	233.18
23180	Isiolo	Silas Guantai M'Ikingu	5.80		5.80
25498	Isiolo	Samuel Mugaa M'laita	1.25		1.25
14159	Isiolo	Borana-Somali Harambee Group		1997.96	1997.96
22487	Isiolo	Erastus Phares Rutere	77.45	918.70	996.15
19996	Isiolo	Director Water Development (Isiolo W/S)	5000.00		5000.00
		Total	5179.35	7013.10	12192.45

Table A-21 Borehole Data around Isiolo Town

Borehole Nd	Location	Coordinates		Ground Elevation	Total Depth	Completion Date	Water Struck Level		Water Rest Level		Yield
		X	Y	(m)	(m)		Depth (m)	Elevation (m)	Depth (m)	Elevation (m)	(m3/hour)
C2114	Isiolo				136.8	08/12/53	54.8		64.0		0.60
C2212	Isiolo				97.5	07/06/54	47.2		36.0		10.90
C2502	Isiolo				213.4	30/04/56	65.5		52.0		18.20
C3129	Mlango				83.8	08/07/61	68.0		62.5		5.18
C6877	(no data)										
C7344	(no data)										
C7406	(no data)										
C7409	Maliala	0 23' 16" N	37 47' 20" E	1143.0	127.0	11/07/87	112.0	1031.0	79.0	1064.0	8.00
C7631	(no data)										
C7734	(no data)										
C7924	Isiolo Air Strip	0 20' 18" N	37 35' 49" E	1040.0	184.0	31/07/89	112.0	928.0	18.0	1022.0	
C7925	Ngare Mara River	0 23' 35" N	37 40 '06" E	1025.0	48.0	26/10/89	28.0	997.0	19.0	1006.0	25.00
C7926	Near Bule Shime Rive	0 25' 57" N	37 45' 55" E	1057.0	138.0	25/08/89	52.0	1005.0	41.0	1016.0	100.00
C7927	Near 78 Barracks	0 21 '42" N	37 36' 39" E	1080.0	78.0	25/09/89	22.0	1058.0	15.0	1065.0	30.00
C7969	(no data)										
C87	Isiolo				64.0	10/02/40	26.2		13.4		4.60
C8976	Ngare Mara Village	0 29' 34" N	37 38' 20" E	950.0	45.7	10/01/90	31.0	919.0	21.0	929.0	30.00
C90	Isiolo				54.8	08/04/40	37.5		29.0		4.80
C9385	(no data)										
C97	Isiolo				36.6	25/04/40	24.4		14.6		14.00
C98	Isiolo				62.0	01/06/40	30.5		24.4		15.90
SA6	Isiolo	0 20' 15" N	37 48' 15" E	1082.0	39.3	29/09/40	28.0	1054.0	12.2	1069.8	4.53

Source : WRAP

Table A-22 Chemical Data for Boreholes around Isiolo Town

Borehole Nc	Date	pH	EC	Fe	Mn	Ca	Mg	Na	K	Total Hardness	Total Alkatinity	Cl	F	HCO3	NO2	SO4	Free CO2	TDS
			(microS/cm	(mg/l)														
C7344	30/09/88	7.8	1560	< 0.1	< 0.1	9.6	122	91	12	524	-	44	0.6	186	-	7	-	936
C7409	16/06/88	7.3	910	2.6	< 0.1	27	20	92	25	148	360	21	1.5	438.8	< 0.01	30	22	546
C7631	05/01/88	8.6	1100	0.8	0.15	86	53	137	11.5	440	-	26	-	652	-	6	-	800
C7924	28/07/89	7.4	7278	0.2	< 0.1	-	-	1323	82	468	442	176	0.1	538.8	< 0.01	288	460	4367
C7926	30/08/89	7.6	855	< 0.1	< 0.1	25	80	116	27	392	352	22	1.2	429.1	< 0.01	11	22	513
C7927	07/11/89	7.1	1696	0.7	< 0.1	90	81	168	13	558	860	22	0.4	1048	< 0.01	17	398	1017
C8976	19/01/90	7.1	1700	< 0.1	< 0.1	205	33	126	15	650	-	38	0.8	834	-	15	-	650
C90		6.9	-	0.3	-	-	-	-	-	100	-	1.2	0.3	453	-	-	-	585
C10557	27/11/96	6.9	1660	0.1	< 0.1	62	90	125	13	526	698	47	0.2	-	< 0.01	37	232	1225
C11340	15/05/96	6.8	1500	< 0.1	< 0.1	80	87	125	13	560	800	61	0.8	-	< 0.01	27	100	1370

Source : WRAP, NWMP, Isiolo District Water Office

Table A-25 Summary of The Pumping Test

Well No.	TestType	Statistic Water Level	Discharge (Q)	Drawdown(Sw)	Specific Capacity	Sw/Q	Aquifer Loss Coeffient	Well Loss Coeffient	Aquifer Loss (BxQ)	Well Loss (CxQ2)	Total Drawdown(BQ+C	Ratio of Well Loss (CQ2)/(BQ+CQ2	Transmissivity <Jacob/TimeDrawdown>	Transmissivity <RecoveryTest>
		(m)	(l/sec)	(m)	(l/sec/m)	(m/l/s)	B	C	(m)	(m)	(m)	(%)	(m2/day)	(m2/day)
TW1	C.	24.71	5.28	13.46	0.39	2.55	1.67	0.17	8.82	4.71	13.53	34.8	55.6	52.5
	ST-1	23.72	1.94	3.85	0.50	1.98	1.67	0.17	3.24	0.64	3.88	16.4		
	ST-2		3.33	9.55	0.35	2.87	1.67	0.17	5.56	1.87	7.44	25.2		
	ST-3		4.44	11.05	0.40	2.49	1.67	0.17	7.42	3.33	10.75	31.0		
	ST-4		5.13	12.85	0.40	2.50	1.67	0.17	8.57	4.45	13.02	34.2		
TW2	C.	0.90	4.90	12.43	0.39	2.54	2.70	0.11	13.25	2.54	15.79	16.1	129	129
	ST-1	0.00	3.19	9.70	0.33	3.04	2.70	0.11	8.63	1.07	9.70	11.1		
	ST-2		3.70	11.45	0.32	3.09	2.70	0.11	10.00	1.45	11.45	12.6		
	ST-3		4.10	11.78	0.35	2.87	2.70	0.11	11.09	1.78	12.86	13.8		
	ST-4		4.90	12.12	0.40	2.47	2.70	0.11	13.25	2.54	15.79	16.1		
TW3	C.	2.53	5.40	6.25	0.86	1.16	0.35	0.10	1.89	2.92	4.81	60.7	76	80
	ST-1	2.24	3.20	1.63	1.96	0.51	0.35	0.10	1.12	1.02	2.14	47.8		
	ST-2		4.40	2.86	1.54	0.65	0.35	0.10	1.54	1.94	3.48	55.7		
	ST-3		4.90	3.26	1.50	0.67	0.35	0.10	1.72	2.40	4.12	58.3		
	ST-4		5.50	3.52	1.56	0.64	0.35	0.10	1.93	3.03	4.95	61.1		

Table A-26 Water Quality at Intake Sites

Parameters	Unit	Meru	Nkubu	Chuka	Chogoria	Maua	Tigania	Isiolo	
		Kathita River	Kiguandegwa River	Ruguti River	Mara Manyi Stream	Mboone Steam	Thangatha Stream	Isiolo River	Kithima Spring
pH		7.89	7.69	7.97	7.57	7.5	7.52	8.04	7.7
Apparent Color	oH	< 5	10	10	5	5	< 5	10	15
True Color	oH	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Conductivity	us/cm	104	93	103	70	65	92	558	219
Turbidity	F.T.U.	0.3	1.4	1.2	0.5	0.6	0.2	1.3	1.2
Calcium Hardness as CaCo3	mg/l	2	4	10	12	12	4	20	40
Total Hardness as CaCo3	mg/l	6	12	38	36	42	12	70	114
Total Alkalinity as CaCo3	mg/l	50	47	46	32	32	46	262	96
Carbonate Alkalinity	mg/l	0	0	0	0	0	0	0	0
Iron	mg/l	0.04	0.02	0.02	0.02	0.02	0.06	0.02	0.02
Fluorides	mg/l	0.45	0.3	0.42	0.26	0.27	0.43	0.48	0.34
Sulfates	mg/l	44	25	29	36	33	60	33	46
Phosphates	mg/l	0.05	0.03	0.03	0.02	0.01	0.06	0.01	0.01
Silica	mg/l	47	22	55	47	45	85	30	60
Dissolved Oxygen	p.p.m.	6	5.9	6	5.8	5.7	5.9	5.7	5.6
Nitrates	mg/l	0.06	0.02	0.02	0.01	0.04	0.04	0.04	0.01
Manganese	mg/l	0	0	0	0	0	0	0	0
Chlorides	mg/l	25	10	12	8	10	27	64	22
Chromium	mg/l	0.02	0	0	0	0	0.01	0	0
Copper	mg/l	0.02	0	0	0	0	0	0	0
Total Coliform	/100ml	60	300	20	10	25	270	50	20
Total Faecal Coliform	/100ml	5	55	10	0	4	20	11	0
Dissolved Solids	mg/l	182	45	40	35	45	191	325	90
Suspended Solids	mg/l	0	15	10	5	0	0	15	30
Total Solids	mg/l	182	60	50	40	45	191	340	120
Biochemical Oxygen Demand	mg/l	2	5	2	10	6	2	3	130
Chemical Oxygen Demand	mg/l	8	8	4	12	8	6	4	160