REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

VOLUME [illegible]

WATER RESOURCES DEVELOPMENT AND USE PLAN TOWARDS 2010

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

THE STUDY
ON
THE NATIONAL WATER MASTER PLAN

MAIN REPORT
VOLUME I
WATER RESOURCES DEVELOPMENT AND USE PLAN TOWARDS 2010

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

LIST OF REPORTS

EXECUTIVE SUMMARY

MAIN REPORT

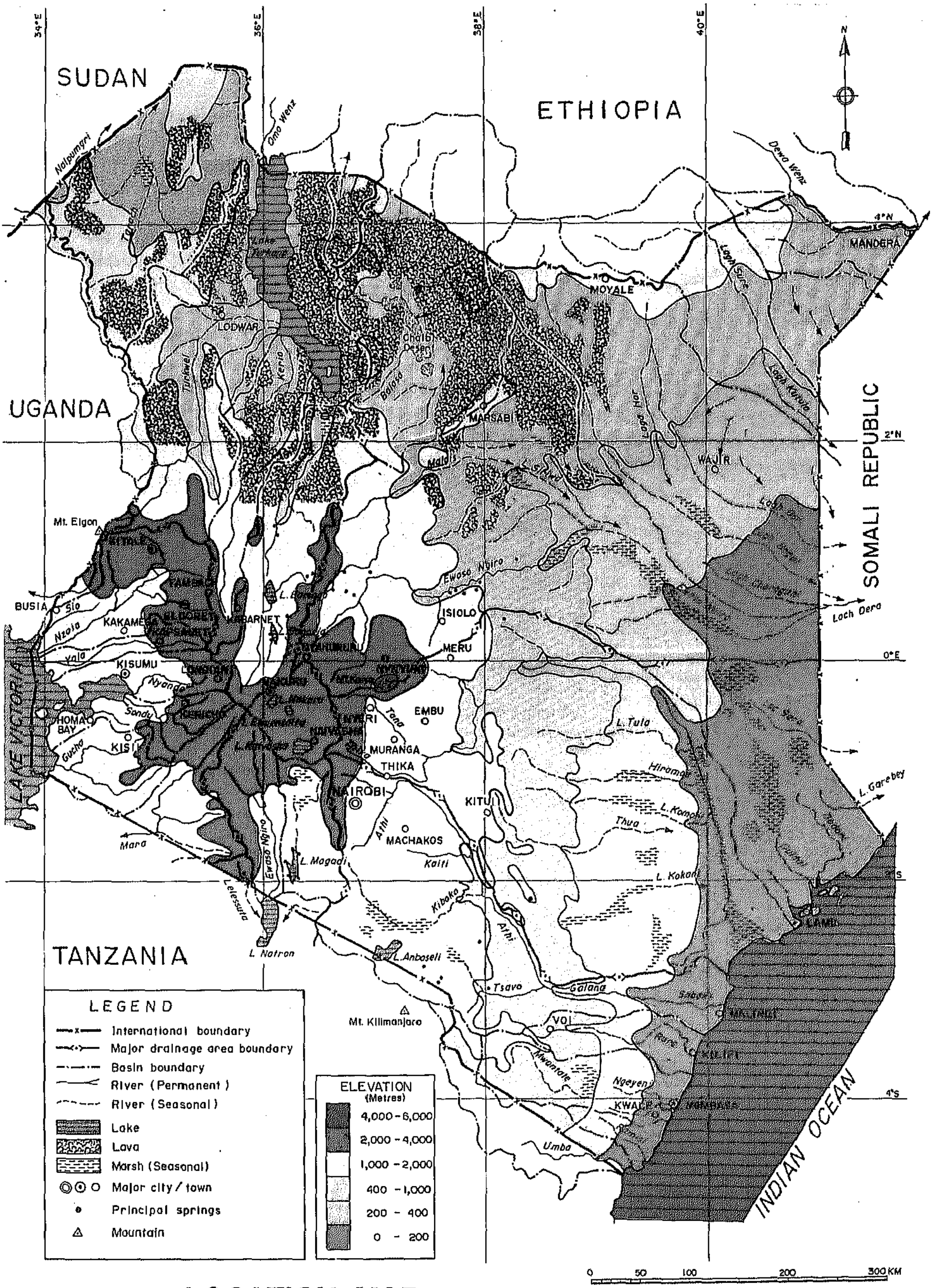
1.	Vol.1	Water Resources Development and Use Plan towards 2010
2.	Vol.2	Master Action Plan towards 2000 Part 1 : National Water Master Action Plan
3.	Vol.3	Master Action Plan towards 2000 Part 2 : Action Plan by Province/District

SECTORAL REPORT

1.	A	Socio-economy
2.	B	Hydrology
3.	C	Groundwater Resources
4.	D	Domestic and Industrial Water Supply
5.	E	Agriculture and Irrigation
6.	F	Livestock, Wildlife and Fishery
7.	G	Flood Control Plan
8.	H	Dam Development Plan
9.	J	Dam Geology
10.	K	Topographic Survey of 11 Damsites
11.	L	Power Development Plan
12.	M	Integrated Water Resources Development Planning
13.	N	Environmental Conservation
14.	P	Laws and Institutions
15.	Q	Database
16.	R	Remote Sensing Analysis
17.	S	GIS-based Analysis

DATABOOK

1.	DB.1	Hydrological Data (Study Supporting Data)
2.	DB.2	Groundwater Data (Aquifer Test and Well Survey)
3.	DB.3	Groundwater Data (Study Supporting Data)
4.	DB.4	Topographic Survey Data
5.	DB.5	Inventory of Irrigation/Drainage Schemes
6.	DB.6	Project Sheet for Urban Water Supply



LOCATION MAP

PREFACE

Interpretation of Report

The original objective of this NWMP Study is to propose a nationwide framework for orderly planning and development of water resources in the country. The Study also deals with the formulation of individual development schemes. However, it should be noted that the plans formulated in this Study remain at a national level and do not provide complete details at local level. Further details should be examined in subsequent studies on each river basin, district, and project basis which are separately recommended in this Study.

Administrative Division of Districts

In this Study, the original 41 districts were considered and various statistical data, particularly socio-economic information, were collected for these districts. During the progress of the Study, six districts were detached from the original ones and established as new districts. In the report, the data on these new districts are grouped together with the corresponding original districts as shown below.

	Original Districts	New Districts	Data included in:
1.	Machakos	Makueni	Machakos/Makueni
2.	Kisii	Nyamira	Kisii/Nyamira
3.	Kakamega	Vihiga	Kakamega/Vihiga
4.	Meru	Tharaka-Nithi	Meru/Tharaka-Nithi
5.	Kericho	Bomet	Kericho/Bomet
6.	South Nyanza	Migori	South Nyanza/Migori

(Note: The last three Districts were established very recently.
The report refers only to the names of the original 41 districts.)

The administrative boundary map used in this Study is the latest complete map set covering the whole country (41 Districts, 233 Divisions and 976 Locations), prepared in 1986 by the Survey of Kenya, Ministry of Land, Housing and Physical Planning.

Data and Information

The data and information contained in the report represent those collected in the 1990-1991 period from various documents and reports made available mostly from central government offices in Nairobi and/or those analyzed in this Study based on the collected data. Some of them may be different from those kept in files at some agencies and regional offices. Such discrepancies if any should be collated and adjusted as required in further detailed studies of the relevant development projects.

Development Cost

The cost and benefit estimate was based on the 1991 price level, and expressed in US$ equivalent according to the exchange rate of US$1 = KShs25.2 prevailing at that time. The same exchange rate was used in calculating the development cost in K£/KShs currency.

SUMMARY

1. Contents of the Report

The Study on the National Water Master Plan in Kenya has been carried out by the Study Team of the Japan International Cooperation Agency (JICA) in collaboration with officials of the Republic of Kenya for two years since January, 1990 in order to establish the national water master plan toward the year 2010 for the basic framework of orderly planning and the national water action plan toward the year 2000 for the implementation of water resources development programmes.

This report contains the formulation of a Master Plan for the water resources development toward the year 2010. Water resources development schemes presented in this Report are candidates to fulfill various potential demands projected for the year 2010.

2. Socioeconomic Conditions in the Year 2010

The socioeconomic conditions in the year 2010 were forecast as follows:

Population	40.3 million
GDP at 1989 constant price	US$ 18.9 billion
Demand for agricultural products	
Maize	4.7 million tones
Wheat	0.6 million tones
Beef	0.4 million tones
Milk	3.2 million tones

3. Potential Water Resources

Potential perennial water resources were roughly estimated at 20.2 billion cubic metres per year.

Perennial surface water	19,590 million m^3/year
Groundwater	
Boreholes	193 million m^3/year
Shallow well	426 million m^3/year
Total	20,209 million m^3/year

4. Potential Water Demand

The potential water demand in the year 2010 was estimated at 8.5 million cubic metres per day or 3,096 million cubic metres per year.

		Potential Demand in 2010	
		1,000 m^3/day	Ratio
Domestic & Industrial			
Urban		1,906	(12.0%)
Rural		1,162	(7.3%)
Industry		494	(3.1%)
	Sub-total	3,562	
Livestock		621	(3.9%)
Irrigation		11,655	(73.1%)
Wildlife		21	(0.1%)
Fishery		78	(0.5%)
	Total	15,937	(100.0%)

5. Development Plan for Domestic and Industrial Water Supply

To comply with the Government policy to supply potable water to all the people, water supply schemes were examined to ensure the reliability of 10 years probability.

(1) Urban water supply and sewerage

To formulate urban water supply schemes, 158 urban centers which are organized into (i) towns nominated as urban centres and (ii) towns to have population more than 5,000 in year 2000 were selected. Raw water source was examined per urban center and the required cost to fulfill the potential demands in 2010 was estimated at US$ 4,949 million including dam cost of US$ 577 million.

Urban sewerage system development is necessary for protection of the urban environment and human health. It was presumed that the urban sewerage system development be done in pace with the urban water supply development. The development cost was estimated at US$ 705 million equivalent.

(2) Rural water supply

In view of the vastness of the study area and varying type of water sources envisaged, it was impracticable to formulate definite water supply plans specific to each rural area. The Study therefore attempted to evaluate potential water sources available in each area and to estimate the conceptual costs of the development. Source potential which was organized into surface water, groundwater, water harvesting and existing water pipeline was evaluated by Location. The cost was estimated at US$ 2,627 million.

6. Development Plan for Livestock water supply

Livestock water supply schemes were also evaluated in the same manner as rural water supply. The cost was estimated at US$ 670 million.

Another target may be the expansion of nomadic pasturage activities in semi-arid and arid areas in the season wet when the pastures grow there. The cost for providing watering points was estimated at US$ 85 million equivalent.

7. Wildlife and Fishery

Insufficient data for the projection of wildlife water demand made cost estimation of the facilities for wildlife water supply impractical. The Study recommended harnessing the minimum flow of perennial rivers during dry months and rehabilitating the existing watering facilities in the national park and game reserve.

The perennial river water has been utilized for inland fishery during the wet season. Present and future water uses for inland fishery may not have a negative effect on the water balance to downstream users in the dry period.

8. Development Plan for Agriculture

The results of a reassessment of irrigation potential (for upland crops) were about 470,000 ha by surface water and 2,400 ha by groundwater in the whole of Kenya. To absorb the large food demand by rapid increasing population within Kenya and to generate farmers income and agricultural export earnings, about 140 small scale irrigation schemes and 18 large scale schemes were selected as candidates for future development. The cost of irrigation development was estimated at US$ 11 million for small scale irrigations schemes and US$ 1,015 million for large schemes including dam cost of US$ 176 million.

9. Source Development Plan

The reliability of water supply for domestic and industrial water use demand was set at once in 10 years (supply failure of about 21 days in ten years). Water balance analysis was made between the projected potential domestic, industrial and livestock water demands and the available surface water with potential groundwater. The analysis showed that out of 164 subbasins, 63 subbasins would suffer from water deficit in 2010. In order to solve the water deficit problems in the country, water source development was examined including a water harvesting method.

In total, 28 damsites were conceived in the Study: they were, 19 for urban water supply, 2 for irrigation water supply, 2 for hydropower development, and 5 for multipurpose uses. The construction cost was estimated at US$ 1,410 million. In order to transfer water from water source points to urban centers, 24 intra-basin water transfer schemes and 16 inter-basin schemes were conceived.

Groundwater development was widely applied to the domestic water supply which has insufficient perennial surface water sources.

Water harvesting consisting of roof catchment, rock catchment, small dams and sub-surface dams was conceived for the rural areas for which the groundwater development is insufficient to meet the rural and livestock water supplies.

10. Hydropower Development

The latest study carried out by the Ministry of Energy/Kenya Power and Lighting Company listed five schemes as candidates for hydropower development up to the year 2010; Sondu/Miriu, Low Grand Falls, Oldorko, Gitaru #3, and Mutonga. Including Magwagwa which was also evaluated favourably in the feasibility study by JICA, the cost for hydropower development was estimated at US$ 1,034 million.

11. Flood Protection and Drainage

After reviewing the present conditions, the Study examined in more detail nine selected flood prone areas where the extent of flooding area and damage is relatively large. Several flood control dams were also examined, but found to be more costly. In terms of B-C and B/C, five schemes with relative attractiveness were selected to be implemented towards year 2010; they are, Kano Plain, Nairobi city, Yala Swamp, Kuja river mouth, and Lumi river mouth. The cost was estimated at US$ 63 million.

Other river improvement and drainage projects were also examined in the Study: they are, urban drainage projects, minor ad-hoc river improvement projects, and the pilot work of channel stabilization of Lower Tana River. The cost was estimated at US$ 1,004 million.

12. Total Cost

The construction costs of the proposed schemes were estimated at the construction price in February 1990. The total cost to be required for implementation of water resources development to meet all the potential demands up to the year 2010 was estimated at US$ 12,163 million.

Development Cost for Water Resources Development towards the Year 2010

(Unit : million US$)

	Purpose	Development Cost
(1)	Urban Water Supply	
	- Water supply system	4,949
	- Sewerage system	705
(2)	Rural Water Supply	2,627
(3)	Livestock Water Supply	
	- Livestock water supply	670
	- Watering points for nomadic pasturage activities	85
(4)	Irrigation Water Supply	
	- Small scale irrigation scheme	11
	- Large irrigation projects	1,015
(5)	Hydropower Development	1,034
(6)	Flood Protection and Drainage	
	- Flood protection projects	63
	- Urban drainage and minor river improvement	1,004
	TOTAL	12,163

Note : (1) Base cost excluding price escalation; at 1991 price

(2) Expenditure on disbursement basis during 1993-2010 period is US$12,110 million (see Main Report Vol.II), since the implementation of some irrigation projects are proposed to commence before 1992 or continue to 2011 onward.

MAIN REPORT Vol. I

WATER RESOURCES DEVELOPMENT AND USE PLAN

TABLE OF CONTENTS

ATTACHED DRAWINGS

1. WATER RESOURCES DEVELOPMENT PLANS
2. SURFACE WATER INFORMATION MAP

LIST OF TABLES

LIST OF FIGURES

ABBREVIATION

CBK	Coffee Board of Kenya
CBS	Central Bureau of Statistics
CRF	Coffee Research Foundation
CSS	Computer Service Section of MOWD
DAO	District Agricultural Officer
DC	District Commissioner
DDC	District Development Committee
DO	District Officer
DRSRS	Department of Resource Surveys & Remote Sensing
EAMD	East Africa Meteorological Department
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIS	Geographical Information System
GRDP	Gross Regional Domestic Product
GTZ	German Agency for Technical Cooperation
HCDA	Horticultural Crops Development Authority
IBRD	International Bank for Reconstruction and Development
ICDC	Industrial and Commercial Development Corporation
IDA	International Development Association
ILUS	Integrated Land Use Survey
IPC	Investment Promotion Center
IRS	Integrated Rural Survey
JICA	Japan International Cooperation Agency
KBS	Kenya Bureau of Standard
KIRDI	Kenya Industrial Research & Development Institute
KIE	Kenya Industrial Estates Limited
KMD	Kenya Meteorological Department
KPCU	Kenya Planters' Cooperative Union
KPLC	Kenya Power and Lighting Co.
KS	Kenya Standard
KSA	Kenya Sugar Authority
KSB	Kenya Sisal Board
KSS	Kenya Soil Survey
KTDA	Kenya Tea Development Authority
KVDA	Kerio Valley Development Authority
KWAHO	Kenya Water and Health Organization
LBDA	Lake Basin Development Authority
LU	Livestock Unit
MOA	Ministry of Agriculture
MOCSS	Ministry of Culture and Social Services
MOE	Ministry of Energy
MOED	Ministry of Education
MOENR	Ministry of Environment and Natural Resources
MOF	Ministry of Finance
MOH	Ministry of Health
MOHANH	Ministry of Home Affairs and National Heritage
MOI	Ministry of Industry
MOL	Ministry of Labour
MOLD	Ministry of Livestock Development
MOLG	Ministry of Local Government
MOLH	Ministry of Lands and Housing
MOMDE	Ministry of Manpower Development and Employment
MOPND	Ministry of Planning and National Development
MOPW	Ministry of Public Works
MORD	Ministry of Region Development
MORDASAW	Ministry of Reclamation and Development of Arid, Semi-arid and Wasteland
MORST	Ministry of Research, Science and Technology
MOSM	Ministry of Supplies and Marketing
MOTC	Ministry of Transport and Communication
MOTW	Ministry of Tourism and Wildlife
MOWD	Ministry of Water Development
NCC	Nairobi City Commission
NCPB	National Cereals and Produce Board
NES	National Environment Secretariat
NIB	National Irrigation Board
NMWP-I	National Master Water Plan (Stage I)
NWCPC	National Water Conservation and Pipeline Corporation
NWMP	National Water Master Plan
OECD	Organization for Economic Cooperation and Development
OECF	Overseas Economic Cooperation Fund of Japan
OP	Office of the President
PC	Provincial Commissioner
PPCSCA	Presidential Permanent Commission on Soil Conservation and Afforestation
ROK	Republic of Kenya
RTPC	Rural Trade and Production Center
RWSDP	Rural Water Supply Development Project
SEFC	Small Enterprise Financial Corporation
SOK	Survey of Kenya
SP1	Sessional Paper No.1 of 1986 on Economic Management for Renewed Growth
SWAP	Surface Water Extraction Permit
TARDA	Tana and Athi River Development Authority
UNDP	United Nations Development Programme
UNEP	United Nation Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
UNIDO	United Nations Industrial Development Organization
UNPEP	United Nation Population Fund Programme
UON	University of Nairobi
USAID	United States Agency for International Development
WHO	World Health Organization

ABBREVIATION OF MEASURES

Length

mm	=	millimetre
cm	=	centimetre
m	=	metre
km	=	kilometre

Area

ha	=	hectare
m^2	=	square metre
km^2	=	square kilometre

Volume

l, lit	=	liter
m^3	=	cubic metre
m^3/s, cms	=	cubic meter per second
MCM	=	million cubic metre
m^3/d, cmd	=	cubic metre per day

Weight

mg	=	milligram
g	=	gram
kg	=	kilogram
t	=	ton
MT	=	metric ton

Time

sec	=	second
hr	=	hour
d	=	day
yr	=	year

Money

Kshs.	=	Kenya shilling
K£	=	Kenya pound (Kshs.20)
US$	=	U.S. dollar
USc	=	U.S. cent

Energy

Kcal	=	Kilocalorie
KW	=	kilowatt
MW	=	megawatt
KWh	=	kilowatt-hour
GWh	=	gigawatt-hour

Others

%	=	percent
o	=	degree
'	=	minute
"	=	second
°C	=	degree Celsius
cap.	=	capital
LU	=	livestock unit
md	=	man-day
mil.	=	million
no.	=	number
pers.	=	person
mmho	=	micromho
ppm	=	parts per million
ppb	=	parts per billion

CHAPTER 1 INTRODUCTION

1.1 Background

Successful and well balanced physical and economic development of the country depends on comprehensive advance planning of various development sectors. Among them, water resources are some of the most important components to be carefully planned in view of their limited availability and locational maldistribution.

Kenya is located astride semi arid and arid lands and hence water resources are valuable natural resources. Neither large scale urbanization nor agricultural and industrial developments can be undertaken unless firm supplies of clean water are ensured in the long term. These situations require a comprehensive approach to nationwide water resources planning to ensure great efficiency in future water use.

In response to the request of the Government of the Republic of Kenya (GOK), the Government of Japan (GOJ) decided to carry out the Study on the National Water Master Plan. The Japan International Cooperation Agency (JICA), the official agency responsible for the implementation of technical cooperation programmes of GOJ, dispatched the Study Team in January 1990. The Ministry of Water Development (MOWD) is the counterpart agency to the Study Team and also the coordinating body in relation with the other government agencies and non-govenmental organizations. The Study has been carried out by the Study Team for about 2.5 years.

To assist in the execution of the Study, MOWD organized the Steering Committee and the Technical Sub-committee. In the same manner, JICA set up an Advisory Committee to manage the Study effectively.

The objectives of the Study are:

(i) To formulate the National Water Master Plan towards the year 2010, and

(ii) To formulate the Master Action Programme towards the year 2000

In formulating the nationwide water resources development plan in Kenya, the Study is approached in two ways. One is to search the present condition on water use and to clarify water-related issues. The other way is to estimate the water demand towards the year 2010 in proportion to population growth. The formulation of the National Water Master Plan and the selection of the Master Action Programme take in account socioeconomic impact, water resources development efficiency and budgetary constraints as well as project viability.

This nationwide water resources study was preceded by the first study prepared in 1980 (National Master Water Plan by TAMS). In preparing it, this Study attempted to update the information contained in the previous study as much as possible, but on one hand the emphasis was made on the formulation of development plans rather than on the discussion of policies, constraints and problems which are already identified in various earlier documents.

Another implicit objective of the Study is transfer of technology, which could be effected through field work in Kenya and the invitation of a few key Kenyan staff concerned in the Study to Japan for discussing the integrated water resource development plan. The staff training on database systems which were newly established in the headquarters of MOWD was also carried out in September 1991 and May 1992 to learn their application. Furthermore, a seminar will be held in September 1992 under the sponsorship of MOWD and JICA to discuss the basic concept for tackling the nationwide water resources development as part of transfer of technology.

1.2 Report Contents

The output of the Study was submitted to MOWD; it comprises (i) one volume of executive summary, (ii) three volumes of Main Report, (iii) 17 volumes of Sectoral Report and (iv) six volumes of Data Book.

This report is the first volume of the Main Report. It contains the formulation of the National Water Master Plan towards the year 2010.

1.3 Acknowledgement

For implementing the Study, the Study Team has appreciatively been supported by the Steering Committee, the Technical Sub-committee and the Advisory Committee with a lot of helpful assistance and advice. The Study Team wishes to express grateful acknowledgement to all the members of the Committees. Besides, the Study Team has received a lot of co-operation in the fields of data collection and information presentation through the public entities and agencies concerned in the GOK. The Team sincerely expresses many thanks to the officials and individuals of these groups.

CHAPTER 2 NATURAL RESOURCES AND SOCIO-ECONOMIC BACKGROUND

2.1 Land

The Republic of Kenya is located on the eastern side of the vast African continent. It shares international boundaries with Somalia, Ethiopia, Sudan, Uganda, and Tanzania.

Kenya lies approximately between latitudes 5°20'N and 4°40'S, and between longitudes 33°50'E and 41°45'E. The land configuration varies widely ranging from sea level to over 5,500 m in elevation.

Of the territorial area of about 592,000 km^2, the lakes occupy about 11,230 km^2 (2%), and both semi-arid and arid areas occupy about 490,000 km^2 (83%). Thus, only about 89,000 km^2 (15%) of the land area can be used profitably by the over 20 million inhabitants.

Kenya is administratively divided into 8 provinces and then further divided into 47 districts (as at July 1992).

Annual average rainfall over Kenya is estimated at 621 mm ranging from 411 mm in Drainage Area 5 to 1,368 mm in Drainage Area 1. The distinctive rainy and dry months, however, bring about extremely low river flow during dry periods. The drainage areas with a perennial main river is about 254,000 km^2 and about 10% of annual rainfall in the area flows down through the perennial main river. In many drainage areas, almost all of the tributaries dry up annually in the dry period. This phenomenon causes difficulties in ensuring the safe yield for water supply during the dry period.

2.2 Climate

2.2.1 Sources of data

Summaries of the climatological data in Kenya were published in 1953, 1964, 1975 and 1984. The first three publications were printed by the East African Meteorological Department (EAMD) and the latest by the Kenya Meteorological Department (KMD). The latest edition contains climatological data at 84 meteorological stations having data from the early 1920's to 1980 (Ref.1).

In spite of its location astride the equator, Kenya experiences wide variations in climate due to great differences in altitude as shown in Figure 2.2.1. A relatively wet and narrow tropical belt lies along the Indian Ocean coast. Behind the coastline stretch large areas of semi-arid and arid lands. The land then rises steeply to the temperate highland plateau through which the Rift Valley runs. All the mountain ranges in the area have high rainfall while dry tongues are found in the valleys and basins. Another wet area covers western Kenya just east of Lake Victoria.

All the climatic data on monthly mean basis were, therefore, compared with their altitude by using the least square method. Some data have a distinctive relationship to their altitudes.

2.2.2 Winds and circulation

The climate in Kenya is controlled by the northward and southward movement of the Intertropical Convergence Zone (ITCZ). However, wide varieties in the altitude of the country brings considerable variations in climate. The characteristics of monthly circulation can be explained as follows;

January to February	:	The northeast monsoon dominates and bifurcates to coast area and to the south of Lake Turkana. This bifurcation results in a dry season in Kenya.
March	:	Convergence is beginning to develop as the winds in the coast area, although the northeast monsoon is still present.
April	:	South-east wind with rain dominates over the whole country. The wettest "Long Rains" period is established.
May	:	South monsoon is firmly established. This southerly wind causes a maximum monthly rainfall in coast area. Many coastal stations usually record over 20 rainy days.
June to September	:	South monsoon is dominant in the flat area east of 38°E. On crossing the equator, these wind becomes a part of the southeast monsoon. Rainfall depth over the whole country shows a marked drop. These months are dry season between "Long Rains"in April and "Short Rains" in November. While the rains of western Kenya come partly from the unstable Congo air stream and partly from convection thunderstorms associated with breezes introduced by the pressure of Lake Victoria and augmented by the Congo air stream.
October	:	The south monsoon has almost disappeared and is replaced by the strengthening northeasterlies. Some convergence takes place between these two winds which brings about some rainfall. These winds mark the beginnings of "Short Rains".

November	:	Both northeast monsoon at higher level and south monsoon are dominant and convergence is more widespread and this month normally records the peak of "Short Rains".
December	:	North-east monsoon restores its strengthening and a dry and clear weather spread. "Short Rains" disappears.

The surface wind movement on monthly basis is shown on Figure 2.2.2.

2.2.3 Temperature

Kenya has a wide range in both maximum and minimum temperatures from below freezing point on snow-capped Mt.Kenya as minimum to over 40°C in the north and north-east areas as maximum.

Although daily variation of air temperature is large, daily mean temperature does not show remarkable change throughout the year, about 5.5°C at Lamu in the coast and to 18.2°C at Rumuruti in the highlands, according to the existing records.

The annual mean temperature at a certain place is closely related to its elevation, and the relationship between them may be expressed by the equation;

$$T = a + b \times EL \quad \text{(Eq.2.2.1)}$$

where,
- T : annual mean temperature (°C),
- EL : Elevation (m), and
- a and b : constant

(NB: Eq.2.2.1 to Eq.2.2.4 show only broad relationships between some average climatic values and the altitudes, and therefore are of limited use only for acquiring general information.)

Based on the climatic data so far provided, coefficients of the above formula were worked out as follows:

Annual Mean	a	b
Daily mean maximum	33.926	-0.00517
Daily mean minimum	23.529	-0.00663
Extremely High	37.804	-0.00475
Extremely Low	18.475	-0.00680

The above relationships are shown in Figure 2.2.3. The highest temperature of 41.8°C has been recorded at Lake Magadi in the Rift Valley. Two other stations have each recorded over 40°C; that is, 41.4°C at Garissa and 40.3°C at Mandera. While the lowest temperature of -3.3°C has been recorded at Eldama Ravine and -2.2°C has been recorded at Kericho.

2.2.4 Relative humidity

Readings are commonly taken at the main synoptic hours since these hours would give a fair approximation to the maximum and minimum values. Relative humidity is generally highest at 6 a.m. and lowest at 3 p.m. in Kenya. The rather high range between the two readings is due to high temperature changes. The distinctive relations to their elevation was not found out as shown in Figure 2.2.4.

2.2.5 Sunshine hours

Sunshine hours are generally related to the latitude of observation point. However, the range of variation of latitude in Kenya astride the equator seems to decrease such latitude effects. Then decrease of sunshine hours by cloud cover might be another factor, which was evaluated in terms of the relation to the altitude of observation points. Sunshine hours have been recorded at 56 stations. The relation to their elevation is derived by the equation;

$$SH = 8.557 - 0.00081 \times EL \quad \text{(Eq.2.2.2)}$$

where, SH : Sunshine hours (hrs), and
EL : Elevation (m)

The above relationship is shown in Figure 2.2.5.

2.2.6 Evaporation and evapotranspiration

Class "A" pan has been used for measuring evaporation depth in Kenya. Mean annual evaporation depths, which were recorded at 65 stations, vary ranging from 1,215 mm at Kimakia forest station to 3,945 mm at Lokori in South Turkana. The relation to their elevation is defined by the equation;

$$Eo = 2,575 - 0.4838 \times EL \quad \text{(Eq.2.2.3)}$$

where, Eo : Evaporation (mm), and
EL : Elevation (m)

The above relationship is shown in Figure 2.2.6.

Evapotranspiration corresponds to the total water vaporized from the ground by plant transpiration and evaporation from free water surface and soil. MOWD has calculated the value of evapotranspiration on the basis of 90 stations in Kenya (Ref.2). The values were also plotted with their elevations as shown on Figure 2.2.6. The relation to their elevations is defined by the equation;

$$ETo = 2329.9 - 0.03235 \times EL \quad \text{(Eq.2.2.4)}$$

where, ETo : Evapotranspiration (mm), and
EL : Elevation (m)

2.2.7 Rainfall

(1) Sources of data

In Kenya, rainfall has been measured with different observation periods station by station. The rainfall station at Mombasa was established in 1891. Daily rainfall data has been published on a monthly basis since 1934 by three principal agencies; they are, the East African Agricultural Department (EAAD) for the period of 1904 to 1929, EAMD from 1930 to 1979, and KMD since 1980.

Rainfall data have been collected at meteorological gauging station of KMD and through the water related government agencies such as MOWD, MOA, and MOENR. The data on daily basis are finally stored in the computerized database system of the headquarters of the KMD.

The registration code of the stations are organized into 7 digits: The first 2 digits indicate the North Polar Distance of the latitude circle forming the northern edge of the degree square in which the station is located, the subsequent 2 digits indicate the meridian of longitude forming the western edge of the degree square. The last 3 digits are set in ascending order corresponding to the date when the station was established.

At present, 2,867 rainfall gauging stations are registered in the database of KMD. The stations over the whole of Kenya are plotted as shown in Figure 2.2.7.

(2) Annual rainfall

An isohyetal map of annual rainfall depth was developed on the basis of 212 rainfall stations with their records of more than 20 years as shown in Figure 2.2.8. The isohyetal map of annual rainfall depth is shown in Figure 2.2.9. The annual mean rainfall depth over all of Kenya was estimated at 621 mm ranging from 411 mm in Drainage Area 5 to 1,368 mm in Drainage Area 1.

Of the 212 selected stations, annual rainfall depth at 24 stations having relatively long recording period (more than 70 years) were further selected and the variations of annual rainfall depth are shown in the figures in Sectoral Report B. The figures indicate that annual rainfall varies with a rather long periodicity of 30 to 40 years. The autocorrelation coefficient which contributes to the forecasting of the periodicity of drought, however, shows that none of periodicity appears in the series of annual rainfall.

(3) Monthly rainfall

As described in Section 2.2.2, Kenya is dominated particularly by 3 distinct air masses; they are, (i) very dry winds from the Sahara Desert dominate the western part of the country from November through March, (ii) the southeast trade winds from the Indian Ocean which gives influences to many of the central, southern and eastern parts of Kenya in April and (iii) the southwest trade winds which were felt mostly in the western parts of Kenya in July.

The distribution of monthly rainfall depth at representative rainfall gauging stations is shown on Figure 2.2.10. In western Kenya, especially in the Lake Victoria basin, there is no distinctive dry season during the year. A double maxima in April and November is well defined in Central Kenya, while, there is in the coastal area a remarkable single maximum in May.

(4) Daily rainfall

Daily rainfall records of 212 selected stations were collected from the database of KMD. The data, however, do not cover the whole period for which monthly rainfall was recorded. The reasons are: (i) daily rainfall records for the limited period of 1958 to 1988 have been stored in the database, (ii) in the case when monthly rainfall was less than about 5.0 mm, daily rainfall data was not been stored in the database and (iii) the old rainfall recording forms before 1957 have been abandoned and summarized monthly rainfall recording papers have been stored at the KMD.

In the Study, daily rainfall data were mainly applied to the flood analysis for estimating probable rainfall depth and probable maximum precipitation.

(5) Number of rainy days

The rainy day was defined as a day with rainfall of more than 1.0 mm. The number of rainy days is one of the important factors in determining not only the suitability for agricultural development but the harvesting of rain waters.

The relationship between the annual mean number of rainy days and the annual mean rainfall depth is shown in Figure 2.2.11. The data show the following relationship;

$$NR = 0.083 \times R + 15.1 \quad \text{(Eq.2.2.5)}$$

where, NR : number of rainy days per annum (days),
R : annual mean rainfall depth (mm)

2.2.8 Drought

The annual rainfall data of 14 stations from 1911 to 1985 were examined to estimate the magnitude of historical drought in Kenya, although the data in semi-arid and arid areas were not included because of the limited recorded period. Mean rainfall depths for successive 5 years periods were calculated and ranked in ascending order as given in Table 2.2.1.

The table shows that the worst drought occurred in 1931-1935 in central Kenya, the second worst in 1941-1945. In the last two decades, severe droughts occurred in 1971-1975 and 1981-1985. The records show that the occurrence of drought is quite erratic area by area. Attempt at probabilistic prediction of the droughts appears to be almost impractical as far as the existing records indicate.

Both climatological records and oral knowledge show that major droughts, with serious results to man, livestock and wildlife, have occurred in the following years : 1928, 1933-1934, 1942-1944, 1952-1955, 1960-1961 and 1965 (Ref.3). NMWP-I Study defined the drought in the early 1970's as the worst for the period from 1945 to 1974 (Ref.4).

These anomalies in rainfall have caused widespread famine as drought brings about crop failure. A further hazard appears to be that serious droughts in Kenya have commonly been coupled with an invasion of locusts.

2.2.9 Flood

Major floods in certain low-lying parts of the Lake Victoria catchments and the Lower Tana river basin in particular, occurred in 1937, 1947, 1951, 1957-1958, 1961, and 1977-1978. Especially, the 1961 floods, having a peak discharge of about 3,000 m^3/s at Garissa on 20 to 21 November, was estimated at a probability of once in over 50 years for the upper catchment of Tana River. The inundated area around Garissa was estimated at about 500 km^2 .

The 1961 floods also hit large areas of the Kano Plains, Yala Swamp and other low-lying parts of Lake Victoria catchment. The water level of Lake Victoria rose by 1.25 m in 1962 over that of the previous year. The lake water level started rising in November 1961 and reached its peak in May 1964. Such a peak had not been recorded since the lake water level recorder was installed at Entebbe in 1899. Although the early stage of flooding at low-lying areas occurred from overbank spill from the main river course, a latter one was created by the backwater effect due to high lake water level.

The effects of flood inundation and attendant damages have been recorded in very few documents in Kenya. However, according to the "District Development Plans", Siaya and Kisumu Districts which are located in the Kano Plain and Yala Swamp have indicated the necessity of flood control protection works as their high priority.

2.3 Hydrology

2.3.1 Data collection

(1) Sources of Data

Hydrological data relating to the surface water were collected from the Hydrology Section of MOWD which is responsible for collecting and evaluating data on rivers in Kenya. The database system at the headquarters of the MOWD was established in 1983 and is mainly organized into 3 items: (i) Surface water database, (ii) Groundwater database, and (iii) Water permit database.

Surface water database is further organized into the following categories of data;

(1) Basic information of water level gauging station,
(2) Daily water level (including lake water level), and
(3) Rating curve equation

Daily discharge is computed upon user's request. The data are interpolated linearly in case of missing data within 7 consecutive days.

The Lake Basin Development Authority (LBDA) also has its own database system in Kisumu. All the surface water data of the MOWD concerning the Drainage Area 1 were backed up when the LBDA established their own database system. The LBDA then verified the existing rating curves and attempted to re-establish more accurate ones.

(2) Daily water level

Daily water level data at 923 stations are registered in the database of the MOWD. Almost all existing water level gauges have been installed at the river bank of perennial rivers and at lake shores. Their locations are plotted in Figure 2.3.1.

The first 8 gauging stations started their operation in 1921 on the streams in the highlands; they were in Kiambu and Nairobi districts (Subbasin: 3B) and Thika River (Subbasin: 4C). While, lake water level observation started in 1908 on Lake Naivasha (Ref.5).

In the early 1930's, the low flow observation network was extended to the highland where estates began to concentrate. Due to the need to administrate water affairs, the drainage area was firstly divided into 5 main drainage areas. In the late 1940's and 1950's the observation network was extended to cover not only highland but low potential areas.

(3) Discharge measurement data

Of the 923 registered stations, discharge measurement data of only 115 rated stations are stored in the database of the MOWD. For converting water level data into discharge data, all the discharge measurement data were calibrated to confirm accuracy of discharge measurement, hence its rating curve. In addition, the rating curves of 132 stations which are stored in the database of the LBDA are compared with those in the MOWD. Finally, the rating curves of 331 stations were adopted in the Study, including another 216 stations extracted from the LBDA data and/or newly prepared by the Study.

(4) Suspended load

No suspended load measurement data had been stored in the database of the MOWD. Under this Study, all the existing data (36 stations, see Table 2.3.1) has been stored in the new database system in the MOWD. "Suspended load" defined here means the load floating in the flowing water, classified separately from "bed load".

(5) Water quality

The MOWD has carried out surface water quality analysis at 120 sampling points since the 1970's. The sampling points cover almost all the major rivers as shown in Figure 2.3.2.

2.3.2 Basin boundary map

The drainage system in Kenya is organized into 5 main drainage areas. The existing basin boundary map was prepared during the colonial days in the 1930's. This basin boundary has been used in Kenya. The station code of existing water level gauge has also been named after subbasin code in the basin boundary map.

The basin boundaries which were divided into 158 subbasins in the existing map were verified by referring to the topographic map on the scales of 1:50,000 and 1:100,000, and basin boundary maps which had been prepared by the MOWD and those of NMWP-I. Landsat imageries of 1:1,000,000 scale were also used for confirmation of configuration of the river systems particularly in the semi-arid and arid areas when a 1:50,000 map is unavailable. Some relatively large subbasins were further sub-divided for the Study. Finally, 197 subbasins were verified under this Study as shown on the attached drawing in Sectoral Report B. The new basin boundary map thus prepared was used for low flow analysis, flood control schemes, and dam planning in this Study.

Coding of drainage areas and subbasins is according to that in use by the MOWD as follows:

Drainage Area 1 :	Lake Victoria Basin
Drainage Area 2 :	Rift Valley Basin
Drainage Area 3 :	Athi River and Coast
Drainage Area 4 :	Tana River Basin
Drainage Area 5 :	Ewaso N'giro and North

2.3.3 Basin mean rainfall

Of the registered 2,867 stations in the database of the KMD, 91 stations were extracted for developing Thiessen's polygon as shown in Figure 2.3.3, taking into account length and continuity of observation period of each station.

The monthly rainfall for those stations in the period from 1959 to 1988 were applied to estimate the basin mean rainfall depth for each subbasin. The missing data were either interpolated by correlation analysis among the stations or filled in using concurrent records at nearby stations. The annual mean rainfall depth from 1959 to 1988 was estimated at 621 mm as enumerated below.

Drainage Area	Catchment Area (*) (sq. km)	Annual Rainfall (mm)
1 Lake Victoria	46,229	1,368
2 Rift Valley	130,452	562
3 Athi River and coast	66,837	739
4 Tana River	126,026	697
5 Ewaso N'giro and North	210,226	411
Total	579,770	621 (**)

Note : (*) land surface area excluding lakes and small islands
(**) weighted average

2.3.4 Low flow condition

(1) Introduction

Low flow analyses in the previous studies were mainly carried out by discharge correlation among the stations. Hydrological modeling was applied in a few water resources studies - they were, (i) conceptual model for the Kimakia catchment, (ii) Sacrament model for some Lake Victoria catchments, and (iii) NWMP-I for whole basin in Kenya.

(2) Dimensionless flow duration curve

Dimensionless flow duration curve is one tool used to estimate low flow frequency at an ungauged catchment by applying the relationship obtained at a nearby station.

Flow duration curves were established for gauging stations selected by the following criteria:

(i) At least 300 daily discharge data are recorded per annum for more than 3 years, and
(ii) Missing data does not exist seasonally.

The water level data at rated stations were converted into daily discharges. In the dimensionless flow duration curves, the daily discharge is expressed as percentage against the mean discharge during the observation period. The curves so prepared for some 40 stations are shown in Sectoral Report B.

(3) Rainfall-runoff balance calculation in Drainage Area 1

The global hydrologic cycle is divided into 3 sub-systems: namely, (i) "atmospheric water system" containing the processes of precipitation, evaporation, and transpiration; (ii) "surface water system" containing the processes of over land flow, surface runoff, subsurface, and groundwater outflow; and (iii) "subsurface water system" containing the processes of infiltration, groundwater recharge, subsurface flow, and groundwater flow (Ref.6).

The flowchart of rainfall-runoff balance calculation (Ref.7) is shown in Figure 2.3.4. The method of calculation of each rainfall-runoff balance component is described in Sectoral Report B.

However, rainfall-runoff balance calculation was deemed applicable only to Drainage Area 1, where relatively large low flow is still observed even after water abstraction.

The result shows that simulated monthly discharges in the dry months fitted well with observed ones, while there were some differences between the discharges during wetter months because no incremental water abstraction during flood flow was taken into account in the model. It is however deemed that this preliminary water balance model can be adopted in this master plan level study for the estimation of low flow frequency of the basin.

(4) Discharge correlation in high & mid potential zones

In the other drainage areas in the high and mid potential zones, water abstraction during the low flow condition is large in relative terms even in small subbasins, and this preliminary rainfall-runoff balance model could not be applied to the basin. Therefore, monthly discharge correlation method was applied to these subbasins.

In the analysis, monthly discharge correlation established for the recorded stations was applied to the other subbasins having no discharge records. The missing monthly discharges were filled with those at nearby stations with correlation coefficient of more than 0.65. The stations used in the Study was enumerated in Sectoral Report B.

(5) Runoff ratio of rivers in semi-arid zone

With the exception of Rift Valley basin, the water level observation in tributaries in semi-arid area has been carried out on the Tsavo River for a relatively long period. The water level gauges are at Tsavo (3G02) which is located in the most downstream end of Tsavo River, and at Mzima springs (3G03) which is located immediately downstream of Mzima spring's intake.

The outflow of Tsavo River, having a catchment area of 6,300 km^2, was estimated as the difference of discharge at 3G02 and that at 3G03.The runoff ratio of the Tsavo River was applied to the basin in semi-arid zones, such as 2B, 2C, and 4H.

(6) Loss in river channel

Rivers flowing in the arid zone appear to lose their runoff as they flow down. Losses in river channel are generally caused by abstractions, seepage along river channel and evaporation from river surface. The amount of loss was estimated on the basis of comparison of simultaneous discharges recorded at plural stations in Tana and Athi rivers. The results are shown below.

River	Loss (m^3/sec/100 km*)
Middle reach of Tana River	0.68
Lower reach of Tana River	4.10
Lower reach of Athi (Sabaki) River	1.48

Note : * Length of river stretch

Along the Tana River, gentle riverbed gradient and meandering in the lower reach causes rather large losses in river channel which correspond to 6 times those in the middle reach, while, in the lower reach of the Athi River, its extreme low flow discharge depends on the runoff from the Tsavo River which has a stable annual mean discharge of 6.4 m^3/s on average without much monthly fluctuation.

2.3.5 Flood condition

(1) Regional Flood Frequency

Regional characteristics of the magnitude of flood peak discharges were elaborated by frequency analysis of annual maximum peak discharge at 78 water level gauging stations. The runoff coefficient during flood was also estimated by referring to the recorded flood hydrographs and concurrent rainfall data. The data show that the coefficient varies from 0.10 to 0.39 which appears to be relatively small, but within a practical range when compared to another study (Ref.8). The regional flood frequency curves were also compared with the results developed by the University of Nairobi (see details Sectoral Report B).

(2) Probable Rainfall

Probable rainfall depth was calculated at 161 stations having a relatively long recorded period without missing data during wetter months. The isohyetal maps of probable rainfall depth were delineated for various return periods as shown in Sectoral Report B.

(3) Probable Maximum Precipitation

Hershfield's method was applied to estimate probable maximum precipitation (PMP). The equation is;

$$Xm = Xn + Km \times Sn \quad \text{(Eq.2.3.6)}$$

where,
- Xm : PMP (mm),
- Xn : mean annual maximum rainfall (mm),
- Km : adjustment factor for standard deviation, and
- Sn : standard deviation of annual maximum rainfall (mm)

Obasi and Nimira (Ref.9) made an attempt to adjust the value of Km by geographic zone, namely, Km=11 for Arid and Coast areas and Km=15 for Highland and Inland. In this JICA Study, the isohyetal map of PMP was delineated applying the above adjustment factors of Km as shown in Figure 2.3.5.

The area reduction factor of probable rainfall depth was estimated from the isohyetal map produced from the data collected during the heavy "Uhuru Rains" in the Upper Tana River basin in 1961.

(4) Design Flood for Flood Control Scheme

Design discharges for proposed flood control schemes were evaluated on regional flood frequency basis. Almost all design discharges on the previous studies are in an adequate range. However, the design discharge of the Yala Flood Control Scheme of 300 m^3/sec is relatively low comparing with those in adjacent basins.

(5) Probable Maximum Flood for Dam Scheme

Probable maximum flood (PMF) for existing and proposed dam schemes was compared with PMP in and around their catchments. The relationship between PMF and PMP was obtained by the equation;

$$Q = (0.094 \times R - 9.86) \times A^{0.75} \quad \text{(Eq.2.3.7)}$$

where,
- Q : PMF (m^3/sec),
- R : PMP (mm), and
- A : catchment area (km^2)

The above relationship is shown in Figure 2.3.6.

(6) Design Discharge in Small Catchment

Design discharge for small catchment with a catchment area of less than 100 km^2 was estimated by Richard's method which is basically derived from the Rational formula.

2.3.6 Lakes

Most lakes in eastern Africa are associated with the Rift Valleys as shown in Figure 2.3.7 (Ref.10). It has been known that many African lakes once stood at substantially higher levels than they do today. With the exception of Lake Turkana, these lakes tend to be rather small and saline. While, Lake Victoria, once a shallow basin, is believed to have been impounded by the same earth movements which led to the formation of the rifts. Some features of the lakes are listed below.

Lake	Altitude (El;m)	Area (sq.km)	Max.depth(2) (m)	Water quality
Victoria	1,133	69,500(1)	79	fresh
RIFT VALLEY				
Turkana	375	6,405	120	blackish
Logipi		Seasonal		saline
Baringo	975	130	10	fresh, but containing fluoride
Bogoria	991	34	10	saline
Nakuru	1,758	26-52	1.3	saline
Elementaita	1,776	18	1.1	saline
Naivasha	1,884	180	6.5	fresh
Magadi	579	100	0.5	saline
FOOT OF MT. KILIMANJARO				
Chala	839	2	90	fresh
Jipe	701	18-28	2.0	fresh
Amboseli		Seasonal		saline

Note : (1) 3,850 km2 is Kenyan territory.
(2) Lake water level has changed drastically. Some lakes have sometimes dried up.

The fresh water lakes hold about 315 MCM of water that is currently under-utilized. It is expected that domestic water supply and small-scale irrigation projects in the riparian regions will be initiated to utilize the lake water. Besides, irrigation, fish farming and recreational use of lakes will be added forms of economic activities that might boost development around the lakes.

It has to be appreciated that the fluctuations of lake water level may not be in phase with climatic events. Some lakes which are primarily fed by groundwater can show greater time lags in their responses to climatic events. In the Study, the variations of annual mean lake water level of Lakes Victoria and Naivasha (Figure 2.3.8) were looked into to observe the general aspect of the relationship between their water level and rainfall depth, while, the general aspect of the other lakes are described in Sectoral Report B on the basis of some references.

2.3.7 Springs

The flow of a perennial river in dry seasons usually consists of discharge from one or more groundwater reservoirs; this may occur at springs, or along a reach of the river where the riverbed intersects a groundwater table. As the dry season advances, the river runoff gradually decreases as the storage in the groundwater reservoirs becomes depleted. While, during a wet season, river runoff is usually increased by surface runoff. Under such a condition, some of the rain will also provide increments to the groundwater storage, and the increased groundwater flow will add to the river discharge.

Some of river runoff in dry seasons still remain in the river channel, even in the months without rainfall. This river runoff is assumed to be the amount of discharge from groundwater reservoir including springs.

Springs are generally located at the fringe of forest areas as shown in Figure 2.3.9. It is therefore possible to point out their groundwater reservoirs, while, the hot springs are signs that there is hot magma not very far below the land surface. Such hot springs are located around the lakes in the Rift Valley.

2.3.8 Sedimentation

(1) Suspended load

Suspended load measurements have been carried out by the MOWD at representative water level gauging stations.

The suspended load rating curves were established at 36 stations having more than 30 datum as given in Table 2.3.1. The rating curves established are summarized in Sectoral Report B. It is to be noted that the curves are still of limited use, since most of the existing sampling data represent the load concentration during low flow period. The data during high flow period should be added to improve the reliability of the curves.

Although the trend analysis for suspended load concentration is useful for estimating the variation of soil erosion rate of catchment, there are only 5 stations with the monitoring data of more than 20 years - they are, 1DA02 at Nzoia River, 4AA05 and 4AC03 at Sagana River, 4CA02 at Chania River and 4CB04 at Thika River. The data at the above stations, however, show that a number of monitoring had been carried out in the 1960's, while little monitoring had been carried out after 1970. The long-term tendency of suspended load concentration, therefore, is deemed to be a subject of future studies to be attempted after more data have been accumulated.

(2) Sediment deposit volume in the reservoir

Since the rating curves of suspended load are of limited use (applicable only for the estimation of sediment volume during low flow discharge), the sediment deposit volume in the potential damsite was estimated on the basis of the actual survey data of sediment accumulation in Masinga reservoir and the estimated sediment yield rates for several proposed dams. Referring to those data, then, regional denudation rates were derived using the probable 1-day rainfall depth with a probability of once in 10-year as a parameter of estimation.

The results are enumerated below;

Region	Denudation Rate (m^3/km^2 /year)	Remarks
Upper Tana River	350	Survey result
Upper Kerio River	47.66 * Ri - 3016	
Machakos Area	10.00 * Ri - 550	
Dams in the forest	120	Average design value
Others	10.89 * Ri - 465	

Note : Ri means average probable 1-day rainfall in the dam catchment with 10-year probability. (See Sectoral Report B)

2.4 Groundwater

There are two types of groundwater aquifers. An unconfined aquifer is one which the water surface is free and the groundwater pressure is equal to atmospheric pressure. A confined aquifer is one where the water bearing layer is covered by an impermeable confining layer. The water in this aquifer is under pressure greater than atmospheric pressure. The pressure is released when the confining layer is punctured and the water level rises to the piezometric level which is determined by the pressure condition present in the aquifer.

2.4.1 Existing borehole data and groundwater database

(1) Existing Borehole Data

Boreholes have been drilled by government departments, corporations and related institutions, private firms and by individuals. Borehole drilling is preceded by the following procedure:

(a) A letter of request for drilling in the case of government departments or related in situation,
(b) Completion of either Forms WAB 245 and WAB 26 or Forms 245B and WAB 29, depending on the location of the project,
(c) Investigation and recommendation of the drilling by MOWD,
(d) Authorization for the drilling by Water Apportionment Board within MOWD. When a borehole has been drilled, it is assigned a serial number, listed and plotted on a base map. Borehole data are filed in both Groundwater and Drilling Sections of MOWD.

Registered completion records received by March, 1991 accounted for 9,462 boreholes. The Water Act provides that certain data should be submitted within one month of the completion of a borehole. The standard form (WAB.28) should include information on location, ownership, purpose of use, date of construction, well dimension, property of aquifer, pumping test data, water potability, monitoring frequency of water level, rock type, initial yield, and casing installation.

A step-drawdown pumping test and a recovery test have been generally conducted, but constant-discharge pumping test has rarely been carried out in Kenya. Recovery test data can be analyzed only when the pre-pumping is done at a constant rate, to estimate hydraulics of aquifers and drawdown of wells. The existing recovery test data which match this condition were calculated to estimate transmissivity and storage coefficient of the aquifer.

Water quality analyses have been conducted for geochemical interpretation and classification of potability. The geochemical interpretation and classification of potability should include water temperature, electric conductivity, PH, total dissolved solid (TDS), total hardness, colour, turbidity, permanganate No., chloride (Cl), Nitrite (NO_2), Nitrate (NO_3), Iron (Fe), Manganese (Mn), Fluoride (F), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Bicarbonate (HCO_3), Sulphate (SO_4), Silica (SiO_2), Carbonate (CO_3).

The major uses of boreholes are public water supply, agricultural, domestic and industrial uses in order as shown in the following table. About half of boreholes have no information ("Unknown" and "Undescribed" in the table), and hence the actual number of boreholes for various uses (items from public water supply to livestock in table below) would be more than the figures indicated in the table.

Number of boreholes by use.

Borehole use	No. of boreholes	Percentage (%)
Public Water Supply	2,137	22.6
Agricultural	948	10.0
Domestic	434	4.6
Industrial and Commercial	224	2.4
Livestock	177	1.9
Observation	62	0.6
Exploratory	52	0.5
Other	973	10.3
Unknown	2,496	26.4
Undescribed	1,959	20.7
Total	9,462	100.0

Rock type remarkably affects aquifer characteristics. The country is considered to consist of three major rock types, that is, volcanic, metamorphic basement and sedimentary rocks. The number of boreholes in each rock type are shown in the following table.

Number of boreholes by rock type

Rock type	No of boreholes	Percentage (%)
Volcanics	3,882	41.0
Basements	1,592	16.8
Sediments	878	9.3
Volcanics over basements	162	1.7
Sediments over basements	67	0.7
Sediments over volcanics	72	0.8
Volcanics over sediments	52	0.6
Other	20	0.2
Unknown	255	2.7
Undescribed	2,482	26.2
TOTAL	9,462	100.0

Groundwater abstractions have seldom been investigated in Kenya except for two studies (Chilton, 1970; Swarzenki & Mundorff, 1977) regarding a rather small part of the country for one or two years. The completion borehole record demands information on initial yield for all boreholes, but annual or seasonal values of actual groundwater abstraction have not been investigated nationwide.

Annual and seasonal groundwater levels have seldom been measured nationwide. The completion borehole record demands information on struck and rest water levels for all boreholes, in which the information on initial water levels are available nationwidely.

(2) Groundwater Database

1) Borehole database

Borehole data up to 1985 for the whole country are stored on the Wang VS-15 computer in the Ministry of Water Development. During this National Water Master Plan Study, borehole data after 1986 were inputted and stored on a database system, a Vax station and Macintosh computers, established newly under the Study.

The stored borehole data contain 31 information codes for a borehole:

- Borehole reference number
- Location (district code; longitude; latitude; elevation)
- Name of owner
- Purpose of well use
- Date of construction
- Status of the borehole
- Well dimension (depth; casing diameter; length and type; screen length)
- Aquifer (rock type; rest and struck water levels)
- Pumping test (discharge; drawdown; pumping hours; recovery hours)
- Potability
- Monitoring frequency of water level

The coding of these parameters is described in detail in Sectoral Report C.

The chemical properties are only indicated as a potability code. The logging data are expressed as a rock type code. The completion borehole record should include information on initial yield and water levels for all boreholes, but monitoring of groundwater abstraction and water levels have seldom been carried out and data of groundwater abstraction and water levels are not stored on the computer.

2) Groundwater quality database

Water quality data have been filed in MOWD. They are compiled as shown in the Databook DB.3. Using those data, a database of water quality was prepared by the Study and stored on the Vax station and Macintosh computers. The following chemical parameters are included in the database : water temperature, electric conductivity, pH, total dissolved solids, total hardness, colour, turbidity, permanganate no., chloride, nitrite, nitrate, iron, manganese, fluoride, sodium, potassium, calcium, magnesium, bicarbonate, sulphate, silica, carbonate, etc .

2.4.2 Basic characteristics of boreholes

(1) Aquifer Characteristics by Rock Type

Rock types remarkably influence groundwater occurrence. The country is simplified to consist of three major rock types - basement, volcanic, and sedimentary rocks.

The influence of rock type on average aquifer characteristics is summarized in the following table :

Aquifer characteristics by rock type

Rock type	Elevation (m)	Total depth (m)	Water level Struck (m)	Water level Rest (m)	Pumping test Yield (m^3/hr)	Pumping test Drawdown (m)	Specific capacity (m^3/hr/m)
Volcanics (V)	1762.74	124.70	93.96	48.68	7.45	37.05	0.20
Basements (B)	1266.59	79.59	55.30	26.40	4.54	31.08	0.15
Sediments (S)	439.48	81.22	54.25	34.80	5.55	17.39	0.32
(V) over (B)	1079.47	82.53	54.39	28.53	7.39	25.87	0.29
(S) over (B)	1073.65	91.28	51.16	25.97	5.67	32.28	0.18
(S) over (V)	1265.85	90.44	63.22	28.98	7.57	24.14	0.32
(V) over (S)	1332.28	106.71	79.37	26.60	10.76	41.22	0.26
Others	1054.23	103.95	63.00	38.88	4.58	19.39	0.24
Unknown	1391.61	78.66	55.76	25.68	4.89	24.44	0.20

1) The boreholes in volcanics have highest value of elevation, 1763 meters, whereas those in sediments have the lowest, 439 meters.

2) The total depth of boreholes in volcanics is deepest and the average is 125 meters. Boreholes in basements and sediments are shallower and have mean values of 80 and 81 meters, respectively.

3) The struck water level of boreholes in volcanics is deepest, 94 meters, whereas those in sediments and basements are about 55 meters.

4) The rest water level of boreholes in volcanics is deepest, 49 meters, whereas that in basements is shallowest, 26 meters.

5) The boreholes in volcanics have highest value of artesian pressure, 45 meters, whereas those in sediments have the lowest, 20 meters. The artesian pressure means a pressure of struck water level minus rest water level.

6) The yield in volcanics is highest, 7.5 cubic meters per hour (m^3/h), whereas that in basement rocks is lowest, 4.5 cubic meters per hour (m^3/h).

7) The specific capacity in basement rocks is lowest, 0.15 cubic meters per hour per meter ($m^3/hr/m$) whereas that in sediments is by far the highest, 3.4 cubic meters per hour per meter ($m^3/hr/m$). Thus the sediments have a higher groundwater potential than the basement rocks.

8) The boreholes in volcanics have highest value of drawdown 37 meters, whereas those in sediments have the lowest, 17 meters.

(2) Aquifer Characteristics by District

The aquifer characteristics by province are summarized as shown in the following table :

Aquifer characteristics by province

Province	Elevation (m)	Total depth (m)	Water level Struck (m)	Rest (m)	Pumping test Yield (m^2/hr)	Drawdown (m)	Specific capacity ($m^3/hr/m$)
Nairobi	1721.30	152.50	112.50	56.70	7.70	39.50	0.20
Central	1835.35	129.58	96.94	45.86	7.84	41.81	0.19
Coast	240.62	67.96	42.31	23.81	5.80	14.27	0.41
Eastern	1258.65	92.57	64.74	34.55	5.40	31.83	0.17
North Eastern	377.09	122.93	98.63	79.19	4.83	20.23	0.24
Nyanza	1319.42	76.00	54.58	19.30	6.39	31.13	0.21
Rift Valley	1728.17	112.56	83.40	46.54	6.70	35.60	0.19
Western	1348.50	53.04	35.04	11.70	3.66	19.43	0.19

1) The elevations of boreholes in the Central (especially Nyandarua District), Rift Valley (especially Nakuru, Narok and Kericho Districts) and Nairobi Provinces, composed of volcanics in geology, are highest, 1835, 1728 and 1721 meters, respectively.

2) The total depths of boreholes in the Nairobi and Central (especially Kiambu Districts) Provinces, composed of mainly volcanics in geology and North-Eastern (especially Mandera District) Province, composed of mainly old sedimentary rocks, are deepest, 153, 130 and 123 meters, respectively.

3) Boreholes in the Nairobi, North-Eastern (especially Garissa District) and Central (especially Nyandarua District) Provinces have deepest value of struck water levels, 113, 99, and 97 meters, respectively whereas those in the Western (especially Kakamega District) Province, composed of basement rocks and in the Coast (especially Lamu District) Province, composed of sedimentary rocks have the lowest, 35 and 42 meters, respectively.

4) Boreholes in the North-Eastern (especially Garissa District) Province have deepest value of rest water levels, 79 meters, whereas those in the Western (especially Kakamega District) Province, composed of basement rocks and in the Coast (especially Lamu District) Province, composed of sedimentary rocks have the lowest, 11 and 24 meters, respectively.

5) Boreholes in the Nairobi and Central (especially Kiambu District) Provinces have largest value of artesian pressure, 56 and 51 meters, respectively, whereas those in the Coast (especially Lamu and Mombasa Districts) and North-Eastern (especially Garissa District) Provinces, composed of sedimentary rocks, have the lowest, 18.5 and 19 meters, respectively.

6) The yields of boreholes are lowest in the Western (especially Kakamega District) and Eastern (especially Embu and Kitui Districts) Provinces, which are composed of metamorphic rocks in geology; and North-Eastern (especially Wajir and Mandera Districts) Province, 3.7, 5.4, and 4.8 cubic meters per hour per meter (m^3/hr/m), respectively, whereas the yields of boreholes in the Central (especially Kiambu District) and Nairobi Provinces are highest, 7.8 and 7.7 cubic meters per hour per meter (m^3/hr/m), respectively.

7) The boreholes in the Central (especially Murang'a District) and Nairobi Provinces have largest value of drawdown, 42 and 40 meters, respectively,while those in the Coast (especially Lamu and Mombasa Districts) Province have the lowest, 14 meters.

8) The boreholes in the Eastern (especially Kitui and Machakos Districts) Province have lowest value of specific capacity, 0.17 cubic meters per hour per meter (m^3/hr/m) ,while those in the Coast (especially Lamu and Mombasa Districts) Province have the largest, 0.41 cubic meters per hour per meter (m^3/hr/m).

(3) Aquifer Characteristics by Drainage Basin

The influence of drainage basin on average aquifer characteristics is summarized as shown in the following table :

Aquifer characteristics by major drainage basin

Basin	Elevation (m)	Total depth (m)	Water level Struck (m)	Water level Rest (m)	Pumping test Yield (m^2/hr)	Pumping test Drawdown (m)	Specific capacity (m^3/hr/m)
Lake Victoria	1399.61	70.87	50.59	19.33	4.98	26.41	0.19
Rift Valley	1839.24	113.15	86.82	55.12	7.29	25.07	0.29
Athi River	1431.87	115.88	84.02	40.85	7.16	35.25	0.20
Tana River	1244.18	109.17	75.08	38.40	6.58	39.15	0.17
Ewaso N'giro	1309.70	111.67	88.58	52.52	5.25	39.50	0.13

1) The elevation of boreholes in the Rift Valley basin, composed of mainly volcanics in geology, is highest, 1839 meters, whereas that in the Tana River, composed of mainly sedimentary rocks, has the lowest, 1244 meters.

2) The total depth of boreholes except for in the Lake Victoria basin which is composed of mainly basement rocks in geology, is about 110 meters.

3) The boreholes except for in the Lake Victoria basin have almost same value of struck water levels, about 80 meters.

4) The boreholes in the Rift Valley and Ewaso N'giro river basins have highest values of rest water levels, 55 and 53 meters,respectively, whereas those in the Lake Victoria Basin, have the lowest, 19 meters.

5) The boreholes except for in the Athi river basin have almost same value of artesian pressure, about 30 meters.

6) The yields of boreholes are lowest in the Lake Victoria and Ewaso N'giro river basins, 5.0 and 5.3 cubic meters per hour (m^3/hr), respectively, whereas the yields in the Rift Valley and Athi river basins, 7.3 and 7.2 cubic meters per hour (m^3/hr), respectively, are highest

7) The boreholes in the Ewaso N'giro and Tana river basins have largest value of drawdown, about 40 meters,while those in the Rift Valley and Lake Victoria Basins, have the lowest, 25 meters.

8) The boreholes in the Ewaso N'giro river basin have lowest value of specific capacity, 0.13 cubic meters per hour per meter (m^3/hr/m), while those in the Rift Valley have the largest, 0.29 cubic meters per hour per meter (m^3/hr/m).

Based on the data in existing borehole completion records, the geographical distribution of yield rates (representing the initial yield tested at time of drilling) was analyzed as shown in Figure 2.4.1.

2.4.3 Groundwater occurrence

Water storage and transmitting capacities of rocks are attributed principally to hydrogeological properties. These capacities of rocks are a function of their lithology. Sandstones of Tertiary and Quaternary ages with almost the same granular properties would occur in similar aquifers. Variation in age of the rocks becomes important especially in very old rocks where post-depositional alterations have affected the primary porosity of the rocks.

Hydrological maps are composed of various information on the basis of the reports, the existing borehole data and groundwater investigation results. Figure 2.4.2 shows a reduced copy of the 1:1,000,000 map. Figure 2.4.2 (2/2) shows a groundwater potentiality map.

The hydrogeological areas of Kenya can be classified into the following three major geological areas (Figure 2.4.2):

1) Volcanic Rocks (Patterns 3 and 4 of Figure 2.4.2)

2) Pre-cambrian metamorphic basement rocks (Pattern 5 of Figure 2.4.2) and Pre-cambrian intrusive rocks (Pattern 9 of Figure 2.4.2)

3) Sedimentary rocks (Patterns 1, 2, 6, 7, 8 of Figure 2.4.2)

(1) Volcanic rocks area

The volcanic rocks cover about 26% of the country, more commonly in Western Kenya, where the volcanics exhibit a linear alignment with the Rift Valley System. The general pattern is north-south, stretching from Tanzania into Sudan and Ethiopia.

The lithology is widely variable and include phonolites, trachytes, tuffs and basalts. Groundwater is stored typically in the old weathered surfaces between lava flows and older formations (mainly the metamorphic basement rocks) as well as between successive lava flows. Fractures, faults, fissures and joints are also suitable sites for groundwater storage.

The thickness of the volcanic overburden varies from nil to several hundred meters and hence groundwater occurs at very varying depths. This also means that several aquifers are struck in a borehole.

The aquifers in the volcanic areas are confined. Yield, depth to aquifers and static water level vary enormously within the volcanic rocks. The yield is about 7.5 m^3/hr with a standard deviation of about 6.5 m^3/hr. The depth to main aquifer is about 94 metres with a standard deviation of about 58 metres. The artesian pressure is about 45 metres.

The groundwater in the volcanic area is generally of bi-carbonate type with low total dissolved solids (TDS) or low electric conductivity. There are local pockets of high fluoride content which is believed to be of volcanic and fumarolic origin.

(2) Pre-cambrian metamorphic basement rocks and intrusive rocks area

The Pre-cambrian rocks are widely distributed in the central, western and north-western parts of Kenya and cover about 17% of the country

The lithology is dominated by granites, gneisses, schists and sediments. These rocks are deeply weathered in places although the extent of weathering differs. Where faults and fractures are distributed both laterally and vertically, groundwater occurs in rather deep horizons.

The aquifers in the basement area are rather confined. Yield, depth to aquifers and static water level vary within rocks . The yield is about 4.5 m^3/hr with a standard deviation of about 5.2 m^3/hr. The depth to main aquifer is about 55 meters with a standard deviation of about 40 meters. The artesian pressure is about 31 meters.

The confined groundwater is generally hard with moderate electric conductivity.

In the upper parts of the basement rocks at various stages of weathering and fracturing, unconfined groundwater occurs locally at depths varying from a few to several tens of meters. The water level fluctuates considerably and may dry up in dry season.

(3) Sedimentary rocks area

The sedimentary rocks area accounts for about 55 % of Kenya, predominantly in eastern and north-western part of the country and around Lake Victoria. The rocks range in age from Paleozoic to Cenozoic and are composed of sands, clays, sandstones, shales and limestones.

The average depth to aquifers is about 48 meters with a standard deviation of about 54 meters. The artesian pressure is lowest (about 20 meters), but the specific capacity is highest at about 0.32 m^3/hr/m.

1) Quaternary sediments

The Quaternary sediments area accounts for almost one-third of the country, stretching essentially from the Tanzanian border to the Ethiopian border , and as far east as longitude 38°E.

The lithology is dominated by alluvial, lake and beach sands, coral reefs and limestones. The sediments are loose and permeable.

The aquifers are generally shallow and unconfined. The success ratio of boreholes is very high.

The serious problem in groundwater development is that of salt water, which has caused the failure of many boreholes. The groundwater is generally of a chloride type. The origin of the saline water is believed to be due to accumulation of solute evaporate minerals within the sediments which have not been removed by groundwater circulation. However, salty groundwater in the coast part is believed to be due to the seawater intrusion.

2) Older sedimentary rocks area.

The older sediments are distributed in the south-eastern and north-eastern corners of the country. The three major sedimentary rocks, viz, sandstones, limestones and shales dominate the lithology.

The aquifers are typically confined and deep. Considerable faulting and folding are believed to have occurred and the groundwater occurs in the syncline parts of the folds and the fractured parts of faults.

The groundwater is generally of a chloride type.

Hydrogeological maps were prepared in a scale of 1:250,000 under this Study and compiled in the form of "Atlas of Groundwater in Kenya". Hydrogeological maps are composed of the information which have been made available from various previous reports, existing borehole data and the results of groundwater investigation carried out under the Study.

2.4.4 Groundwater abstraction

(1) Present abstraction

Aquifer tests and well surveys were carried out under the Study to obtain supplemental information on existing boreholes and confirm present condition of aquifers. On a local contract basis, 45 and 594 boreholes were investigated for aquifer tests and well surveys, respectively. The field work was completed in the middle of February, 1991. Figure 2.4.3 shows the location of boreholes served for the aquifer test and well survey.

The results of the well survey show the following condition of pump operation :

Condition of pump operation

	Hourly (hours)	Weekly (days)	Annual (days)
Average	12.02	6.57	341.81
Minimum	0.42	1	48
Maximum	24	7	365
Number of data	300	330	331

The utilization ratio, a ratio of annual production to the sum of initial yield of boreholes in use, was estimated to be 0.48 from the results of well surveys as shown in Table 2.4.1. The utilization factor was calculated from the data of 114 boreholes for which information of operation records was obtained in the well surveys.

The groundwater abstraction was seldom observed in Kenya except for two reports (Chilton, 1970 ; Swarzenski & Mundorff, 1977). Both reports refer to a rather small part of the country for one or two years. Chilton estimated an annual factor of 15.3 %, a ratio of annual production to the sum of initial yield of "all boreholes" in Nairobi. Therefore, this ratio cannot be nominally compared with the above-mentioned utilization factor which represents a ratio of annual production to the sum of initial yield of "boreholes completed and in actual use".

If the ratio, a ratio of production to the sum of initial yield of all boreholes, would be estimated from the data of the well surveys, the ratio is calculated to be 22.6 %.

The present groundwater abstraction rates by drainage basin were estimated using this ratio (Table 2.4.2). The results are given in the table below. The total present groundwater abstraction rate in Kenya is estimated at 57.21 million m^3/year, which is equivalent to about 1.5 times the value estimated by TAMS in 1980. The geographical distribution of present groundwater abstraction is shown in Figure 2.4.4.

Present groundwater abstraction rates by basin

Drainage basin	Rainfall (million m^3/year)	Abstraction (million m^3/year)
1 Lake Victoria	63,241	9.34
2 Rift Valley	73,314	11.67
3 Athi River	49,393	27.76
4 Tana River	87,840	4.79
5 Ewaso N'giro River	86,403	3.65
TOTAL	360,191	57.21

Note: Estimate based on well survey data

In terms of the groundwater abstraction rate, the major uses of boreholes in the country are agricultural, public water supply, and domestic as shown in the following table.

Present abstraction rates by use

Use of boreholes	Abstraction (million m^3/year)
Agricultural	11.75
Public water supply	11.13
Domestic	3.46
Irrigation	2.08
Livestock	1.07
Exploratory	0.10
Observation	0.08
Others	7.89
Unknown	19.65
TOTAL	57.21

Note: Estimate based on well survey data

(2) Estimates of safe abstraction rates

<u>Boreholes</u>:

Water level of well and aquifer falls when the pumping is continued. Drawdown of the water level depends on aquifer property and pumping rate. Boreholes should be designed so as not to cause excessive drawdown of the pumping water level; say, down to the top of the pump which is installed just above the screened part of the boreholes.

The existing recovery test data and the recovery test data obtained in the field surveys of this Study were analyzed (927 boreholes in total) and drawdown analyses were carried out (see Sectoral Report C for the results). The results of drawdown analyses show that only 71 boreholes of the 927 boreholes could continue to be pumped at the rate of their initial yield for 20 years of pumping with the maximum drawdown of less than 10 meters. These boreholes are regarded to be "safe-yielding boreholes". Table 2.4.3 shows the summary of results by District (see Sectoral Report C for breakdowns by location).

A very bold assumption set forth here is that the ratio of safe-yielding boreholes to all the boreholes may represent the ratio of safe abstraction to the potential yield which is estimated on the basis of yield rates assessed in Figure 2.4.1. The ratio is calculated as 7.6% (71/927), which represents an average value for the whole country.

The potential yield was estimated for each Location assuming the borehole density of a borehole per 2 km^2 and applying the yield rate shown in Figure 2.4.1. Safe abstraction rate was then calculated for each Location by applying the ratio of 7.6%.

Total safe abstraction rate of boreholes throughout Kenya is estimated as 193 million cubic meters per year as summarized by District in Table 2.4.4 (see Sectoral