# REPUBLIC OF KENYA

## MINISTRY OF WATER DEVELOPMENT

REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

# THE STUDY

# ON

# THE NATIONAL WATER MASTER PLAN



# SECTORAL REPORT (B)

# HYDROLOGY

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

# LIST OF REPORTS

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## SECTORAL REPORT

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# 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.

THE STUDY ON THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT (B)
HYDROLOGY

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# B1. CLIMATOLOGY

## 1.1 Sources of Data

Summaries of 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 89 meteorological stations covering periods of several years to some 60 years (Ref.B.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 B1.1. A relatively wet and narrow tropical belt lies along the Indian Ocean coast. Behind the coastline large areas of semi-arid and arid lands stretch. 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 climatic data on a monthly mean basis was, therefore, compared with their altitude by using the least square method. Some data has a distinctive relationship to their altitudes.

## 1.2 Winds and Circulation

The climate in Kenya is controlled by the northward and southward movement of the Intertropical Convergence Zone (ITCZ). Considerable variation of climate occurs throughout the country because of the great difference in topography.

The sun is approximately overhead in Kenya at the end of March, and also at the end of September so that ITCZ can be expected to be most effective about a month later; that is, late April to May and late October to November, and these months correspond to the 2 rainy seasons in Kenya. The former is referred to as "Long Rains" and the latter as "Short Rains".

At these times the pressure is high in the subtropical latitudes of the Sahara and South Africa and there is a general movement of air mass from these high pressure belts towards the trough of low pressure in the equatorial region. This usually results in organized South-easterly and North-easterly winds meeting in a zone of convergence or more often winds, which are not well organized converging locally. Both types of convergence result in vertical upward motion of the air, condensation, formation of clouds and precipitation.

While a trough of low pressure extends over Uganda and Lake Victoria throughout the year, so that there is always a tendency for more convergence and therefore more rain in this area at any season.

The influence of ITCZ for the East and Central African Region is summarized as follows;

| Months | Location of ITCZ | Country affected |
|---|---|---|
| January to April | Southern-most position | Zambia, Malawi, Tanzania |
| April to June | Back near the Equator, moving northwards | Kenya (Long Rain), Uganda, South Somalia |
| July to October | Northern-most position | North Kenya, Uganda, Ethiopia, North Somalia |
| October to December | Near the Equator, moving southwards | Kenya (Short Rain), Uganda, South Somalia |

Source : Ref.B.2

The characteristics of monthly circulation can be explained as follows;

January to February : A northeast monsoon dominates and bifurcates the 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 : A southeast wind with rain dominates over the whole country. The wettest "Long Rains" period is established.

May : The south monsoon is firmly established. Its southerly wind causes maximum monthly rainfall in the coast area. Many coastal stations record over 20 rainy days.

June to September : The south monsoon is dominant in the flat area east of $38^{o}$E. On crossing the equator, its wind becomes part of the southeast monsoon. Rainfall depth over the whole country shows a marked drop. These months are the dry season between the "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 north-easterlies. Some convergence takes place between these two winds which brings about some rainfall. These winds mark the beginnings of the "Short Rains".

November : Both the northeast monsoon at higher level and south monsoon are dominant and convergence is more widespread and this month normally records the peak of the "Short Rains".

December : Northeast monsoon restores its strength and dry and clear weather spreads. The "Short Rains" disappear.

The surface wind movement on a monthly basis is shown in Figure B1.2. The annual mean surface wind speed is shown in Figure B 1.3.

## 1.3 Temperature

Kenya has a large range in from below the freezing point on snow-capped Mt.Kenya as a minimum to over $40^{o}C$ in the north and northeast areas as maximum.

Although the daily variation of air temperature is large, the daily mean temperature does not show remarkable change throughout the year, about $5.5^{o}C$ at Lamu on the coast to $18.2^{o}C$ at Rumuruti in the highlands as shown in Figure B 1.4.

The annual mean temperatures are closely related to their elevations, and the relationship is described by the equation:

$$T = a + b \times EL \qquad \text{( Eq.1 )}$$

where, T : annual mean temperature ($^{o}C$),
EL : Elevation (m), and
a and b : constants

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 |
| Extreme Highest | 37.804 | -0.00475 |
| Extreme Lowest | 18.475 | -0.00680 |

The above relationships are shown in Figure B 1.5.

An extremely high temperature of $41.8^{o}C$ has been recorded at Lake Magadi in the Rift Valley. Two other stations have each recorded over $40^{o}C$; $41.4^{o}C$ at Garissa and $40.3^{o}C$ at Mandera. While a extremely low temperature of $-3.3^{o}C$ has been recorded at Eldama Ravine and $-2.2^{o}C$ has been recorded at Kericho.

## 1.4 Relative Humidity

Reading 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. A distinctive relations to their elevation was not found as shown on Figure B1.6.

## 1.5 Sunshine Hours

Sunshine hours are generally related to the latitude of the observation point. However, the range of variation of latitude in Kenya astride the equator seems to decrease such latitude effects. Then the decrease of sunshine hours by cloud cover might be another factor.

Sunshine hours have been recorded at 56 stations. The relation to their elevation is defined by the equation;

$$SH = 8.557 - 0.00081 \times EL \quad \text{( Eq.2 )}$$

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

The above relationship is shown in Figure B1.7.

## 1.6 Evaporation

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;

$$Eo = 2{,}575 - 0.4838 \times EL \quad \text{( Eq.3 )}$$

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

The above relationship is shown in Figure B1.8.

## 1.7 Evapotranspiration

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.B.3). These values were also plotted with their elevations as shown in Figure B1.8. The relation to their elevations is defined by the equation;

$$ETo = 2{,}329.9 - 0.03235 \times EL \quad \text{( Eq.4 )}$$

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

## 1.8 Hailstorms

The hailstones in East Africa have been known to be 25 mm in diameter on an average. These are much larger than those of temperate regions. They, therefore, cause a lot of damage to crops and their control is an urgent matter for research.

In September 1958, a single hailstorm in a tea estate in Kericho caused damage which was estimated at 120,000 Shs. at the 1961 price level, while the loss of coffee products due to hailstorms in western Kenya for the successive 5-year period was estimated at 1.2 million Shs. at the 1961 price level (Ref.B.4).

## 1.9 Tropical Cyclone

Tropical cyclones have very rarely been observed in the zone ranging from $5^{o}N$ to $5^{o}S$. In the Southwest Indian Ocean, cyclones originate from 2 areas; (i) between about $5^{o}S$ to $20^{o}S$ and $50^{o}E$ to $70^{o}E$ and (ii) Mozambique Channel.

The latter sometimes affects the East African coast when it takes rather unusual tracks in the direction to west or northwest. Two cyclones have been recorded: The Cyclone "Lindi" (14 to 15 April, 1952) and the Tropical Cyclone "Lily" (19 April to May, 1966). Whereas the main effect of the Cyclone "Lily" was only an increase in rainfall in the coastal area of Kenya, the Tropical Cyclone "Lindi" caused considerable damage to property in Tanzania, demolishing building and plants.

# B2. RAINFALL

## 2.1 Sources of Data

Daily rainfall data has been published on a monthly basis since 1904 by the East African Agricultural Department (EAAD) for the period of 1904 to 1929, EAMD from 1930 to 1979, and KMD since 1980. The data on a daily basis is presently stored in the computerized database system of the headquarters of KMD.

Rainfall data at 2,867 stations have been collected at meteorological gauging stations of KMD and through the water related government agencies such as MOWD, MOA and MOENR.

## 2.2 Network of Rainfall Gauging Stations

In Kenya, rainfall has been measured for a period ranging from a few years to about 90 years at various stations. The rainfall station at Mombasa was first established in 1891 and the systematic collection of rainfall data as well as climatic data was done by EAMD.

Registration code of the station is 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, and 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 in KMD. The stations over Kenya are plotted as shown in Figure B2.1.

## 2.3 Annual Rainfall

### 2.3.1 Periodicity

Of the registered stations, annual rainfall at 24 stations having relatively long recording period were selected and the variations of annual rainfall are shown in Appendix B.1. The figures show that annual rainfall varies with a rather long periodicity for 30 to 40 years. The autocorrelation coefficient, however, shows that no periodicity appears in the series of annual rainfall.

### 2.3.2 Isohyetal map

An isohyetal map of annual rainfall was developed on the basis of 212 rainfall stations with their records of more than 20 years as shown in Figure B2.2. The isohyetal map of annual rainfall is shown in Figure B2.3.

## 2.4 Monthly Rainfall

### 2.4.1 Monthly rainfall characteristics

As described in Section B1.2, Kenya is dominated particularly by 3 distinct air masses; (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 influence many of the central, southern and eastern parts of the country in April and (iii) the southwest trade winds which are felt mostly in the western parts of Kenya in July.

The distribution of monthly rainfall at representative rainfall gauging stations is shown in Figure B2.4. In western Kenya, especially in Lake Victoria basin, there is no distinctive dry season throughout a year but with double maxima in April and October. A double maxima in April and November is well defined in Central Kenya, while, the coastal area has a remarkable single maximum in May.

### 2.4.2 Isohyetal map of monthly rainfall

The isohyetal maps on monthly rainfall were developed on the basis of 212 selected stations as well as ones for annual rainfall. The isohyetal maps of monthly rainfall are shown in Appendix B.2.

## 2.5 Daily Rainfall

Daily rainfall records of 212 selected stations were collected from the database of KMD. The data, however, does not cover the whole period in which monthly rainfall was recorded. The reasons are: (i) daily rainfall records for the period of 1958 to 1988 have been stored mainly in the database, (ii) in case the monthly rainfall was less than about 5.0 mm, daily rainfall data were never stored, and (iii) the old rainfall recording forms before 1957 have been abandoned and summarized monthly rainfall recording papers have been stored in KMD.

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

## 2.6 Hourly Rainfall

Annual and monthly patterns of diurnal variation of rainfall were examined for 54 stations in Kenya, giving hourly distributions of rainfall month by month (Refs.B.5 and B.6). The diurnal variation of hourly rainfall was divided into 5 patterns as follows :

(1) Coast area

The diurnal pattern shows a distinctive minimum rainfall in the evening. It increases in the midnight and shows a plateau-like distribution until noon. There is a decreasing trend in the afternoon.

(2) Eastern slope of highland

In this region, a distinctive maximum hourly rainfall has been recorded from midnight through early morning, while the minimum is around noon.

(3) Highland

The diurnal pattern shows a distinctive maximum rainfall in the evening and minimum around 9:00 a.m. There is usually a rapid increase of shower activity in mid-afternoon. After the peak of maximum hourly rainfall, rainfall recessed gradually.

(4) Lake Victoria basin

The characteristics of this area is basically similar with those in the highland. The maximum hourly rainfall occurs slightly later than one of the highland area. The minimum hourly rainfall occurs also at 9:00 a.m.

(5) Low land

The area is located in a semi-arid zone having annual rainfall depth less than 500 mm. The pattern of diurnal variation is different at different stations.

The diurnal variation of hourly rainfall at representative stations are illustrated in Appendix B.3.

## 2.7 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 also the harvesting of rain waters.

The relationship between the annual mean number of rainy days and annual mean rainfall is shown on Figure B2.5. The data shows that their relationship is represented by the equation:

$$NR = 0.083 \times R + 15.1 \quad \text{( Eq.5 )}$$

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

## 2.8 Drought

The annual rainfall data of 14 stations for the period from 1909 to 1988 were examined to estimate the magnitude of historical drought for high potential areas in Kenya, although the data in semi-arid and arid areas was not included because of the limited observation period. Mean rainfall depth for successive 5 years periods was calculated and ranked in ascending order as given in Table B2.1.

The table shows that the worst drought occurred in 1931-1935 in central Kenya, the second worst was in 1941-1945. In last two decades, a severe drought occurred in 1971-1975 and 1981-1985.

Both climatological records and oral knowledge show that major droughts, with serious results to man, livestock, and game, have occurred in the following years : 1928, 1933-1934, 1942-1944, 1952-1955, 1960-1961, and 1965 (Ref.B.7). NMWP-I Study defined the drought in the early 1970's as the worst for the period from 1945 to 1974.

In Central Kenya, the 1933-34 drought brought the famine known as "Kimouito", so called because people ate hides and skins. The 1971-1975 and 1984-1985 droughts attracted worldwide attention in the north of Kenya's borders.

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

## 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. Among them, the exceptionally heavy and widespread rainfall experienced during October and November 1961 resulted in unusually severe floods in many areas. Peak discharge of about 3,000 $m^3/s$ at Garissa on November 20 to 21 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. Lake water level at Lake Victoria rose by 1.25 m in 1962 over that of the previous year. The lake water level actually started rising in November 1961 and reached its peak in May 1964. Such a peak had not been recorded since the lake water level recorders was first installed at Entebbe in 1899. Although the early stage of flooding at low-lying areas occurred from overbank spill from main river course, latter flooding was created by the backwater effect due to rather high lake water level.

The conditions of flood inundation and its damages has been printed in very few documents in Kenya. However, according to the "District Development Plans", Siaya and

Kisumu Districts, which are located in Kano Plain and Yala Swamp, have indicated the necessity of flood control protection works with their high priority.

# B3. HYDROLOGICAL DATA COLLECTION

## 3.1 Sources of Data

Hydrological data relating to surface water was collected from the Hydrology Section of MOWD which is responsible for collecting and evaluating data on rivers in Kenya. Their database systems in the headquarter of MOWD was established in 1983 and is organized into 3 items; (i) Surface water database, (ii) Groundwater database, and (iii) Water permit database.

The surface water database is further organized into the following 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 every time upon user's request. The data is interpolated linearly in case of missing data within 7 consecutive days.

The Lake Basin Development Authorities (LBDA) also has their own database system in Kisumu. All the surface water data of MOWD concerning to Drainage Area 1 was backed up when LBDA established their own database system. LBDA then carried out the verification of existing rating curves and made efforts to reestablish more accurate ones.

## 3.2 Daily Water Level Data

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

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

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

Distribution of the current (1990) number of registered water level gauging stations by drainage areas are enumerated in Table B3.1 and their geographic distributions are shown in Figure B3.1. Of these stations, 399 stations are being operated by MOWD in 1991 as enumerated below.

| Drainage Area | Registered Station (nos) | | |
| --- | --- | --- | --- |
| | Operation | Abandoned | Total |
| 1 | 114 | 115 | 229 |
| 2 | 50 | 103 | 153 |
| 3 | 74 | 149 | 223 |
| 4 | 116 | 89 | 205 |
| 5 | 45 | 68 | 113 |
| Total | 399 | 524 | 923 |

### 3.3 Discharge Measurement Data

Of the registered stations, rating curves at 115 stations were stored in the database of MOWD. For converting water level data into discharge data, all the discharge measurement data was calibrated to confirm accuracy of discharge measurement, hence its rating curve. Those at 331 stations were finally stored in the new database system of MOWD. In addition, the rating curves of 132 stations, which are stored in the database of LBDA, are compared with those in MOWD.

### 3.4 Suspended Load Data

In general, sediment load is classified into 3 categories; (i) bed load, (ii) suspended load, and (iii) wash load. In Kenya, suspended load monitoring was initially done on ad-hoc basis. In the middle of seventies the systematic data collection was started by MOWD. However, none of the suspended load measurement data had been stored in the database of MOWD. All the existing data of 5,843 samples at 277 stations in 195 rivers was stored in the newly established database system in MOWD. Distribution of suspended load monitoring stations are enumerated below:

| Drainage Area | Station (nos) | River (nos) | Sample (nos) |
| --- | --- | --- | --- |
| 1 | 67 | 58 | 554 |
| 2 | 52 | 36 | 907 |
| 3 | 50 | 32 | 1,304 |
| 4 | 90 | 58 | 2,447 |
| 5 | 18 | 13 | 271 |
| Total | 277 | 195 | 5,843 |

Among the stations, 36 stations have more than 30 samples.

### 3.5 Water Quality Data

MOWD has carried out surface water quality analysis at 110 sampling points. The sampling points cover almost all the major rivers as shown in Figure B3.2.

Although the locations of some monitoring stations correspond to existing water level gauging stations, the exact location of others are not mentioned. But, the data was able to be grouped into lower, middle, and upper reaches of the river. Finally, they were classified into 20 stations (183 samples) at existing water level gauging stations and 41 groups ( 416 samples ) without exact locations.

# B4. BASIN BOUNDARY MAP

## 4.1 Drainage System

The drainage system in Kenya is organized into 5 drainage areas. The present basin boundary map was prepared under the colonial days in 1930's. Such a basin boundary has been used in Kenya. The station code of existing water level gauge has been also named after the subbasin code in the basin boundary map. In the Study of NMWP-I, the necessity of confirming basin boundaries mainly for north of latitude $1^{O}$N and of sub-dividing into upper and lower catchments of Kerio and Turkwel rivers were mentioned.

Although their basin boundaries, which were divided into 158 subbasins, were verified by the remote sensing method on the scale of 1:1,000,000, the area covered by clouds could not be confirmed clearly. Those boundaries were delineated by referring to topographic maps on the scales of 1:50,000 and 1:100,000, basin boundary maps which were prepared by MOWD and those of NMWP-I. These in-depth basin boundary maps are useful for low flow analysis, flood control schemes, and dam planning.

In this Study, 2 sets of basin boundary map are, therefore, used for the analysis, that is, (i) the existing basin boundary map and (ii) basin boundary map including the boundaries considering existing and potential damsites for surface water balance calculation of perennial rivers.

(i) Existing basin boundary map

The existing basin boundary map consisting of 158 subbasin, however, contains some errors in their boundaries since they were delineated on the basis of a topographical map without contour lines on a scale of 1:50,000. Such a part of boundaries were elaborated referring to the latest topographical maps with contour lines on a scale of 1:50,000. Some relatively large subbasins were also sub-divided further for the Study. Finally, 192 subbasins were verified by GIS and presented as the drawing attached on the back cover of this report.

(ii) Basin boundary map including the boundary considering existing and potential damsites.

The above basin boundary map at a scale of 1:50,000 was then used for dam planning and rainfall-runoff balance calculations. All potential damsites were plotted on the map and the catchment area for each damsite was delineated on the map. The catchment of major tributaries were also sub-divided in order to reflect the difference of hydrological characteristics in the subbasin.

## 4.2 Drainage System for Major Rivers

The above basin boundaries were delineated systematically by the following procedures.

(1) Numbering of subbasin:
Subbasin is numbered in ascending order in the downstream direction.

(2) Subbasin code :
Subbasin codes correspond to the existing ones established by MOWD, which are organized into a combination of the number of drainage area and letters in alphabetical order.

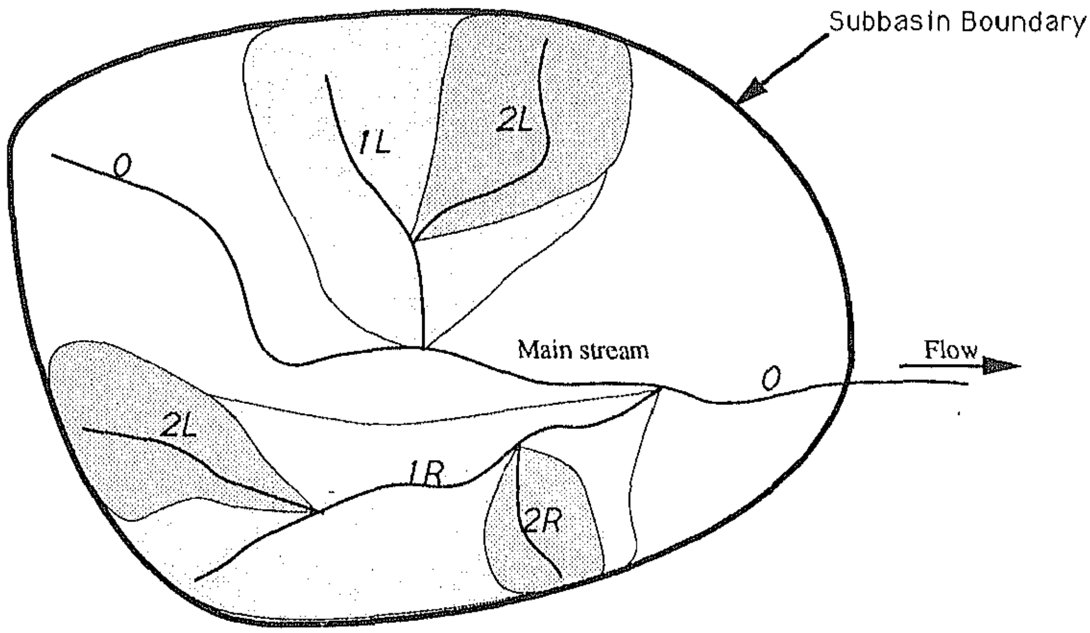
(3) Subordinate subbasin code :
A subordinate subbasin is defined for each subbasin. A subordinate subbasin is divided into 2 parts along a main river course. The right bank is added a letter "R:, while, "L" adds to the left bank.

(4) Main river : The largest river in the subbasin.

(5) River code : The code corresponds to those established by MOWD.

(6) River order :
The systematic number of river is defined in ascending order on the basis of "0" of main stream. All the tributaries to main river is numbered at "1", while those to tributaries of "1" is numbered at "2" and so on. The schematic diagram of river order is shown below.

(7) Subbasin name : Subbasin name corresponds to the name of main river.




Schematic Diagram of River Order

Summary of the above drainage system are enumerated in Appendix B.4 and the schematic diagram of drainage area and river length are shown in Appendix B.5.

# B5. BASIN MEAN RAINFALL

## 5.1 Development of Thiessen's Polygon

Of the registered 2,867 stations in the database of KMD, 91 stations were extracted for developing Thiessen's polygon as shown in Figure B5.1, taking into account length and continuity of observation period of each station.

## 5.2 Basin Mean Rainfall

The monthly rainfall for those station in the period from 1959 to 1988 was applied to estimate the basin mean rainfall for each subbasin. The missing data was either interpolated by correlation analysis among the stations or filled in using concurrent records at nearby stations. Monthly mean rainfall for each subbasin is enumerated in Appendix B.6. The annual mean rainfall for the period of 1959 to 1988 was estimated at 621 mm as enumerated below.

| Drainage Area | Catchment Area(*1) (sq.km) | Annual Rainfall (mm) |
|---|---|---|
| 1 | 46,229 | 1,368 |
| 2 | 130,452 | 562 |
| 3 | 66,837 | 739 |
| 4 | 126,026 | 697 |
| 5 | 210,226 | 411 |
| Total | 579,770 | 621 (*2) |

Note; (*1) : Land surface area excluding lakes and small islands.
(*2) : Weighted average

The monthly variation of basin mean rainfall can be divided into 25 patterns as shown in Figure B5.2, and their locations are also shown in Figure B5.3.

# B6. LOW FLOW CONDITIONS

## 6.1 Introduction

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

(1) Conceptual model for Kimakia catchment

J. R. Blackies developed a model to utilize data from the East African Agriculture and Forestry Research Organization (EAAFRO) covering a catchment area of 0.37 $km^2$. Since the model was developed for the scientific needs of such a small catchment, it would have required an inordinate amount of time to adapt to broad preliminary water resource planning.

(2) Sacrament model for some Lake Victoria catchments

The model was employed by the UNDP/WMO Hydromet Project on several rivers which flow into Lake Victoria (Ref.B.9). Input data is basin mean daily rainfall over the catchment. The model, however, requires the calibration of at least 16 parameters. Evaluation of more than 16 parameters for all subbasins may be difficult for preliminary water resource planning.

For specified river basins, take the Nyando River for instance, the tank model method was applied on monthly basis to clarify the water balance.

(3) TAMS rainfall/runoff model

In NMWP-I (Ref.B.10), the model used for daily discharge synthesis consists of 2 major components, namely, (i) storm runoff due to excess rainfall and (ii) base flow consisting of ground water flow and delayed subsurface runoff. The curve numbering procedure developed by the U.S. Soil Conservation Service (USSCS) was adopted. The curve number was estimated on the basis of 5 soil classifications. The model was verified with some well-instrumented experimental catchments having areas ranging from 0.16 $km^2$ to 7.0 $km^2$. After the calibration works, the model was applied to every subbasins in Kenya taking their soil classification and vegetation indexes into considerations.

## 6.2 Dimensionless Flow Duration Curve

The dimensionless flow duration curve is generally prepared to estimate low flow frequency in an ungauged catchment by applying it at a nearby station.

The water level data at rated stations was converted into daily discharges. Flow duration curves having relatively high accuracy were established by the following criteria:

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

Some dimensionless flow duration curves in which the daily discharge is expressed as a percentage against the mean discharge during the observation period are shown in Appendix B.7. The curves were then classified into the following categories corresponding to their catchment areas:

| Category | Catchment Area (sq.km) |
|---|---|
| 1 | less than 100 |
| 2 | 100 - 500 |
| 3 | 500 - 1,000 |
| 4 | 1,000 - 5,000 |
| 5 | more than 5,000 |

Average dimensionless flow duration curves by drainage area are shown in Figure B6.1. These curves were broken down according to the above category as shown in Figure B6.2.

## 6.3 Estimation of Low Flow Discharge

### 6.3.1 Water balance calculation in Drainage Area 1

The global hydrologic cycle is represented as a system as shown in Figure B6.3. The system 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 as shown in Figure B6.4 (Ref.B.11).

Prior to preliminary water balance calculations the following principal data was prepared on the basis of rainfall records and references.

(1) Monthly mean rainfall (R)

Monthly basin mean rainfall was calculated for the period of 1959 to 1988 as described in Section B5.2.

(2) Monthly mean potential evapotranspiration (Et)

Value of Et is extracted from the results of 90 stations in Kenya as shown in Figure B6.5 (Ref.B.3).

(3) Maximum groundwater storage capacity (G)

The maximum groundwater storage capacities at 53 stations in Kenya were estimated taking vegetation, soil and rock types, and empirical table into considerations (Ref.B.12). The values have a wide range varying from 100 mm in arid areas to 300 mm in Lake Victoria basin as shown in Figure B6.6.

(4) Soil evaporation (S)

Soil evaporation is often described as occurring at 2 separate stages beginning with wet soil. In the first stage, the drying rate is limited by and equals the evaporative demand. During the second stage, water availability progressively becomes more limiting. The third stage is described as an extension of the second stage but is limited to a more constant rate.

Shown in Figure B6.7 is the soil evaporation relationship which incorporates the first 2 stages. This curve was developed from those suggested in literature and field calibrations (Ref.B.13).

(5) Water abstraction

Water abstraction for each subbasin was calculated on the basis of the "Water Permit" data in the database of MOWD. The "Water Permit" data is basically organized into 2 categories; namely, (i) water permit amount during low flow discharge and (ii) those during flood flow. Since the purpose of these water balance calculations is to estimate the low flow frequency, the former data was applied to the calculation.

The flowchart of preliminary water balance calculation is shown in Figure B6.8. The method of calculation of each water balance component is described below;

(1) Selection of subbasin with small abstraction

Subbasins having not only relatively long periods of monthly discharge data but a small amount of abstraction were selected. Selected subbasins are located in Drainage Area 1 as shown in Figure B6.9.

(2) Computation of water balance components

The method of computation for each water balance component involved the following relationships:

(i) For $R \geq Et$

$$R - Et = S \quad \text{( Eq.6 )}$$
$$AE = Et \quad \text{( Eq.7 )}$$

in which, R : monthly mean rainfall (mm),
Et : monthly mean potential evapotranspiration (mm),
S : monthly soil evaporation (mm), and
AE : monthly actual evapotranspiration (mm)

provided the soil is already at its maximum storage capacity (G) during the previous month. Otherwise,

$$R - Et = dG + S \quad \text{( Eq.8 )}$$

where, dG is the component of monthly rainfall used to a recharge the soil to its maximum storage capacity. Then, the excess of (R - Et) over dG is assumed as S.

(ii) for $R < Et$, assuming the water deficit is D,

$$Et - AE = D \quad \text{( Eq. 9 )}$$
$$AE = \int_{0}^{Ef} dE \quad \text{( Eq.10 )}$$

in case no rainfall (R=0) and the soil is complete dry (S=0), Ef is estimated at 0. Otherwise, in case $Ef < Et$,

$$AE = R + a \times G \quad \text{( Eq.11 )}$$

where, $0.0 < a < 1.0$.

(3) Groundwater flow

In case the month has no rainfall and the soil is completely dry, the river flow may only depend on groundwater flow. Comparing the monthly rainfall less than 10.0 mm with the concurrent observed discharge on a monthly mean basis, the amount of groundwater flow was estimated in the driest period. The data was plotted in Figure B6.10. Monthly groundwater flow was then calculated in proportion to the monthly groundwater storage depth and catchment area for each subbasin.

(4) Subsurface flow

In case the groundwater storage depth reaches its maximum, the soil moisture content will become high. Part of the soil moisture may come to subsurface water outflow. For such a month, the ratio of direct runoff to rainfall of the previous month was applied to rainfall of the month. The remaining amount of river runoff after subtracting the amount of groundwater and direct runoff from the measured runoff was assumed to be the subsurface flow of the month.

The results of calculations for subbasins were summarized in Appendix B.8. Finally, the ratio of direct runoff, subsurface flow, and groundwater flow to measured runoff was estimated for each subbasin.

Furthermore, the relationship between monthly rainfall and monthly runoff was applied to the whole basin which contains the above subbasin, and the monthly runoff in the basin was computed for the period of 1959 to 1988. The results were compared with the observed monthly runoff at the station which is located at the most downstream end in the basin as shown on Appendix B.9.

The results show 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 consideration of water abstraction during flooding was made. This preliminary water balance model can be adopted to the master plan level, especially, for the estimation of low flow frequency of the basin. Finally, the model was adopted to estimate low flow frequency in the basin which contains the selected subbasins.

### 6.3.2 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 even in small subbasins, and thus the aforementioned preliminary rainfall-runoff balance model could not be applied to the basin. Therefore, the monthly discharge correlation method as applied to these subbasins.

In such a drainage area, the monthly discharge correlation method among the stations was applied to the other subbasins with in the perennial river. The missing monthly discharges were filled with those at nearby stations with a correlation coefficient of more than 0.65.

The list of stations used in the Study are enumerated in Table B6.1.

### 6.3.3 Annual mean discharge in semi-arid zone

With the exception of Rift Valley basin, the water level observation of tributaries in semi-arid areas has been carried out at the Tsavo River for a relatively long period. The water level gauges are at Tsavo (3G02) which is located in 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.

## 6.4 River Channel Loss

River flowing in the arid zone lost their runoff during the flow down. Losses in river channel are generally caused by abstractions, seepage along the river channel and evaporation from the river surface. These amounts were estimated on the basis of simultaneous discharge records for Tana and Athi rivers.

(1) Tana River

In the middle - lower reaches of the Tana River, the driest month is well defined as September. The losses in river channel of the Tana River were estimated at the concurrent daily discharge data between water level gauging stations; (i) in the middle reach of 230 km length between Grand Falls (4F01) and Garissa (4G01) and (ii) in the downstream reach of 184 km length between Garissa (4G01) and Hola (4G04). The location map of the stations is shown in Figure B6.11.

(i) Middle reach from Grand Falls down to Garissa

Concurrent daily discharge measurements have been carried out at Grand Falls and Garissa on the Tana River since 1946. In the Study, the data in September from 1947 to 1961 was used in the analysis taking the low flow in September and the naturalized flow before dam construction of the upper reach of the Tana River into considerations. Besides, the concurrent daily discharges of less than 100 $m^3/s$ were extracted to minimize the incremental discharges from residual basin between stations.

The relationship of discharge at stations is plotted in Figure B6.12. The results of regression analysis show that losses in river channel in middle reach are taken as ;

$Qgf = 5.216 + 0.939 \times Qgr$ .............................. ( Eq.12 )

where, Qgf : discharge at Grand Falls ($m^3/s$), and
Qgr : discharge at Garissa ($m^3/s$)

Assuming a mean annual low flow discharge of 60 $m^3/s$ with 95% probability at Garissa, the losses in river channel was estimated at 1.56 $m^3/s$ for 230 km reach which is equivalent to 0.68 $m^3/s$ per 100 km reach.

(ii) Lower reach from Garissa down to Hola

Similarly, the concurrent discharges in September at Garissa and Hola were examined. The losses in the lower reach are taken as :

$Qhl = -20.200 + 1.211 \times Qgr$ ............................ ( Eq.13 )

where, Qhl : discharge at Hola ($m^3/s$), and
Qgr : discharge at Garissa ($m^3/s$)

The above relationship is also shown in Figure B6.12. Assuming also the mean annual low flow discharge of 60 $m^3/s$ at Garissa, the losses in river channel were estimated at 7.54 $m^3/s$ for 184 km reach which is equivalent to 4.10 $m^3/s$ per 100 km reach.

In the Tana River, gentle riverbed gradient and meandering in the lower reach causes rather large losses in river channel, 6 times those in the middle reach.

(2) Athi River

The water level reading in the lower reach of the Athi River, which changes its name to Galana and Sabaki rivers, has never been carried out continuously because of the maintenance problems in the sparsely populated area. The location map of existing and abandoned stations is shown in Figure B6.13. Since there is insufficient data, the losses in Athi River were estimated on a monthly basis among Athi River (3F01), Tsavo River (3G02), and Sabaki River (3HA05). In the reaches of 342 km length from 3F02 down to 3HA05, the main tributary is the Tsavo River having a catchment area of 6,214 $km^2$. Of the tributaries in the lower reach of Athi River, the Tsavo River only has a perennial flow because of the confluence of Mzima springs. During the low flow discharges at 3HA05, the flow can be assumed as the amount of both inflow from upstream of the Athi River and that from the Tsavo River.

Assuming that none of the inflow comes from tributaries when the discharge at 3HA05 is less than 5.0 $m^3/s$ after subtracting the inflow from Tsavo River (3G02), the relationship between discharges at 3F02 and 3HA05 is plotted in Figure B6.14. The losses are taken as :

$Qf = 2.011 + 2.268 \times ( Qha - Qg )$ ............................ ( Eq.14 )

where, Qf : monthly discharge at 3F02 ($m^3/s$)
Qg : monthly discharge at 3G02 ($m^3/s$) and
Qha : monthly discharge at 3HA05 ($m^3/s$)

Assuming the low flow discharge of 4.82 $m^3/s$ at 3HA05 and that of 3.47 $m^3/s$ at 3G02, the losses in the lower reach 342 km long was estimated at 5.07 $m^3/sec$ which is equivalent to 1.48 $m^3/sec$ per 100 km reach.

## 6.5 Naturalized Discharge

Naturalized discharge without present water abstraction was estimated for subbasins with a perennial main river. In the Study, the objectives of the estimation of naturalized discharge were (i) to clarify the water deficit by subbasin during low flow discharge and (ii) to specify subbasins where a water deficit will occur in 2010.

The generation of naturalized discharge was carried out on a monthly basis for 30 years by one of 3 method as described in Section B6.3; they are, (i) preliminary water balance model for Drainage Area 1, (ii) discharge correlation for perennial rivers, and (iii) runoff ratio in semi-arid areas on the basis of that derived from the Tsavo River.

Although the naturalized discharges by methods (i) and (iii) could be generated at the downstream end of each subbasin, those by method (ii) could be generated only at the sites of selected stations for discharge correlation analysis. The naturalized discharges generated by method (ii) were then converted into specific naturalized discharges by station and they were applied to non-gauged catchment taking their locations and hydrological conditions into consideration. After computing naturalized discharge by using a perennial flow model, the generated discharges at the sites of selected stations were compared with those by method (ii).

In the Tana river basin, the naturalized discharge was estimated taking the flow regulation of the existing 5 dams into considerations; that is, Masinga, Kamburu, Gitaru, Kindaruma, and Kiambere dams.

Finally, the naturalized discharges at the downstream end of subbasins were generated for 30 years. The monthly mean naturalized discharges were enumerated in Appendix B.10.

## 6.6 Low Flow Frequency

Estimation of low flow frequency is important to define the magnitude of safe yield for water resources development. The concept of safe yield is mentioned in the "Design Manual for Water Supply in Kenya (MOWD)" as follows;

(1) for principal towns and urban centers

The 96% - probable daily low flow shall be regarded as the safe yield of a river. The flow-frequency analysis shall be made by using the lowest recorded daily flow of each calendar year for which records are available for the dry season.

(2) for rural areas and local centers

The 96% - probable monthly low flow shall be regarded as the safe yield of a river. The flow-frequency analysis shall be made by using the recorded lowest average flow during one calendar month for each year for which records are available for the dry season.

Since rivers having daily discharge records with long enough duration for probability analysis are limited in number, and long-term river discharges over the country had to be generated on the monthly basis due to a limitation of data, the relationships between the probability of daily discharges and the monthly discharge needed to be checked.

In checking, taken were the discharge records at 15 water level gauging stations having daily discharge records for more than 15 years with a few missing data. The data, however, is not for 15 consecutive years. At first, the flow-frequency analysis was made by using the lowest recorded daily flow of each calendar year and the probable low daily discharges were estimated for the recurrence intervals of 2, 5, and 10 years. Secondly, the flow duration curves by station were developed by sorting all the monthly data in descending order.

Table B6.2 shows the relationship between the probable daily low flow discharges and flow duration curve on monthly basis. The probability of low flow discharge is equivalent to the following duration on average.

| Recurrence interval (years) | Duration on monthly basis (%) | Supply failure on daily basis (days/10-year) |
|---|---|---|
| 2 | 95.6 | 161 |
| 5 | 99.2 | 30 |
| 10 | 99.8 | 8 |

Therefore, the recorded minimum monthly discharge is almost equivalent to the daily discharge with the probability of once in 10-year. In case a water supply system is designed on the basis of recorded minimum monthly discharge, supply failure would occur for 8 days on an average in 10 years. While, if the design discharge having 96% - probable monthly low flow discharge is adopted for rural areas as mentioned in the "Design Manual for Water Supply in Kenya", its probability of daily low flow discharge is equivalent to the recurrence interval of once in about 2 years on an average; namely, supply failure would occur for 161 days in 10 years.

Although the maintenance of minimum flow of perennial river is not mentioned in the "Design Manual for Water Supply in Kenya", a minimum flow of perennial river is required to maintain water surface depth, conservation of groundwater, and people's amenity. The minimum flow of perennial river is also an indicator of the allowable limit of water withdrawal from the river. In the Study, the recorded lowest daily discharge was assumed as the minimum flow to be maintained. The ratio of recorded lowest daily discharge to annual average discharge was roughly estimated at 6.2% on an average on the basis of the records at the aforementioned 15 stations.

The annual mean discharge and monthly minimum discharge along the representative perennial main rivers are shown in Appendix B.11.

## 6.7 Runoff Depth

Table B6.3 shows the runoff ratio of perennial rivers in Kenya. The annual runoff volume in the Table is based on the naturalized discharge at the downstream end of river basin. Although the loss of water along river channel was assumed for the estimation of the discharge at the downstream end of river basin, about 9.5% of annual rainfall depth flows down through main river channel.

An isohyetal map of annual average runoff depth is shown in Figure B6.15 and that of minimum monthly runoff depth is also shown in Figure B6.16.

# B7. FLOOD CONDITIONS

## 7.1 Past Flood Records

Daily water level data at 923 stations is registered in the database of MOWD. Of the registered stations, rating curves are available for 331 stations. The water level data at those rated stations is converted into daily discharge. The data, however, contains a lot of missing data points at ordinary flows as well as records of peak flood discharge because the water level exceeded the staff gauge height.

Annual maximum flood records appearing to have relatively high accuracy were selected according to the following criteria:

(i) Stations having records of more than 20 years
(ii) Stations having enough gaugings to cover flood water levels

Finally, 78 stations, 39 for Area 1, 9 for Area 2, 7 for Area 3, 15 for Area 4 and 8 for Area 5, were selected as shown in Table B7.1. Annual maximum floods at respective stations are shown in Appendix B.12.

## 7.2 Probable Floods at Respective Stations

Using annual maximum flood discharge records, probable floods were estimated by applying the following analytical methods which were commonly used in previous hydrological studies in Kenya:

(i) Gumbel Extreme Distribution
(ii) Log Normal Distribution
(iii) Log Pearson Type III Distribution

The results of analysis are shown in Appendix B.13.

## 7.3 Regional Flood Frequency Curve

Based on the probable flood discharges obtained for a number of rivers/streams, regional flood frequency curves were derived for major rivers in 5 drainage areas.

The derivation of regional flood frequency curves used the following steps:

(1) Probable flood discharges, which are extracted from maximum values among estimates from the three analytical methods, are made dimensionless by dividing by the mean annual maximum flood at the station.

(2) Mean ratios for each return period are then plotted on a graph, and a regional flood frequency curve is drawn out.

(3) The relation between mean annual flood and catchment area is also plotted.

Essentially regional flood frequency curves are developed in subbasins considering hydrological similarity. Available data in each drainage area is limited, however, in this study regional flood frequency curves are derived for major river basins. Regional flood frequency curves for major rivers are shown on Figure B7.1, and mean annual flood discharges for varying catchment area are shown on Figure B7.2. Information in Figures B7.1 and B7.2 are summarized in Tables B7.2 and Figure B7.3, being expressed by equations and multipliers to enable estimation.

Mean annual flood discharges for varying catchment areas were also analyzed for drainage areas 1 and 4 by the University of Nairobi (Ref.B.14). The results were also plotted on Figure B7.2.

The curves would be useful for preliminary estimates of flood discharges at ungauged catchments and/or catchments having only a few years on record. The probable flood discharge for an ungauged basin can be estimated first by reading the mean annual flood Figure B7.2, the ratio of each return period in Figure B7.1, and then multiplying both figures.

## 7.4 Flood Hydrograph and Hyetograph

Water level gauging stations selected for flood analysis are mostly manual reading staff gauges being recorded once or twice a day. Automatic recording gauges are installed at a limited number of locations and, furthermore, continuous records for long periods are rarely obtained from these stations. These are causes of the limited availability of flood hydrograph information.

The Study attempted to pick up hydrographs of major flood events appearing on the recorder chart, and also corresponding rainfall records at automatic rainfall records which are located in and around the basins. The extracted flood events are given in Table B7.3. Flood hydrograph and hyetograph of these flood events are shown in Appendix B.14, and the 1961 storm called "Uhuru Rain" is also shown for reference.

## 7.5 Flood Characteristics

(1) Time of Concentration (Tc)

The time of concentration (Tc) is a measure of the time for a particle of water to travel from the uppermost distant point in the basin to the point where the recorder is located, or the point where the scheme is proposed. Tc is determined from the following relationship:

$Tc = 2 \times L$ ........................................................ ( Eq.15 ) in which, L is the lag from rainfall peak to flood peak. Estimation of Tc for representative floods is given in Table B7.4.

(2) Peak Runoff Coefficient (K)

Richard's Method, which was derived basically from the Rational formula, gives consistent and good results for rivers in Kenya and, hence, is commonly used for flood studies. The equation is as follows:

$$Qp = K \times i \times A \quad \text{( Eq.16 )}$$

where, Qp : peak flood discharge in $ft^3/sec$
K : peak runoff coefficient
i : average intensity of rainfall over the catchment in inches/hour
A : catchment area in acres

Estimation of K for representative floods is given in Table B7.4, and K is also shown for mean rainfall intensity within the concentration time in Figure B.7.4. Further, generalized values of K (Ref.B.15) are given in Table B7.5. However, it is noted that K value is very sensitive and a slight change causes a significant difference in flood estimation. More data collection on flood should be emphasized to obtain more reliable estimation of K value.

These catchment areas are located in the southwestern part of Kenya, an area that approximately comes under the combined type of heavy forest, cultivated absorbent soil and slightly permeable, partly cultivated or covered with vegetation. The range of generalized values of K is, therefore, between 0.1 and 0.4. The average K value of 0.27 is within this range, however, in case of the design flood estimation which deals with heavier rainfall intensity, the upper limit value of 0.4 should be taken.

(3) Relationship among Tc and other factors

There are various formulas for defining the time of concentration. Kadoya (Ref.B.16) proposed a practical formula to estimate concentration time. This formula is derived from concentration time based on the Kinematic Wave Theory and from the topographic relation between the basin size and river length. It has the form:

$$Tc = C \times A^{0.22} \times Re^{-0.35} \quad \text{( Eq.17 )}$$

where, C : coefficient of basin characteristics,
A : catchment area in $km^2$, and
Re : effective rainfall intensity in mm/hr

Based on the data of Table B7.5, values of $Tc/Re^{-0.35}$ and its regression line are plotted for catchment area as shown in Figure B7.5. In conclusion, the accumulation of examples of K and Tc based on observed data is linked with higher accuracy of design discharges by Richard's Method.

(4) Runoff Coefficient during Flood

The runoff coefficient plays an important role in estimating of excess rainfall for the hydrologic model. The first step to calculate runoff coefficient is to separate the base flow from direct runoff for the representative flood. The volume of direct runoff is then divided by basin mean rainfall depth. The calculated runoff coefficients are given in Table B7.6 and in Figure B7.6.

The calculated runoff coefficients vary from 0.10 to 0.39, while in the previous study (Ref.B.17) the range of standardized runoff coefficients was between 0.09 and 0.50. These values change according to soil type, slope, and type of vegetation or land use, however, the calculated values seems to be approximately adequate.

## 7.6 Probable Rainfall Depth

(1) Data and stations

Rainfall data of 2,867 gauging stations is registered in the database of KMD. Of the registered stations, 161 stations were extracted for the purpose of storm analysis with the following criteria:

- rule out the years with missing daily records of more than 15 days in March, April, May, or November
- select stations with records of more than 20 years

(2) Testing of fitness of probability functions to empirical distributions

(a) Selection of stations

Five rainfall stations with relatively long record periods were selected, each representing a different geographic zone.

| Station Code | Location | Geographic zone | Nos. of recorded years |
|---|---|---|---|
| 8635000 | Lodwar | Arid (North) | 59 |
| 9035002 | Londiani | Inland | 56 |
| 9136130 | Nairobi | Highland | 29 |
| 9338001 | Voi | Arid (South) | 60 |
| 9339004 | Kilifi | Coast | 58 |

(b) Empirical distribution

There are various formulas for defining return periods to associate with annual maximum rainfall, known as the plotting position. In this study Weibull's formula was adopted.

(c) Probability functions

The following 3 probability functions were adopted:

(i) Gumbel Extreme Distribution
(ii) Log Normal Distribution
(iii) Log Pearson Type III Distribution

(d) Selection of probability function

Probable rainfall amounts and probability distributions were calculated and they are shown in Appendix B.15. These figures indicate that probability functions conform well to empirical distributions.

Overviewing the difference between the relative value of observed data and the calculated probable value, Gumbel Extreme Distribution shows the best fit. Furthermore, this distribution is used in the "Rainfall Frequency Atlas of Kenya" (Ref.B.18) and also in many previous studies. Therefore, Gumbel Extreme Distribution was adopted for the analysis henceforth.

(3) Frequency Analysis

Probable rainfall depth at 161 gauging stations was computed by Gumbel Extreme Distribution. The results of computation are shown in Appendix B.16, for return periods of 5, 10, 20, 25, 50, and 100-year, and isohyetal maps of 1-day, 3-day and 15-day probable rainfall in return periods of 10, 25, and 100-year are shown in Appendix B.17.

## 7.7 Depth-Area Analysis

Area reduction factors in Kenya were studied by D.Fiddes (Ref.B.19). The data in this Study is based on the Nairobi raingauge network in which there are 18 available gauges covering an area of 1,200 $km^2$. The equations of area reduction factor (ARF) are as follows:

$ARF = 1-0.01\ A^{1/2}$ ( for daily rainfall) ................................ ( Eq.18 )

$ARF = 1-0.02\ T^{-1/3}\ A^{1/2}$ (for hourly rainfall)......................... ( Eq.19 )

where, A : area ($km^2$), and
T : time period (hrs)

These area reduction factors are applicable to areas up to 1,200 $km^2$. In this Study, therefore, depth-area analysis for relatively wide areas was attempted to supplement the Fiddes' study.

In 1961, Kenya was hit by a historical widespread rain storm called "Uhuru Rain". This storm event is believed to provide representative data for assessing the rainfall depth-area relationship. The hourly rainfall records for 3 months from October to December in 1961 were collected. The area taken up for the analysis is the upper reaches of Tana River.

During this storm, maximum rainfall intensity in this area for several periods is shown below, with a recurrence interval as evaluated from the "Rainfall Frequency Atlas of Kenya". The daily rainfall in this area is also shown below, recurrence interval is evaluated with rainfall probability analyzed in Section B7.6.

Hourly Rainfall Station : 8937051 Meru Water Supply

| Duration | Rainfall Depth | Recurrence Interval |
|---|---|---|
| 1 hour | 50.6 mm | 7 year |
| 3 hour | 77.9 mm | 5 year |
| 6 hour | 91.1 mm | 3 year |
| 12 hour | 108.6 mm | 4 year |
| 18 hour | 135.1 mm | 6 year |
| 24 hour | 146.3 mm | 7 year |

Daily Rainfall Station : 9037015 Ragati Forest Station

| Duration | Rainfall Depth | Recurrence Interval |
|---|---|---|
| 1 day | 96.5 mm | 13 year |
| 2 day | 172.7 mm | 22 year |
| 3 day | 207.5 mm | 22 year |
| 5 day | 260.8 mm | 12 year |
| 10 day | 383.5 mm | 7 year |

Isohyetal maps of 6 varying time periods are shown in Appendix B.18. Computing the area between isohyetal lines and assigning to each sub-area the mean value of the bounding lines, the depth-area relationship for each duration is obtained. Area reduction curves and their values are shown in Figure B7.7 and Table B7.7, respectively. Owing to the relatively wide distribution of the data, the analysis could draw out only two relationships; for 1 to 6-hour and 12 to 24-hour.

Figure B7.7 shows that the area reduction value in this Study is greater than the value in Fiddes' Study. In the case of practical estimation of area rainfall, Fiddes' value is recommended for areas smaller than 1,200 $km^2$, the while for greater areas the value of this study should be adopted, keeping continuity between the two values.

## 7.8 Probable Maximum Precipitation

In some situations where substantial risk of loss of life exists, it may be appropriate to design a facility against what appears to be the worst possible condition. This rests on a policy decision that maximum protection be provided. The probable maximum flood (PMF) is accepted as the standard for design of spillways on dams where failure could lead to catastrophic loss of life.

Determination of PMF begins with the determination of the probable maximum precipitation (PMP). In Kenya, Lumb (Ref.B.20), using a thunderstorm model, has given estimates of the probable maximum 24-hour rainfall values for some selected areas. Obasi and Nimira (Ref.B.21) using the method of maximum likehood have also given estimates of the probable maximum daily rainfall values for 83 stations in Kenya.

Hershfield (Ref.B.22), as an alternative of hydrometeorological analyses, derived a method of statistical maximization which has the form:

$$Xm = \overline{Xn} + Km * Sn \quad \text{.............................. ( Eq.20 )}$$

in which, Xm is PMP, $\overline{Xn}$ is the mean and Sn the standard deviation of the maximum annual depths for the selected duration, and Km is the number of standard deviations that must be added to the mean to obtain Xm. A value of 15 for Km is commonly used, however, it is not applicable to all climatic regions. Especially for tropical and arid regions, the adjustments of Km value is indispensable.

Using $\overline{Xn}$ and Sn at the selected stations and the value of PMP by Obasi and Nimira (Fig. B7.8), the adjustment of Km value was carried out. The results are as follows:

(i) Arid Area Km = 11

| | | | | | |
|---|---|---|---|---|---|
| Lodwar | (8635000): | 8.3 | Wajir | (8840000): | 8.6 |
| Garbatulla | (8938000): | 10.7 | Mtito Andei | (9238009): | 8.3 |
| Voi | (9338001): | 10.6 | | | |

(ii) Coastal Area Km = 11

| | | | | | |
|---|---|---|---|---|---|
| Simba | (9240003): | 10.1 | Lamu | (9241000): | 7.5 |
| Kilifi | (9339004): | 7.8 | Malindi | (9340005): | 10.2 |
| Mombasa | (9439002): | 7.4 | | | |

(iii) Highland Area    Km = 15

| | | | | | |
|---|---|---|---|---|---|
| Rumuruti | (8936049): | 14.8 | Naivasha | (9036025): | 12.3 |
| Nyeri | (9037015): | 14.1 | Thika | (9137002): | 8.3 |
| Taveta | (9337110): | 14.9 | | | |

(iv) Inland Area    Km = 15

| | | | | | |
|---|---|---|---|---|---|
| Londiani | (9035002): | 15.0 | Kericho | (9035003): | 13.5 |
| Sotik | (9035013): | 14.5 | Migori | (9134010): | 14.8 |
| Narok | (9135001): | 9.4 | | | |

As a result, values of Km for respective geographic zones were evaluated: 11 for arid and coastal areas, 15 for highland and inland areas. These values would be useful for preliminary estimate of PMP in the particular area, using the representative station within this area.

## 7.9 Flood Analysis for Flood Control Scheme

The target areas in which the flood control scheme is proposed are located mostly in the downstream reaches of major rivers (see Sectoral Report G : Flood Control Plan ). These areas and design discharges of existing flood protection plans are shown in Table B7.8.

In this study, flood analysis was attempted for following purposes:

(1) confirming the adequacy of design discharges of existing schemes

(2) estimating design discharges for newly proposed flood control schemes

Design discharge for respective schemes is estimated by the following method:

(1) In most target areas design discharges are computed using the regional flood frequency curve

(2) In the middle Turkwel design discharge is computed by adopting the regional flood frequency curve of Ewaso Ngiro, considering the similarity of amount of 10-year probable daily rainfall and hydrological soil condition (Ref.B.23).

(3) The regional flood frequency curve for Athi River basin is confined within 10,000 $km^2$. For extrapolation from this curve to the downmost Athi, the annual maximum flood at the nearest station 3HA12 is extracted from daily discharges which were recorded for 7 years, from 1981 to 1987. Then, design discharge in the downmost Athi is calculated by multiplying annual maximum flood of 604 $m^3/sec$ and the ratio of 10-year flood.

The results of analysis are also shown in Table B7.8. Design discharges were evaluated as follows :

(1) most design discharges are adequate in comparison with design discharges in previous studies and/or specific discharges

(2) design discharge of Yala River in a previous study, 300 $m^3$/sec with 100-year probability, is relatively small compared to the estimate in this study (370 $m^3$/sec at 25-year probability), in addition the former value is also small in comparison with neighboring Nzoia or Nyando rivers.

## 7.10 Flood Analysis for Dam Scheme

(1) Data collection

Reports on dam development schemes, which hydrological analysis was made for, are collected for the preparation of flood analysis. The information on hydrological conditions for design is shown in Table B7.9.

(2) Probable Maximum Flood

For estimation of Probable Maximum Flood (PMF) inflow at any catchment, the following study was carried out.

i) For the catchment that PMF was calculated in previous study, a representative rainfall station from among 161 stations analyzed in B7.6 is selected in or around catchment.

ii) Probable Maximum Precipitation (PMP) at the station is computed by the method described in B7.8.

iii) Area PMP is also computed using area reduction factor and value described in B7.7.

As a result, PMF and PMP are shown in Table B7.10, and the relationship between PMF, catchment area and PMP is shown in Figure B7.9. Figure B7.9 indicates that PMF is proportional to 0.75 power of the catchment area. Therefore, the relationship between PMF , 0.75 power of the catchment area, and PMP is analyzed. Figure B7.10 shows equation of PMF with PMP and catchment area.

(3) Design Discharge for Diversion Works

Return periods of design discharges for diversion works have a wide range , usually varying between 5 and 50-year , depending on the magnitude of the project and the economic losses to be caused by overtopping of the cofferdam and damage to the permanent construction .

Figure B7.11 shows a comparison of peak discharges in a regional flood curve and dam scheme for 10-year return period of which most data can be extracted from Table B7.9. Figure B7.11 indicates that design discharges for diversion works can be approximately estimated by using the regional flood curves.

(4) Design discharges in small catchment

Intake facilities for water supply are commonly located in the upper reaches which have a relatively small catchment. Flood discharge of this type is usually designed on the basis of 100-year return period. As application of the regional flood curves is limited for small catchment,i.e., approximate lower limit of 100 $km^2$, design discharges in small catchment are estimated by Richard's Method as follows:

i) The range of probable daily rainfall depth with 100-year return period is set up in alignment with the isohyetal map. Then a median value of each range is adopted as the representative value of 100-year probable daily rainfall .

ii) This daily rainfall is converted into rainfall intensity within the concentration time by using the formula of Kadoya for estimating concentration time as described in 7.5 and the formula of Mononobe for estimating rainfall intensity during any time from daily rainfall as described below . And peak runoff coefficient K value of 0.4 is adopted from generalized value in Table B7.5 as described in B7.5.

$$r = R\ (24/t)^{2/3}/24 \quad \text{.......................................... ( Eq.21 )}$$

where, r : rainfall intensity (mm/hour)
R : daily rainfall (mm)
t : concentration time (hour)

iii) Peak discharges by catchment area are calculated by Richards Method with rainfall intensity, peak runoff coefficient, and catchment area .

The results are shown in Table B7.11 and in Figure B7.12. For quick estimate of design discharge in small catchments, after confirmation of the intake location the range between isohyetal lines at the point is read on the isohyetal map of daily rainfall with 100-year return period shown on Appendix B.17. And then design discharge is read in Figure B7.12 or interpolated by using Table B7.11.

# B8. LAKES

## 8.1 Introduction

Most lakes in eastern Africa are associated with the Rift Valleys as shown on Figure B8.1 (Ref.B.24). It has been known that many African lakes once stood at substantially higher levels than they do today (Ref.B.25). With the exception of Lake Turkana, these lakes tend to be rather small and saline, while, Lake Victoria occupies a shallow basin, believed to have been impounded by the same earth movements which led to the formation of the rifts. Some features of the lakes are enumerated below.

| Lake | Altitude (El;m) | Area (sq.km) | Max.Depth (m) (*2) | Water Quality |
|---|---|---|---|---|
| Victoria | 1,133 | 69,500 (*1) | 79 | fresh |
| RIFT VALLEY | | | | |
| Turukana | 375 | 6,405 | 120 | saline |
| Logipi | | Seasonal | | saline |
| Baringo | 975 | 130 | 10 | saline |
| Bogoria | 991 | 34 | 10 | saline |
| Nakuru | 1,758 | 26-52 | 1.3 | saline |
| Elementaita | 1,776 | 18 | 1.1 | saline |
| Naivasha | 1,884 | 138-297 | 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) 3,950 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 underutilized. It is expected that domestic water supply and small 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 lags in their responses to climatic events. At present, several water level gauges are managed by MOWD as listed below.

| Lake | Station Code | Record |
|---|---|---|
| Victoria | 1HB05 | 1964-1985 |
| Turkana | 2B 14 | 1970-1985 (intermittently) |
| Bogoria | 2EH01 | 1968-1987 (intermittently) |
| Nakuru | 2FC04 | 1956-1984 (intermittently) |
| Naivasha | 2GD04 | 1957-1975 |
| - do - | 2GD06 | 1958-1987 |
| Chala | 3J 17 | rehabilitated in 1991 |
| Jipe | 3J 03 | abandoned |

In this Report, the variations of annual lake water levels of Lakes Victoria and Naivasha were mentioned 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 on the basis of some references.

## 8.2 Lake Victoria

Lake Victoria, which lies within the countries of Kenya, Tanzania and Uganda, has a surface area of 69,500 $km^2$ (3,950 $km^2$ in the territory of Kenya), and is the second largest freshwater lake in the world. Its highly variable lake water level attracted the attention in recent times when the mean lake water level rose by 1.25 m in 1962 over that of the previous year. The lake water level actually started rising on November 1961 and reached its peak on May 1964 as shown in Figure B8.2. Such a peak had not been recorded since the lake water level recorder was first installed at Entebbe in 1909. The highest monthly increase of 56.0 cm occurred in November 1961 and highest decrease of 22.5 cm in July 1924.

Although the lake water level has been recorded with a variety of fluctuations, it attains generally the highest level from May through June and the lowest in December.

An in-depth water balance study of Lake Victoria was carried out in 1974 (Ref.B.26). The study mentioned the following characteristics could be drawn for a normal year:

(1) Rainfall depth over the lake is about 1.5 times rainfall depth over the land,
(2) Rainfall depth over the lake is about 10 times evaporation amount from the lake,
(3) Rainfall depth over the lake is about 6 times inflow volume into the lake, and
(4) Evaporation from the lake is 5 times inflow into the lake and 2.6 times outflow from the lake.

## 8.3 Lakes in Rift Valley

### 8.3.1 General

Most of the lakes in the Rift Valley are small and lack outlets, and the valley is now a region of internal drainage. However, biogeographic evidence suggests that at least the northern part formerly drained into the Nile River. Lake Turkana, for example, harbors species with nilotic affinities such as the Nile perch.

The valley floor is broken by subsidiary faulting and volcanic activity. Major volcanoes, Longonot, Eburu, and Menengai, help to define the lake catchment.

Lake Turkana is the largest lake lacking an outlet in eastern Africa. The significant inflow is the Omo River with a catchment which includes part of the Ethiopian Plateau. The Suam and Turkwel Rivers also drain into the lake. The lake has always been in a fairly arid area, although the size of the saline lake and the intensity of sediment transport has fluctuated.

Lakes Nakuru, Elementaita, and Naivasha lie just south of the Equator. Lake Naivasha is the largest and freshest, while Lakes Elementaita and Nakuru are smaller, shallower and highly saline. Rainfall in the basin varies markedly with altitude. The wettest slopes of the Aberdares probably receive as much as 1,525 mm per annum on average, whereas Lake Naivasha, in the rain shadow of these mountains, receives about 610 mm. Evaporation at Lake Naivasha is estimated at some 1,360 mm per annum, so the lake clearly depends heavily on rainfall at higher elevations for its existence. The 30- to 40-year trend of declining levels reflects a slight decreasing of rainfall during this period, averaging 5 mm per annum over the basin between 1920 and 1949. Also, perhaps increasing human consumption from river and boreholes contributed to the lake's decline (Ref.B.27). The wetter years beginning in 1961 brought about a sharp rise in the level of Naivasha, as well as of Elementaita and Nakuru. Lakes Elementaita and Nakuru, though receiving greater direct rainfall than Lake Naivasha, occupy smaller catchments with less reliable surface water inflow and have been virtually dry.

Lake Magadi at 604 m AMSL is an ephemeral lake lying at the lowermost point of the southern part of the Rift Valley. The High Magadi Beds, consisting of silts and clays, form a discontinuous shelf 12 m above the present lake level and were deposited at a time when the water level was seasonally higher and somewhat more stable than it is today.

### 8.3.2 Lake Naivasha

Lake Naivasha lies in the Rift Valley at an altitude of 1,884 m. The lake forms an internal drainage having a catchment area of 3,184 $km^2$. The variations of water level from 1909 to 1986 and of annual rainfall depth are also shown in Figure B8.2 with their 10-year moving averages. The figure shows a substantial variation of water level during the last decade. After the rather heavy "Long Rains" in 1977 its water level rose up to 3 m by 1979. While, the drought in 1982 to 1984 resulted in remarkable dropping of the water level.

For decades, several studies dealt with the fact that Lake Naivasha is a fresh water lake but does not have a visible outlet. The most probable outlet through underground water is assumed towards the south (Ref.B.28).

Lar-Erik Ase (Ref.B.29) attempted to clarify its water budget on the basis of the records from 1936 to 1976 as follows;

| | Item of Water Budget | Depth (m) |
|---|---|---|
| 1. | Inflow to the lake | +91.4 |
| 2. | Precipitation over the lake | +26.2 |
| 3. | Evaporation from the lake | -67.9 |
| 4. | Recorded drop of the lake | - 1.5 |
| 4. | Remaining factor (probably underground outlet) | -48.2 |

Assuming an average surface area of the Lake of 180 $km^2$, the outflow from the underground outlet is estimated at 211 million $m^3$ per annum on average, equivalent to 6.71 $m^3$/sec.

## 8.4 Lakes Chala and Jipe

### 8.4.1 Lake Chala

The Lake Chala is 90 m deep and is ringed by an inner wall of steep precipitous cliffs which rise a further 90 m above the mean lake water level. The catchment area is 3.15 $km^2$ and the surface area of the lake is circular with a diameter of 2.5 km on average. The international boundary between Kenya and Tanzania lies at the center of the lake.

The lake water of 300 million $m^3$ is clear and fresh and is maintained almost entirely by groundwater draining off Mt. Kilimanjaro.

Although the gauge was not operational in 1990, the water level records show a variation of some 6 m. There appears to be some correlation between the rainfall on the slopes of Kilimanjaro and the lake water level with 15 to 18 months lag. It also appears that the lake water level and the discharge of the Njoro Kubwa group of springs are related (Ref.B.30).

### 8.4.2 Lake Jipe

The Lake Jipe, a shallow freshwater lake, lies astride the international boundary between Kenya and Tanzania. The lake varies considerably in area and depth, ranging from 18 $km^2$ and 1.1 m deep in 1954 to 28 $km^2$ and 2.1 m deep in 1947. The storage volume, therefore, varies from 20 to 60 million $m^3$ between dry and wet years.

The lake is fringed by extensive swamps including to the north Lumi Delta swamps. The significant increasing of lake water is from the Lumi River and from direct rainfall on the lake surface.

The lake is reported to contain large numbers of small fish including Tilapia which supports a fishing industry of considerable importance.

## B9. 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.

As described in Section B6.3.1, some of river runoff in dry seasons still remains in the river channel, even in the months without rainfall. This river runoff is presumed to be the amount of the discharge from groundwater reservoir including springs.

Although the information on the location and discharge from springs are incomplete, as many as those possible which the location is known were plotted (Fig. B9.1).

As shown in Figure B9.1, the springs are generally located at the fringe of forest areas. It is, therefore, able 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.

Major springs in Kenya are described briefly hereinafter.

(1) Mzima spring

Mzima spring locates on the fringe of the Chyulu Hill. In the Chyulu Hill, there is no surface drainage on the lava field but infiltrated rainfall emerges at several springs situated at the periphery of the lava field. These springs are very unevenly distributed, 3.0 $m^3$/sec of water emerges at Mzima Spring at the southeastern extremity of the lava field, while, only 0.26 $m^3$/sec emerges elsewhere.

According to the water level records at 3G3, the discharge from Mzima spring has no appreciable seasonal variation. At present, 0.43 $m^3$/sec of water is supplied to Mombasa through the Mzima pipeline, about 240 km long.

(2) Njoro Kubwa Springs

The Njoro Kubwa springs emerge in a pool beside the right bank of the Lumi River, about 3 km southeast of Taveta township. It appears that the discharge of the spring and the lake water level at the Lake Chala, which locates about 9 km north of Taveta township, are related closely. The group of springs includes 2 other springs, Njoro Ndogo 1 and 2, which emerges within 100 m upstream of Njoro Kubwa spring.

The spring water is mainly utilized for irrigation water supply to sisal estate.

(3) Nolturesh Springs

Nolturesh springs locate on the slope of Mt. Kilimanjaro. Several springs flow out to form the Oltresh River. A gauging station (3G6) exists on the river and water level records have been available since 1956. A discharge of 0.25 - 0.33 $m^3$/sec has been recorded. The high rainfall on the slope of the mountain and the constant supply from melting snow make the spring a reliable water source.

Nolturesh pipeline was designed as a gravity water supply system by tapping the Nolturesh springs. The pipeline of about 100 km length was first constructed in 1955 by the Kenya Railways Corporation.

(4) Kikuyu Spring

Kikuyu spring emerges in the upstream basin of subbasin 3BA. The discharge of 0.05 $m^3$/sec is one of the minor water sources for Nairobi. The discharge of the spring is collected and transferred into Kabete treatment works and reservoir.

## B10. SEDIMENTATION

### 10.1 Suspended Load

Suspended load measurements has been carried out by MOWD on ad-hoc basis at representative water level gauging stations. There was no definite network for sediment sampling.

The suspended load rating curves were established from 36 stations having more than 30 data points although those samplings were taken at relatively low discharges. The rating curves are expressed by the equation;

$$Qs = a\,Q^{b} \quad \text{( Eq.22 )}$$

where, Qs : suspended load (ppm),
Q : discharge (cms), and
a and b : constant

The values of constant were enumerated in Table B10.1. In the table, suspended volume was estimated on daily discharge basis applying dimensionless flow duration curves at the station or nearby station to the rating curve of suspended load concentration.

Although the trend analysis for suspended load concentration is useful to estimate the variation of soil erosion rate of catchment, there are only 5 stations with the monitoring data of more than 20 years, that is, 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, shows that a lot of monitoring had been carried out in the 1960's, while, little monitoring had carried out after 1970. The long-term tendency of suspended load concentration, therefore, could not be analyzed.

### 10.2 Sediment Deposit Volume in the Reservoir

Since the rating curves of suspended load can be applied for the estimation of its volume during low flow discharge, the sediment deposit volume in the potential damsite was estimated on the basis of the actual survey of the existing reservoir and design condition of the proposed dam. The regional denudation rate was tried to be clarified by using the isohyetal map of 1-day rainfall depth with a probability of once in 10-year.

The results are enumerated below;

| Region | Denudation Rate (m3/km2/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 Appendix B.17)

## B11. INSTALLATION OF WATER LEVEL AND RAINFALL GAUGES

JICA has provided 5 automatic water level recorders and 5 automatic rainfall recorders in accordance with the Scope of Works agreed between JICA and GOK. In due consultation with MOWD, the following locations were selected for the installation of water level recorders:

1) Yala River (1FG02)

The station is located at Bondo water supply station on the Yala River. An automatic water level recorder (AWLR), a staff gauge, and a sub-meteorological station with automatic rainfall gauge (ARG), however, had been out of order for some years. and could be no longer be rehabilitated due to lack of funds. The Yala swamp at this point is well known for its flood so that the well-equipped station gives good account not only for low flow discharges but for flood.

2) Mara River (1LA04)

The Mara River which flows down through Masai Mara National Park is an international river. A few stations are managed in the upper reach, while an old recorder in the lower reach was washed away and no rehabilitation work has been done at the station.

3) Narok River (2K 03)

Several studies on Narok river basin has been carried out for the purpose of water supply and hydropower developments. The proper accounts for low and flood flows is vital.

4) Tana River at Garissa (4G 01)

The station which has the longest recorded period with a high reliability in Kenya used to be referred whenever water-related studies were carried out along the Tana River. AWLR, however, had been out of order for some years.

5) Daua River (5H 01)

The Daua River is an international river which forms the boundary between Kenya and Ethiopia. The river dried up about once in a few years. However, the water supply for Mandera District relies on this river. The station is located at Mandera water supply station and hence the knowledge of reliability of such a river is very vital. AWLR had also been out of order for some years.

Automatic rainfall recorders were also installed in the vicinity of the above locations.

Besides, existing water level gauging stations were rehabilitated at the following stations;

1) Sio River (1AH01)
2) Awach Seme River (1HB05)
3) Turasha River (2GC04)
4) Lake Chala (3J 17)
5) Lumi River (3J15C)
6) Galana River (3HA12)
7) Sagana River (4AA01)
8) Ewaso Ngiro River (5BC04)

All the installation of new equipment and rehabilitation works for the existing gauging stations were completed on February 14, 1991. Location of the above stations are shown in Figure B11.1.

## B12. SURFACE WATER SAMPLING

MOWD has carried out surface water quality analysis at 110 sampling points. The sampling points covers almost all the major rivers.

However, the surface water quality analysis has not been carried out in the coastal area, the foot of Mt. Kilimanjaro and the northeast and southwest areas. In this Study, additional water samplings were carried out at the following sites:

(1) Coast area - Pemba and Ramisi rivers
(2) Foot of Mt. Kilimanjaro - Lake Chala, Lumi and Tsavo rivers
(3) Northeast area - Daua River
(4) Southwest area - Mara River

The water quality test for the above water samples was entrusted to the Kenya Bureau of Standard (KBS) under the Contract with JICA Study Team. The water quality test was completed in March 1991. The results are attached in Appendix B.19.

## B13. RECOMMENDATION

### 13.1 Surface Water Data Gathering Network

Surface water data is the basic elements in the planning, design, construction, and operation of all water projects, which are of extreme importance to a nation's economy due to their impact on agricultural, industrial, and social development. Therefore, systematic collection, processing, and analysis of this data are the primary factors in accurate assessment and management of a country's water resources.

Relative to area and population, Kenya has limited surface water resources with the perennial rivers concentrated in the central and western areas. Therefore, the water resources of Kenya must be determined with sufficient accuracy for conserving, developing, and managing these sources efficiently.

The existing meteo-hydrological data gathering network of Kenya covers the densely populated high rainfall area of the central part of the country fairly well. However, there is considerable need for extension of the network into the semi-arid and arid areas in the northern part of the country where there are few streams and few gauging stations.

The water level gauging network of Kenya has been extended to cover almost all of the perennial rivers. Although 923 stations are registered in the former database system of MOWD, only 399 stations are now under operation. Even at some principal stations with long recorded periods, maintenance and rehabilitation works had not been made because of lack of transport, equipment, staff incentives, proper management and priority of work..

In the next decade, the demand for reliable surface water data will be constantly increasing due to expanding development programs for all types of water resources projects, so the careful monitoring of existing stations and judicious use of the gathered data are inevitable and will prevent random installation of a large number of stations beyond financial limitation.

The concept of the establishment of a reliable surface water data gathering network is attached in Appendix B.21. The report was prepared aiming at not only prioritizing the existing water level gauging stations but also enlightening the staff of MOWD. The report, therefore, contains the general description of climatology and present condition of surface water gathering network.

### 13.2 Data Collection

As well as the collection of reliable water level data, the consistent monitoring of suspended load and water quality is inevitable corresponding to the increasing water demand.

Suspended load monitoring should be carried out more frequently at the principal stations. The monitoring of water quality also should be carried out at least 4 times a year. A preliminary concept of these network is also given in Appendix B.20.

In the study period, the new database system was established in the headquarters of MOWD. Although the latest hydrological data was stored in the database system, additional data, especially rainfall and water levels, should be stored at the beginning of every calendar year. Some rainfall data should be collected from KMD.

## 13.3 Concept of Maintenance Flow

The concept of maintenance flow of a perennial river is not mentioned in the "Design Manual for Water Supply in Kenya (MOWD)". The maintenance flow of perennial river is required to maintain water surface depth, conservation of groundwater, and people's amenity. The maintenance flow of perennial river is also an indicator of the allowable limit of water withdrawal from the river.

In the Study, the recorded minimum daily discharge was assumed as the maintenance flow. The ratio of recorded lowest daily discharge to annual average discharge was roughly estimated at 6.2% on average on the basis of the records at the existing 15 water level gauging stations with daily water level records of more than 15 years.

However, the maintenance flow is basically peculiar by perennial river and depends also on the environmental condition in the downstream reach. An in-depth study should be required for determining the maintenance flow and the maximum exploitable flow for a perennial river.

## 13.4 Telemetering/Telecommunication System for Flood Forecasting

The conditions of flood inundation and its damages has been printed in few documents in Kenya. However, according to the "District Development Plan", some districts mentioned the necessity of flood control protection works with a top priority.

In case such a flood protection works is not envisaged because of financial constraints, a telemetering or telecommunication systems should be introduced as an urgent countermeasure. A few telemetered rainfall stations in the uppermost catchment and a telemetered water level gauge in the upstream reach are helpful to forecast travelling time of flood peak discharge to downstream areas and to warn in advance the people in the downstream areas.

It requires appropriate equipment, forecasting technique and the format of transfer of data through an efficient communication system. It is recommended that such a system be developed by the Research Division of MOWD before use and implementation by Resources Unit of MOWD.

## 13.5 Conservation of Forest Area

As described in Chapter B9, 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.

Springs are generally located at a fringe of forest areas. It is, therefore, able to point out clearly their groundwater reservoirs into the forest area.

In order to maintain a perennial river even in the dry season, the existing forest areas should be conserved in the future and protection works of springs must be effective in keeping the existing reaches of perennial rivers as far as excessive water abstraction is not made.

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# *TABLES*

## Table B2.1 Mean Annual Rainfall Depth for Successive 5-year Period

(Unit: mm)

| Station | 1911 - 1915 | 1916 - 1920 | 1921 - 1925 | 1926 - 1930 | 1931 - 1935 | 1936 - 1940 | 1941 - 1945 | 1946 - 1950 | 1951 - 1955 | 1956 - 1960 | 1961 - 1965 | 1966 - 1970 | 1971 - 1975 | 1976 - 1980 | 1981 - 1985 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kakamega | 1,765 | 1,891 | 1,944 | 1,908 | 1,890 | 1,921 | 1,702 | 1,881 | 1,682 | 1,815 | 2,246 | 2,019 | 2,170 | 2,027 | 2,116 |
| | (3) | (7) | (10) | (8) | (6) | (9) | (2) | (5) | (1) | (4) | (15) | (11) | (14) | (12) | (13) |
| Kapsabet | 1,656 | 1,715 | 1,406 | 1,413 | 1,411 | 1,543 | 1,465 | 1,497 | 1,596 | 1,377 | 1,596 | 1,755 | 1,364 | 1,696 | 1,345 |
| | (12) | (14) | (4) | (6) | (5) | (9) | (7) | (8) | (10) | (3) | (11) | (15) | (2) | (13) | (1) |
| Kisumu | 1,125 | 1,135 | 1,148 | 1,059 | 1,111 | 1,184 | 1,076 | 1,021 | 1,130 | 908 | 1,267 | 1,102 | 1,151 | 1,274 | 1,058 |
| | (8) | (10) | (11) | (4) | (7) | (13) | (5) | (2) | (9) | (1) | (14) | (6) | (12) | (15) | (3) |
| Londiani | 999 | 962 | 1,055 | 1,114 | 1,069 | 1,187 | 1,162 | 1,130 | 1,167 | 1,187 | 1,323 | 1,197 | 1,209 | 1,074 | 1,054 |
| | (2) | (1) | (4) | (7) | (5) | (12) | (9) | (8) | (10) | (11) | (15) | (13) | (14) | (6) | (3) |
| Kericho | 1,811 | 1,803 | 1,778 | 1,838 | 1,744 | 1,875 | 1,751 | 1,940 | 1,864 | 1,820 | 2,129 | 2,006 | 1,773 | 1,827 | 1,995 |
| | (6) | (5) | (4) | (9) | (2) | (11) | (1) | (12) | (10) | (7) | (15) | (14) | (3) | (8) | (13) |
| Naivasha | 610 | 626 | 576 | 651 | 535 | 641 | 552 | 575 | 680 | 694 | 736 | 677 | 621 | 710 | 616 |
| | (5) | (8) | (4) | (10) | (1) | (9) | (2) | (3) | (12) | (13) | (15) | (11) | (7) | (14) | (6) |
| Narok | 733 | 801 | 683 | 707 | 550 | 723 | 651 | 639 | 646 | 893 | 953 | 803 | 744 | 824 | 641 |
| | (9) | (11) | (6) | (7) | (1) | (8) | (5) | (2) | (4) | (14) | (15) | (12) | (10) | (13) | (3) |
| Kiambu | 1,047 | 1,084 | 1,027 | 1,101 | 937 | 1,001 | 966 | 910 | 946 | 1,130 | 1,176 | 1,144 | 916 | 1,158 | 927 |
| | (9) | (10) | (8) | (11) | (4) | (7) | (6) | (1) | (5) | (12) | (15) | (13) | (2) | (14) | (3) |
| Limuru | 1,328 | 1,403 | 1,223 | 1,350 | 1,152 | 1,353 | 1,123 | 1,077 | 1,226 | 1,351 | 1,637 | 1,428 | 1,160 | 1,432 | 1,170 |
| | (8) | (12) | (6) | (9) | (3) | (11) | (2) | (1) | (7) | (10) | (15) | (13) | (4) | (14) | (5) |
| Thika | 834 | 887 | 807 | 902 | 784 | 956 | 897 | 704 | 805 | 738 | 977 | 877 | 776 | 920 | 683 |
| | (8) | (10) | (7) | (12) | (5) | (14) | (11) | (2) | (6) | (3) | (15) | (9) | (4) | (13) | (1) |
| Machakos | 1,074 | 1,002 | 862 | 960 | 924 | 871 | 775 | 827 | 999 | 815 | 1,044 | 994 | 815 | 1,011 | 977 |
| | (15) | (12) | (5) | (8) | (7) | (6) | (1) | (4) | (11) | (2) | (14) | (10) | (3) | (13) | (9) |
| Makindu | 535 | 914 | 1,034 | 588 | 397 | 540 | 507 | 522 | 521 | 498 | 734 | 700 | 433 | 640 | 611 |
| | (7) | (14) | (15) | (9) | (1) | (8) | (4) | (6) | (5) | (3) | (13) | (12) | (2) | (11) | (10) |
| Voi | 565 | 500 | 540 | 588 | 443 | 657 | 459 | 440 | 483 | 556 | 574 | 704 | 461 | 633 | 547 |
| | (10) | (6) | (7) | (12) | (2) | (14) | (3) | (1) | (5) | (9) | (11) | (15) | (4) | (13) | (8) |
| Kwale | 999 | 813 | 904 | 1,066 | 1,084 | 1,235 | 1,029 | 1,271 | 1,129 | 1,126 | 1,097 | 1,112 | 987 | 1,116 | 1,073 |
| | (4) | (1) | (2) | (6) | (8) | (14) | (5) | (15) | (13) | (12) | (9) | (10) | (3) | (11) | (7) |
| Mombasa | 1,087 | 1,083 | 1,201 | 1,105 | 1,311 | 1,403 | 1,168 | 1,201 | 1,096 | 1,142 | 1,032 | 1,376 | 1,060 | 1,138 | 1,316 |
| | (4) | (3) | (11) | (6) | (12) | (15) | (9) | (10) | (5) | (8) | (1) | (14) | (2) | (7) | (13) |
| Total Point | 110 | 124 | 104 | 124 | 69 | 160 | 72 | 80 | 113 | 112 | 193 | 178 | 86 | 177 | 98 |
| Total Ranking | 7 | 10 | 6 | 11 | 1 | 12 | 2 | 3 | 9 | 8 | 15 | 14 | 4 | 13 | 5 |

Note: Parenthesized figure indicates ranking in ascending order.

Table B3.1 Distribution of Water Level Gauging Stations in Kenya (1990)

| No. | Drainage Area | Catchment Area (sq.km) | Ratio to Total Area (%) | Registered Station (nos.) Operation | Abandoned | Total | Catchement per Station (sq.km) | Type of Gauge (nos.) AS | ASW | S | SW | W | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Lake Victoria | 46,229 | 8.0 | 114 | 115 | 229 | 202 | 18 | 4 | 169 | 38 | - | 229 |
| 2 | Rift Valley | 130,452 | 22.5 | 50 | 103 | 153 | 853 | 15 | 3 | 95 | 38 | 2 | 153 |
| 3 | Athi River and Coast | 66,837 | 11.5 | 74 | 149 | 223 | 300 | 15 | 5 | 118 | 49 | 36 | 223 |
| 4 | Tana River | 126,026 | 21.7 | 116 | 89 | 205 | 615 | 19 | 7 | 152 | 18 | 9 | 205 |
| 5 | Ewaso Ngiro and North | 210,226 | 36.3 | 45 | 68 | 113 | 1,860 | 7 | 6 | 58 | 30 | 12 | 113 |
| | Total | 579,770 | 100.0 | 399 | 524 | 923 | 3,830 | 74 | 25 | 592 | 173 | 59 | 923 |

Note : Type of Gauge

AS : Automatic recorder + Staff gauge
ASW : Automatic recorder + Staff gauge + Weir
S : Staff gauge
SW : Staff gauge + Weir
W : Weir

Table B6.1 List of Water Level Gauging Stations used in the Study

| No. | River Basin | Station used in the Study | | | |
|---|---|---|---|---|---|
| **Drainage Area 1** | | | | | |
| 1 | Sio | 1AD02 | 1AH01 | | |
| 2 | Nyando | 1GB03 | 1GB05 | 1GB08 | 1GB09 |
| | | 1GC06 | 1GD02 | 1GD04 | |
| **Drainage Area 2** | | | | | |
| 3 | Turkwel | 2B 09 | 2B 27 | 2B 30 | 3G 02 |
| 4 | Kerio | 2C 05 | 2C 07 | 2C 08 | 3G 02 |
| 5 | Lake Bogoria | 2ED02 | 2EE07 | 2EE08 | |
| 6 | Lake Baringo | 2ED02 | 2EE07 | 2EE08 | |
| 7 | Lake Nakuru | 2EE07 | 2FC05 | 2GB01 | 2GC04 |
| 8 | Lake Naivasha | 2EE07 | 2FC05 | 2GB01 | 2GC04 |
| 9 | Lake Elementaita | 2EE07 | 2FC05 | 2GB01 | 2GC04 |
| 10 | Ewaso N'giro | 2K 01 | 2K 03 | 2K 06 | 3G 02 |
| **Drainage Area 3** | | | | | |
| 11 | Athi | 3AA04 | 3BA29 | 3BA32 | 3BD05 |
| | | 3CB05 | 3DA02 | 3F 02 | 3G 02 |
| | | 3G 03 | | | |
| 12 | Rare, Pemba and Mwachi | 3KG01 | 3G 02 | | |
| **Drainage Area 4** | | | | | |
| 13 | Tana | 4AA01 | 4AA07 | 4AB05 | 4AC03 |
| | | 4AC04 | 4AD01 | 4BB01 | 4BC02 |
| | | 4BE01 | 4BE02 | 4BF01 | 4CA02 |
| | | 4CB04 | 4DA10 | 4DC02 | 4DD01 |
| | | 4DD02 | 4EA03 | 4EB06A | 4EA06 |
| | | 4EB01 | 4EB09 | 4EB11 | 4F 10 |
| | | 4F 13 | 4F 17 | 3G 02 | |
| **Drainage Area 5** | | | | | |
| 14 | Ewaso N'giro | 5AC08 | 5BB02 | 5D 05 | 5E 03 |

Table B6.2 Relationship between Probable Daily Discharges and Flow Duration Curve on Monthly Discharge Basis

| Station No. | Nos. of Years | Annual Average Discharge (cms) | 2-yr Drought | | 5-yr Drought | | 10-yr Drought | | Min. Discharge | | No. of Records (a) (days) | Deficit (b) (days) | Ratio (b) / (a) (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Discharge (cms) | Ratio (%) | Discharge (cms) | Ratio (%) | Discharge (cms) | Ratio (%) | Daily (cms) | Monthly (cms) | | | |
| 1BA01 | 18 | 1.1 | 0.24 | 89.1 | 0.18 | 98.2 | 0.15 | 98.4 | 0.10 | 0.10 | 6,559 | 0 | 100.0 |
| 1FE02 | 22 | 16.6 | 2.01 | 99.2 | 1.01 | 100.0 | 0.73 | 100.0 | 0.57 | 1.90 | 8,018 | 150 | 98.1 |
| 1KC03 | 17 | 16.0 | 0.19 | 99.6 | 0.05 | 100.0 | 0.00 | 100.0 | 0.00 | 0.10 | 6,156 | 19 | 99.7 |
| 1LA03 | 16 | 11.2 | 0.52 | 97.3 | 0.21 | 100.0 | 0.12 | 100.0 | 0.10 | 0.20 | 5,815 | 9 | 99.8 |
| 2C 05 | 19 | 2.2 | 0.56 | 97.1 | 0.39 | 100.0 | 0.32 | 100.0 | 0.19 | 0.50 | 6,921 | 121 | 98.3 |
| 4BC02 | 16 | 30.5 | 7.96 | 98.2 | 6.36 | 100.0 | 5.70 | 100.0 | 5.07 | 6.30 | 5,780 | 30 | 99.5 |
| 4CA02 | 19 | 8.9 | 2.32 | 95.1 | 1.81 | 99.1 | 1.58 | 100.0 | 1.58 | 1.70 | 6,896 | 31 | 99.6 |
| 4CB04 | 25 | 6.4 | 0.93 | 96.6 | 0.58 | 99.7 | 0.45 | 100.0 | 0.39 | 0.50 | 9,091 | 32 | 99.6 |
| 4DA02 | 16 | 1.8 | 0.27 | 98.6 | 0.15 | 99.7 | 0.13 | 99.9 | 0.09 | 0.10 | 5,817 | 1 | 100.0 |
| 4DD01 | 15 | 26.2 | 5.81 | 99.0 | 3.75 | 100.0 | 2.79 | 100.0 | 2.60 | 4.40 | 5,408 | 75 | 98.6 |
| 4G 01 | 22 | 169.6 | 34.04 | 98.1 | 20.11 | 99.9 | 14.01 | 100.0 | 8.83 | 18.20 | 7,996 | 30 | 99.6 |
| 4G 04 | 16 | 142.5 | 28.85 | 89.6 | 12.07 | 94.2 | 4.11 | 98.3 | 0.18 | 1.10 | 5,820 | 45 | 99.2 |
| 5AB04 | 16 | 6.4 | 2.07 | 90.8 | 1.29 | 99.7 | 1.10 | 99.7 | 0.49 | 0.50 | 5,822 | 2 | 100.0 |
| 5AC08 | 28 | 3.2 | 0.24 | 91.8 | 0.13 | 98.1 | 0.10 | 100.0 | 0.09 | 0.10 | 10,160 | 37 | 99.6 |
| 5E 03 | 17 | 16.6 | 1.06 | 93.8 | 0.26 | 99.6 | 0.00 | 100.0 | 0.00 | 0.10 | 6,150 | 21 | 99.7 |
| Ave. | 19 | 30.6 | | 95.6 | | 99.2 | | 99.8 | | | | 40.2 | 99.4 |

Note : Discharge : daily discharge basis (cms)
Ratio : ratio on flow duration curve prepared on basis of monthly average discharges (%)
(a) : number of daily discharge data examined
(b) : number of days of which the daily discharge is less than the minimum monthly discharge

Table B6.3 Runoff Ratio of Perennial Rivers in Kenya

| River Name | Catchment Area (sq.km) | Annual Rainfall (mm) | Annual Runoff (mm) | Runoff Ratio (%) |
|---|---|---|---|---|
| **DRAINAGE AREA 1** | | | | |
| Sio | 1,338 | 1,683 | 269 | 16.0 |
| Nzoia | 12,903 | 1,424 | 310 | 21.7 |
| Yala | 3,240 | 1,565 | 163 | 10.4 |
| Nyando | 3,356 | 1,298 | 222 | 17.1 |
| Kibos | 833 | 1,327 | 414 | 31.2 |
| Awach Seme | 717 | 1,191 | 373 | 31.4 |
| Sondu | 3,487 | 1,497 | 500 | 33.4 |
| Gucha | 6,824 | 1,444 | 266 | 18.5 |
| Mara | 8,608 | 1,037 | 217 | 20.9 |
| **DRAINAGE AREA 2** | | | | |
| Turkwel | 19,906 | 532 | 22 | 4.1 |
| Kerio | 13,460 | 696 | 50 | 7.2 |
| Lake Baringo | 5,770 | 933 | 147 | 15.8 |
| Lake Bogoria | 1,220 | 747 | 121 | 16.2 |
| Lake Nakuru | 1,503 | 1,048 | 131 | 12.5 |
| Lake Elementaita | 551 | 789 | 133 | 16.9 |
| Ewaso N'giro | 8,652 | 832 | 47 | 5.7 |
| **DRAINAGE AREA 3** | | | | |
| Athi | 37,836 | 733 | 17 | 2.3 |
| Pemba | 1,028 | 915 | 77 | 8.4 |
| Mwachi | 7,362 | 638 | 31 | 4.9 |
| Rare | 7,729 | 733 | 26 | 3.6 |
| **DRAINAGE AREA 4** | | | | |
| Tana | 95,989 | 712 | 39 | 5.4 |
| **DRAINAGE AREA 5** | | | | |
| Ewaso N'giro (*) | 12,107 | 707 | 28 | 3.9 |
| Weighted Average | 254,419 | 815 | 77 | 9.5 |

Note : (*) *Archer's Post water level gauging station*

## Table B7.1 List of Water Level Gauging Stations Selected for Flood Analysis (1/2)

| Drainage Area | Station Code | Major River | River | Catchment Area (sq km) | M.A.F. (CMS) | Recorded Period (Year) |
|---|---|---|---|---|---|---|
| 1 | 1AHA | Sio | Sio | 1450 | 52 | 1959 - 1989 |
| | 1BA2 | Nzoia | Moiben | 262 | 10 | 1961 - 1989 |
| | 1BC1 | | Noigameget | 684 | 17 | 1959 - 1989 |
| | 1BG4 | | Kassowai | 54 | 4 | 1950 - 1989 |
| | 1BG5 | | Rongai | 34 | 0.8 | 1949 - 1989 |
| | 1BG6 | | Ewaso Rongai | 530 | 26 | 1960 - 1989 |
| | 1CA2 | | Sergoit | 717 | 22 | 1960 - 1989 |
| | 1CB5 | | Sosiani | 697 | 17 | 1960 - 1989 |
| | 1CC1 | | Onyokie | 588 | 46 | 1948 - 1987 |
| | 1CE1 | | Kipkarren | 2440 | 124 | 1948 - 1988 |
| | 1DA2 | | Nzoia | 8417 | 198 | 1947 - 1989 |
| | 1DB1 | | Kuiwa | 446 | 50 | 1965 - 1989 |
| | 1DD1 | | Nzoia | 10142 | 294 | 1963 - 1989 |
| | 1EB2 | | Isiukhu | 359 | 25 | 1963 - 1989 |
| | 1EE1 | | Nzoia | 11849 | 300 | 1963 - 1987 |
| | 1FC1 | Yala | Kimondi | 909 | 80 | 1965 - 1989 |
| | 1FE1 | | Yala | 1896 | 134 | 1961 - 1988 |
| | 1FE2 | | Yala | 1577 | 100 | 1961 - 1989 |
| | 1FF2 | | Zaaba | 47 | 8 | 1959 - 1989 |
| | 1FF3 | | Edzawa | 262 | 31 | 1963 - 1988 |
| | 1FG1 | | Yala | 2388 | 83 | 1947 - 1989 |
| | 1FG2 | | Yala | 2864 | 104 | 1959 - 1989 |
| | 1GB3 | Nyando | Ainamotua | 1300 | 96 | 1968 - 1989 |
| | 1GB6 | | Mbogo | 67 | 5 | 1956 - 1987 |
| | 1GC5 | | Masaita | 251 | 54 | 1964 - 1989 |
| | 1GD3 | | Nyando | 2625 | 206 | 1968 - 1989 |
| | 1GD4 | | Nyando | 2520 | 111 | 1956 - 1989 |
| | 1GD7 | | Nyando | 1419 | 133 | 1962 - 1989 |
| | 1HA1 | – | Oruba | 62 | 22 | 1959 - 1989 |
| | 1HA4 | – | Kibos | 117 | 12 | 1929 - 1989 |
| | 1HA14 | – | Awach | 104 | 13 | 1963 - 1989 |
| | 1JD3 | Sondu | Yurith | 1586 | 83 | 1969 - 1988 |
| | 1JF4 | | Kipsonoi | 73 | 9 | 1961 - 1989 |
| | 1JG1 | | Sondu | 3287 | 169 | 1946 - 1989 |
| | 1KB3 | Kuja/Migori | Kuja | 1114 | 79 | 1965 - 1987 |
| | 1KB1A | | Kuja | 3115 | 387 | 1965 - 1987 |
| | 1KB5 | | Kuja/Migori | 6600 | 358 | 1969 - 1989 |
| | 1KC3 | | Migori | 3046 | 418 | 1951 - 1989 |
| | 1LA3 | Mara | Nyangores | 679 | 28 | 1964 - 1988 |

M.A.F.: Mean Annual Flood