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REPUBLIC OF KENYA

MINISTRY OF WATER DEVELOPMENT

THE STUDY

ON

THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT
(J)

DAM GEOLOGY

JULY 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

LIST OF REPORTS

EXECUTIVE SUMMARY

MAIN REPORT

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

SECTORAL REPORT

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

DATABOOK

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

PREFACE

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.

THE STUDY ON THE NATIONAL WATER MASTER PLAN

SECTORAL REPORT (J)
DAM GEOLOGY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

J1. INTRODUCTION

The purpose of the dam geological survey is to obtain geological information on potential damsites and to provide the basic data for dam planning in the NWMP study.

Objective damsites for survey were selected by the Study Team's Dam Planners using the following criteria:

(a) Schemes accorded high potential in previous studies.

(b) Schemes where existing information remains at study levels. Schemes at detailed design and/or implementation stages were excluded from the survey.

(c) Newly proposed damsites

The geological survey consisted of collection of existing information, interpretation of aerial photographs, and field reconnaissance.

The study used existing information as much as applicable for schemes where the previous findings were made available. Field reconnaissance was done mainly for those schemes where existing information is scarce and/or for newly proposed schemes.

Dam schemes taken up in this study include the following 36 sites:

Name of Dam	River Basin	Information source
1. Hemsted's Bridge	Nzoia	R
2. Rumbula	Nzoia	R
3. Gongo	Yala	R
4. Mushangumbo	Yala	R
5. Nandi Forest	Yala	R
6. Nyando	Nyando	R+E
7. Magwagwa	Sondu	E
8. Namba Kodero	Kuja	R
9. Katieno	Kuja	R
10. Kerio-A	Kerio	R
11. Sererwa	Kerio	R+E
12. Molo	Molo	R
13. Malewa	Malewa	R+E
14. Oldorko	Ewaso Ngiro south	R+E
15. Leshota	Ewaso Ngiro south	E
16. Marun	Turkwel	R
17. Munyu	Athi river	R+E
18. Kiteta	Athi	E
19. Thwake	Athi	R
20. Yatta Kiboko	Athi	R
21. Tsavo	Athi	E
22. Baricho	Sabaki	R
23. Rare	Rare	R

24. Pemba	Pemba	R
25. Mwachi	Mwachi	R
26. Thiba	Tana	E
27. Karura	Tana	R
28. Mutonga	Tana	E
29. Grand Falls	Tana	E
30. Usueni	Tana	R
31. Adamson's Falls	Tana	R+E
32. Kora	Tana	E
33. Rumuruti	Ewaso Ngiro north	R+E
34. Kirium	Ewaso Ngiro north	R
35. Crocodile Jaw (Lorkinyang)	Ewaso Ngiro north	R
36. Archer's Post	Ewaso Ngiro north	R

Notes: R: Reconnoitered
E: Mainly based on existing information

The geological survey was carried out from September 6th to December 27th, 1990. Location of these 36 damsites is shown in Figure J1.1.

J2. GEOLOGY OF KENYA

This chapter describes the general geology of Kenya and the regional geology for each of the five drainage areas in which damsites are proposed.

2.1 General Geology

Excellent geological studies have been carried out in Kenya and results published in the form of geological reports, geological maps, and various thesis papers. Among them, Pulyrey (1969), Baker (1973), and Thackery (1984) provided valuable results in defining the general geology of Kenya. Detailed geological maps in 1:1,000,000 scale are published by the Ministry of Environment and Natural Resources.

The major physiographic and geological features of Kenya are classified areawise as given in Figure J2.1 and Figure J2.2.

Ancient foundation rocks occur in the western and central parts of the country. They have been classified as Nyanzian, Kavirondian, Basement, and Bukoban system by difference of rocks and ages.

The eastern sedimentary rocks ranging in age from 300 to 100 million years occur in the south-east and northeastern areas in Kenya. The sedimentary rocks, both marine and continental origins, have been accumulated to a depth of thousands of meters, dipping gently eastward.

Volcanic rocks erupted in and along the Rift Valley. The main rock types include phonolites, nephelinites, trachytes, and other volcanic rocks which erupted on the bed rock.

The volcanic eruptions formed the massifs of Mt. Kenya, Mt. Elgon, the Nyandarua range and many other less prominent peaks and ranges. The sheet lava flows also cover the bed rock in extensive sections of Kenya.

Throughout the Neogene and Quaternary periods, inland sediment accumulated in and around the developing Rift Valley, and marine deposits along the coast.

Most of the recent sediments are modern desert sediments. These cover a huge area of eastern Kenya as well as smaller areas in the north-west.

2.2 Regional Geology

Regional geologies are described hereunder for the purposes of reference to the damsite geological assessment in Chapter J3. Most of the information contained herein was extracted or reproduced from existing literature.

2.2.1 Geology of Lake Victoria drainage area

Geology in the Lake Victoria drainage basin consists of Precambrian metamorphic rocks, igneous rocks and Post-Miocene volcanics.

Precambrian rocks are distributed over the Nyanza Low Plateau, the Low Lands, and half of the Western Highlands. All of Precambrian systems from lowest Nyanzian system to uppermost Bukoban system appear in these areas. Moreover, Precambrian and post Cambrian intrusive granites and other rocks occur in wide areas.

The Nyanzian system is composed of ancient volcanic materials such as basalts, tuffs, trachytes, andesites, rhyolites, and greywackes forming great thickness. The volcanics were interbedded with a number of coarse-grained sediments such as conglomerates, quartzites, and banded ironstone. The whole of this system can be considered to have been thermal metamorphosed during the Archaean times by heat rising from greater depths. During these processes, many intrusions were injected into the system. The Nyanzian system is mainly located in the low Nyanza Plateau, where four damsites namely Gongo, Mushagumbo, Namba Kodero and Katieno are proposed. These dams will have their foundations on this Nyanzian system.

The Kavirondian system is geologically younger than the Nyanzian system. Lithologically they are comprised of originally sedimentary rocks; mainly sandstones and other rocks such as greywackes, mudstones and conglomerates. The system extends in areas of less than 20 km wide from Busia town through Butere with Kakamega town marking its northern boundary. The other locations are isolated and small in area. Rambula damsite is located in Kavirondian greywackes.

The Basement system is widespread and covers almost the whole country and most of the major parts of the Kenyan Precambrian. The rocks are distributed from east of Kisii to Tanzanian border in the south, which is one part of the western highlands, and from east of Mt Elgon to Mersuk and Karasuk hills in the north.

This system originated from sedimentary rocks such as sandstones, grits, shales and limestones, which were intensely metamorphosed in one vast geosyncline called the Mozambique Geosyncline or in a series of geosynclines. This metamorphism resulted in the formation grade gneisses and granite to migmatite partially. Hemsted's Bridge damsite is located in basement gneisses area.

The Bukoban system overlies unconformably on ancient rocks located mainly in the Kisii Highlands. They are inferred to be approximately 670 million years old and form a thick layer of some 760 m. They are characterized by three groups of which the lower one and upper group being composed of basalt lava and the middle group being dominated by ferruginous siltstones and quartzites.

The intrusive rocks mainly consist of granites rising up in the Precambrian rocks around Nyanza Low Plateau, Nandi Hills and Kisii Highlands. These areas show singular land

forms such as smooth exfoliation ridges, bare-rock surfaces and inselgergs. Nandi Forest damsite is located in the intrusive granite area.

Tertiary to recent volcanics are seen in the remaining half of the western highlands inclusive of Mt Elgon. The volcanics consist of phonolites, nephelinites, basalts, tephrites, basanites and of their pyroclastics composed of mainly tuffs and welded tuffs. Phonolites are distributed mainly around Mau Hills and the southern part of Kericho, while Mt. Elgon consists of nephelinites and pyroclastics. Nyando/Koru damsite is located in these phonolites having a great thickness.

2.2.2 Geology of Rift Valley drainage area

Geology in the Rift Valley region consists of Miocene Holocene volcanics, lacustrine and fluviatile or colluvial deposits. The Rift valley is a great rift system edged in two or more long faults and was formed during the last 17 million years. The Kenyan Rift Valley is part of an interconnected rift series that runs 3,000km from Mozambique in the south to Red Sea through Ethiopia in the north. In Kenya the rift stands out from Lake Magadi in the south to Lake Logipi in the north.

A number of normal step like faults have developed along the edge of the sinking rift which are made up of tilted blocks.

The Rift Valley first appeared as a long shallow depression formed by down-folding of the rock layers. Great numbers of faults developed first along the valley side before the valley floor subsided. During the subsidence of the floor, lava erupted as soon as the floor sank, so the subsidence of the surface at the highest escarpment visible today is one tenth smaller than the total subsidence of the original floor.

Volcanics of the Rift Valley region consist of phonolites, basalts, basanites, trachytes, other lavas and their pyroclastic rocks as tuffs and agglomerates. Volcanoes which erupted these lavas are classified into two types vent type and the fissure type. The vent type volcanoes are further classified into two varieties; monogenic volcanoes and polygenetic volcanoes. Mt. Longonot and some other polygenetic volcanoes had been built up during the last 2 to 3 million years and erupted within the last 200 years. The most recent eruption was when Central Island of Turkana blew out with clouds of ashes in the late 1960s. These volcanoes have summit calderas. The caldera of Mt. Menengai, the biggest one, is 12km in diameter.

Sediments of the Rift Valley region consist of deposits from lakes and rivers which had appeared or disappeared and colluvium deposits from the rift slopes. Great thickness of Colluvial deposits are distributed along the Kerio River.

The northern upper part of the Rift covering the Arrow river, Embabut river, the Cherangani Hills and Karasuku Hills consists of Precambrian basement gneisses. Thus the lithofacies of the Rift valley are conspicuous in contrast to neighboring highland areas outside the rift.

2.2.3 Geology of Tana River drainage area

The geology of the Tana river drainage area consists of Precambrian basement gneisses, pleistocene to Holocene volcanics, and Pleistocene to Holocene deposits.

The basement system of this area forms the bedrock, with outcrops stretching from Muranga in the south of Mt. Kenya to east surrounding the foot of Mt Kenya. Rock types are granulites, biotite gneisses, banded gneisses, Psamitic gneisses, Pelitic gneisses, granitoid gneisses, migmatites, amphybolites, crystalline limestones, and others.

Foliation varies in direction, varying in the southern part of Mt Kenya to the area downstream from the confluence of Thiba river. Foliations in the southern region of Mt Kenya exhibit NW-SE strikes and 40 degrees to 70 degrees to the NE, while in the downstream region from the confluence of Tana river and Thiba river, foliations exhibit N-S strikes and subvertical dips. Remarkable foldings can be recognized around the Grand Falls area and around the downstream region of the Maddogoni Hills.

The area covered by the basement system is seismicelly stable. Peneplanes of the submiocene erosion plain are widespread. Resistance hills, rock knobs and inselbergs, which are the landform of rock resistance to weathering, are found sporadically in the plain.

Volcanics are lava and pyroclastic rocks from two sources. One source was from Mt. Kenya which erupted during the Pleistocene to Holocene period and spread overlying the basement rock elliptically around Mt. Kenya. The other was distributed around Nyambeni Range which had formed the watershed of Tana River to Ewaso Ngiro North river.

Rock types are trachytes. Phonolites, basalt and their pyroclastics such as tuffs and agglomerates. The lava are interbeded in the tuffs and agglomerates layers, forming great complicated facies.

Pleistocene to Holocene deposits are also widespread eastward, connecting Kora wells through the Hamega swamp to the Mukoga hill line and thinly covered basement rocks. They are Upper Pleistocene superficial deposits, unconsolidated pebble sheets, calcareous crystal deposits, low humid red sandy soils, sandy alluvium and others.

The foundation rocks of six damsites proposed in the Tana River (except Thiba dam) would be basement gneisses, while the Thiba damsite located in the upper area of Tana river would be in Pleistocene basalt and agglomerates.

2.2.4 Geology of Athi River drainage area

The geology of Athi river drainage area consists of Precambrian Basement gneisses, Eastern Palaeozoic to Tertiary sedimentary rocks, Tertiary to Quarternary volcanics and Quarternary unconsolidated sediments.

Basement gneisses are classified into granitoid gneisses, banded gneisses, biotite gneisses, muscovite gneisses, hornbrende gneisses and crystalline limestones including intrusive granites. The rocks are widespread extending eastwards from Machakos area and bordered by Eastern sedimentary rocks with fault at the east of the eastern end of Yatta plateau.

There developed remarkable foldings in this system. Folding axes and foliations are both nearly N-S in direction and dip E or W with varying angles. There are two distinct layers containing many crystalline limestones east of Yatta Plateau and around Amboseli. These layers are stretched in NNW-SSE direction.

Tertiary volcanics are found in Eastern Highlands where Nairobi and Thika are located. Rocks are phonolites, basalts, agglomerates, soft tuffs and welded tuffs. In these, an alkaline lava called Kapiti phonolite is distributed and covers a very wide area from central Kenya to Tanzanian border in the south. One of the lava flows flooded down along the old Tsavo river for a distance of more than 300 Km from Muranga near Thika to east of Voi. This lava forms the top plain of Yatta Plateau.

Quaternary volcanics are located around the Kiosa volcano, Mwani volcano, Ambugur volcano in the Amboseli hills and western Kibwezi.

Rocks are mainly basalts and some kinds of pyroclastic rocks. A portion of these lava flooded along the Kiboko River up to the confluence of the Athi River.

Sedimentary rocks occur in areas from east of the edge of Yatta plateau to coast in the east. They extend in form of N-S belts; oldest in the western part and showing younger age towards the east.

Most ancient strata consisting mainly of shales are Carboniferous to Permian sediments, and are located around Tsavo East national park up to the Tanzanian border in the south.

Triassic sediments are composed mainly of sandstones intercalating with thin limestones and shales. They are found mostly in Kwale district and Kilifi district.

Jurassic sediments consist of limestones, calcarious sandstones and shales, occurring in a relatively narrow belt connecting the west of Mombasa, west of Kilifi and west of Malindi. The border of Triassic sediments and Jurassic sediments often forms faults.

Cretaceous sediments are not found in this area. Post-Tertiary deposits occurs in the east to the Mesozoic sediments with unconformity. The layers appear along the coast.

As Holocene deposits other than these marine origins, there exist residual soils and alluvial sands/clays. Residual clay is thick in the eastern area of Yatta Plateau overlying the basement gneisses and sedimentary rocks. Alluvial sand is deposited thickly in the riverbeds of the Athi, Thwake, Kiboko and Tsavo rivers and also of seasonal rivers joining the Athi river.

2.2.5 Geology of Ewaso Ngiro North drainage area

The geology of this area consists of Precambrian basement gneisses, Neogene to Pleistocene volcanics and Holocene Alluvium desert soils.

Basement gneisses from the bedrock of this area covered widely by younger volcanics erupted by Mt. Kenya and some volcanoes. The distributary areas of the basement gneisses directly on the surface coveredless the volcanics or the other deposits are bordered the eastern side of the line from Ewaso Ngiro flowing west of Nanyuki to Lorobi Forest, west side of the line from north of Nanyuki to Kipsing, and further north side of the line from Kipsing to Nyamben Hills. The rock types are mainly foliated biotite leucogranites, banded biotite gneisses, migmatites and other small quantities of marble, mafic gneisses intrusive rocks. The geological structure is complicated by remarkable foldings, but the development of faults is little and stable foundations have been formed. There exist many landforms such as inselberg, resistant hills, tors and bare-rocks surfaces in this basement rocks distributed area.

Volcanics exist in two ages; one is Neogene volcanics and the other is Pleistocene volcanics.

Neogene volcanics were mainly erupted during the miocene epoch and spread over the upper part of this river basin and around Rumuruti to the west. The rock types consist mainly of phonolites and a small quantity of basalt.

Pleistocene volcanics have been spread around Mt. Kenya and Nyambeni Range. The rock types are mainly basalts and basaltic pyroclastics and others, such as phonolites, trachytes and some kind of pyroclastics.

There are many craters which erupted during the Pleistocene epoch in the Nyambeni Range.

Alluvial sands accumulated thickly along the Ewaso Ngiro river from the downstream side of the Waso hill and residual sandy soils are widespread from the eastern side of Kubilakhalu.

J3. DAMSITE GEOLOGY

3.1 Maps, Aerial Photographs and References

The list of geological survey data referred to in this study is given in "Reference" attached at the end of report. Topographic maps and the aerial photographs used for the survey are listed in Table J3.1.

3.2 Findings from Survey

The purpose of this geological survey was to obtain preliminary geological information necessary for dam planning at each of the proposed dam sites. The survey includes field reconnaissance and review of existing geological data.

The main items examined during this survey comprised of;-

(1) Topography and geology at the damsite
(2) Possibility of dam construction and maximum dam height
(3) Availability of construction materials
(4) Type of dam
(5) Foundation treatment

A summary of the survey findings for 36 damsites is as shown in Table J3.2, and the details of each site are shown in Tables J3.3 through J3.38.

J4. SEISMICITY

4.1 Seismic Zones

A catalog of felt earthquakes in Kenya was compiled by I.S Loupekine (1971). The total number of earthquakes for the period 1892-1969(78 years) is given in the following table:

Total number of earthquakes for the period 1892-1969

Maximum intensity*	Number of earthquakes
IX	1
VIII	0
VII	3
VI	28
V	128
IV	382
III-II	25
TOTAL	567

* Modified Mercalli Scale (Wood and Neumann, 1931)

Distribution of widely felt earthquakes in Kenya is shown in Figure 4J.1. The map illustrates the areas affected by tremors producing intensity effects of at least V on the Modified Mercalli Scale.

A seismic zoning map shown in Figure J4.1 has been produced by I.S Loupekine as a guide for future earthquake occurrences. The map delineated zones of maximum expectable intensities. Preparation of the map was based on ;

(i) Actual past observations of intensities
(ii) Geological factors

According to Loupekin (1971), the influence of earthquakes on buildings and other structures in various zones are as follows,
A Catalog of Felt Earthquakes in Kenya (1892-1969):

IX. Damage considerable in specially designed structures; well- designed frame structures thrown out of plumb; great, in substantial buildings, with partial collapse. Buildings shifted off foundations. Underground pipes broken. (These effects are believed to obtain only locally in Zone VIII-IX, shown in the seismic Zoning Map).

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures.

Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls.

VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken.

VI. A few instances of fallen plaster or damaged chimneys. Damage slight.

V. A few instances of cracked plaster

4.2 Seismic Coefficient for Dam Design

The relation between seismic zoning and dam design seismic coefficients was checked based on design values adopted in existing project study reports. The results are shown below.

Seismic zone and Dam Design seismic coefficient

Name of Dam	Seismic Zone (FigureJ4.2)	Horizontal seismic coefficient in dam design
Magwagwa	VI	0.10g
Sondu/Miriu	VI	0.15g
Kiteta	VI	
Tsavo	VI	
Rare	VI	
Kiambere	VI	0.10g
Sererwa	VII	
Ruaka	VII	
Thika	VII	
Thiba	VII	0.14g
Rumuruti	VII	0.16g
Kirandich	VI-IX	0.07g
Malewa	VIII-IX	0.10g
Chemosusu	VIII-IX	0.15g
Turkwel	VIII-IX	0.15g

(NB: Not complete. Additional information to be included in subsequent study.)