REPUBLIC OF ZAMBIA

MINISTRY OF ENERGY AND WATER DEVELOPMENT

FINAL REPORT

VOLUME IV

MAIN TEXT

THE MASTER PLAN STUDY ON HYDROLOGIC OBSERVATION SYSTEMS OF THE MAJOR RIVER BASINS IN ZAMBIA

MARCH, 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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Preface

In response to a request from the Government of the Republic of Zambia, the Government of Japan decided to conduct a Master Plan Study on Hydrologic Observation Systems of the Major River Basins in Zambia, and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Zambia a study team headed by Mr.Yoshio Nakagawa, Yachiyo Engineering Co.,Ltd., five times between December 1989 and March 1992.

The team held discussions with the officials concerned of the Government of Zambia, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the Project and to the enhancement of the friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Zambia for their close cooperation extended to the team.

Tokyo, March 1992

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

THE MASTER PLAN STUDY ON HYDROLOGIC OBSERVATION SYSTEMS
OF THE MAJOR RIVER BASINS IN ZAMBIA

FINAL REPORT
M A I N

<< CONSTITUTION OF FINAL REPORT >>

(1) S U M M A R Y
(2) M A I N
(3) S U P P O R T I N G
(4) D A T A B O O K

CONTENTS OF MAIN REPORT

[A P P E N D I C E S]

THE MASTER PLAN STUDY ON HYDROLOGIC OBSERVATION SYSTEMS
OF THE MAJOR RIVER BASINS IN ZAMBIA

FINAL REPORT
M A I N

LIST OF FIGURES AND TABLES

THE MASTER PLAN STUDY ON HYDROLOGIC OBSERVATION SYSTEMS
OF THE MAJOR RIVER BASINS IN ZAMBIA

FINAL REPORT
M A I N

ABBREVIATIONS

< G E N E R A L >

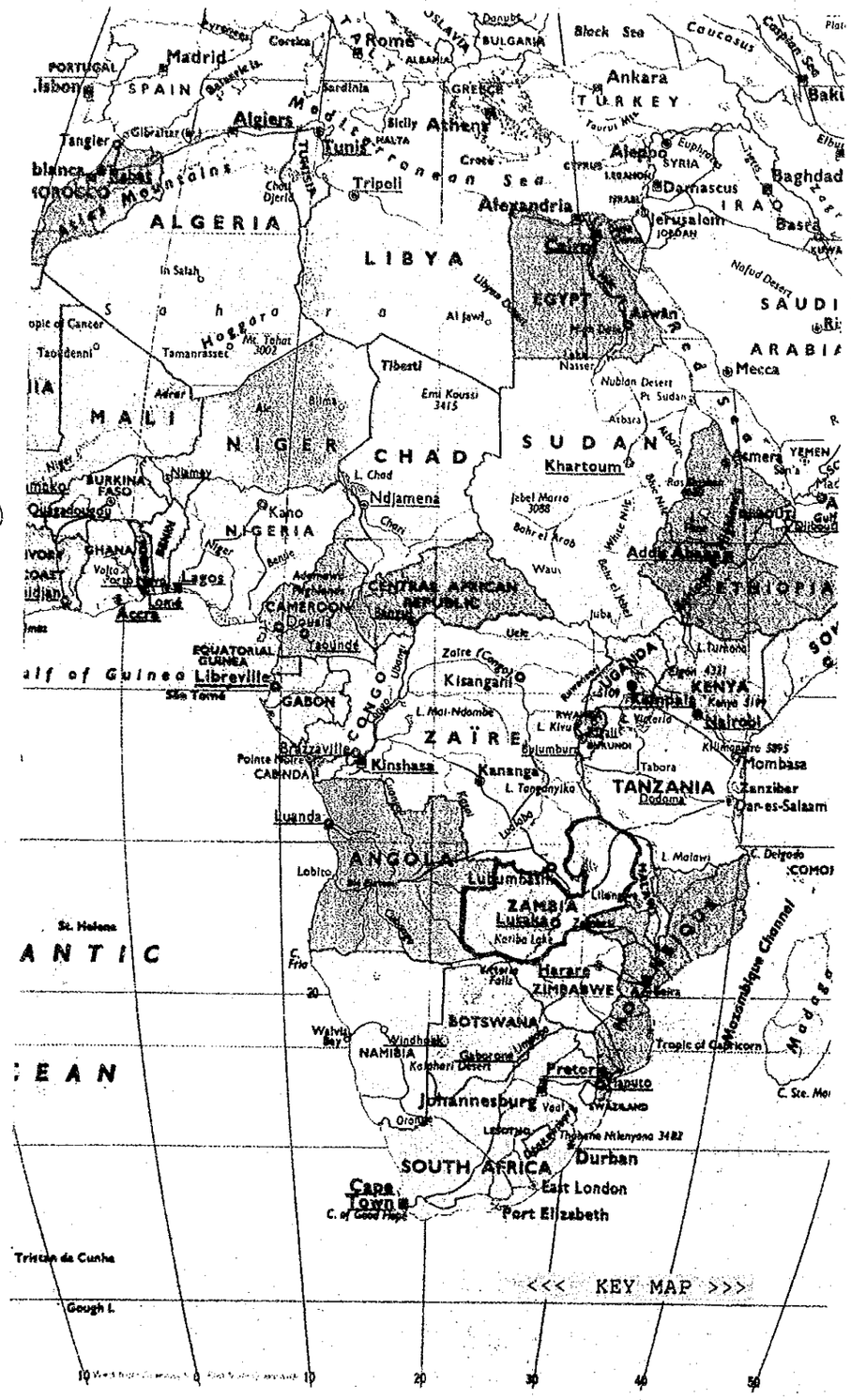
Study	: The master plan study on hydrologic observation systems of the major river basins in Zambia
Study Team	: The team dispatched by JICA to carry out Study
Study Area	: The area covered by Study
GDP	: Gross Domestic Product
FNDP	: Forth National Development Plan
BOD	: Biochemical Oxygen Demand
COD	: Chemical Oxygen Demand

< O R G A N I Z A T I O N AND F I R M >

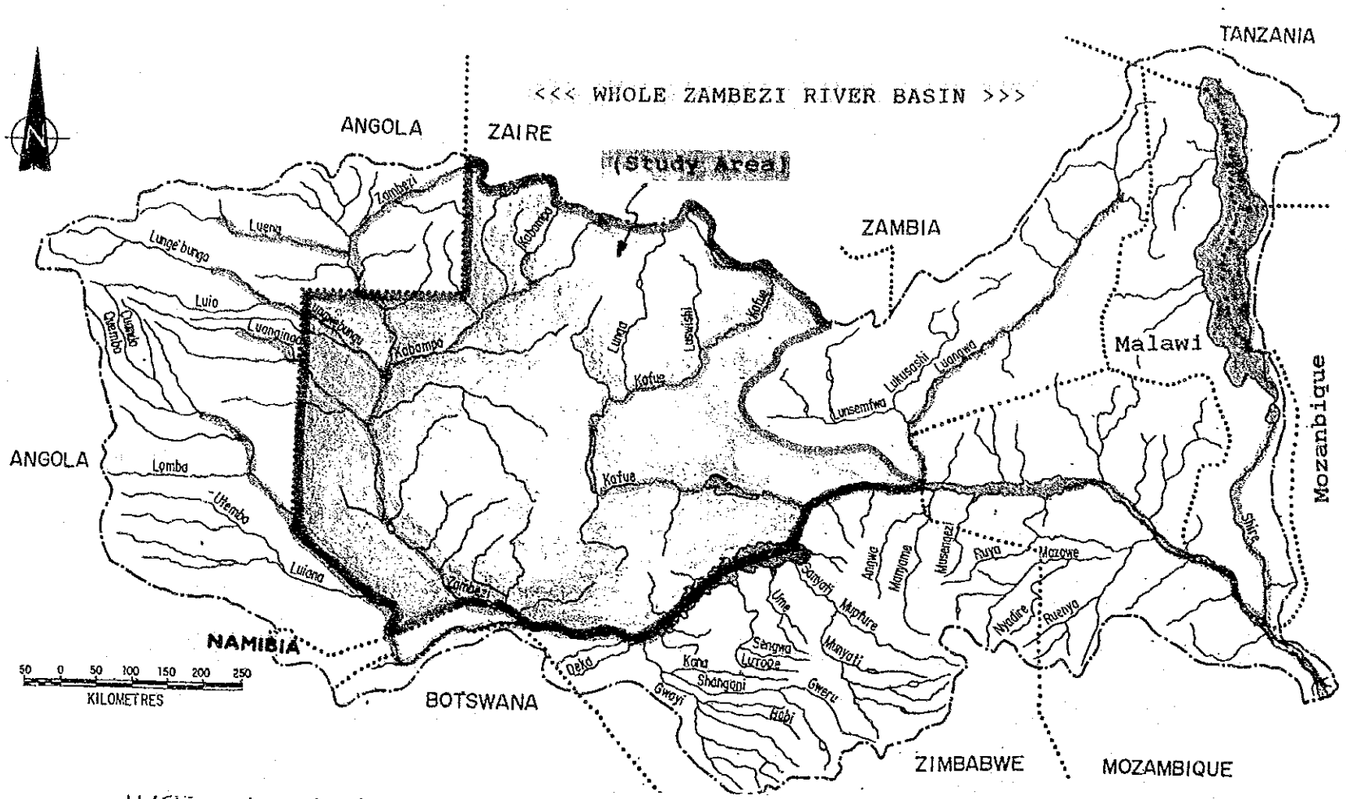
J I C A	: Japan International Cooperation Agency
D W A	: Department of Water Affairs, Ministry of Energy and Water Development, Republic of Zambia
Z R A	: Zambezi River Authority
Z E S C O	: Zambia Electric Supply Company
Z R	: Zambia Railways
TAZARA	: Tanzania - Zambia Railway Authority
IDWSSD	: International Drinking Water Supply and Sanitation Decade
U N	: United Nation
UNDP	: United Nation Development Program
WMO	: World Meteorological Organization
MEWD	: Ministry of Energy and Water Development
SADCC	: South African Development Coordination Conference

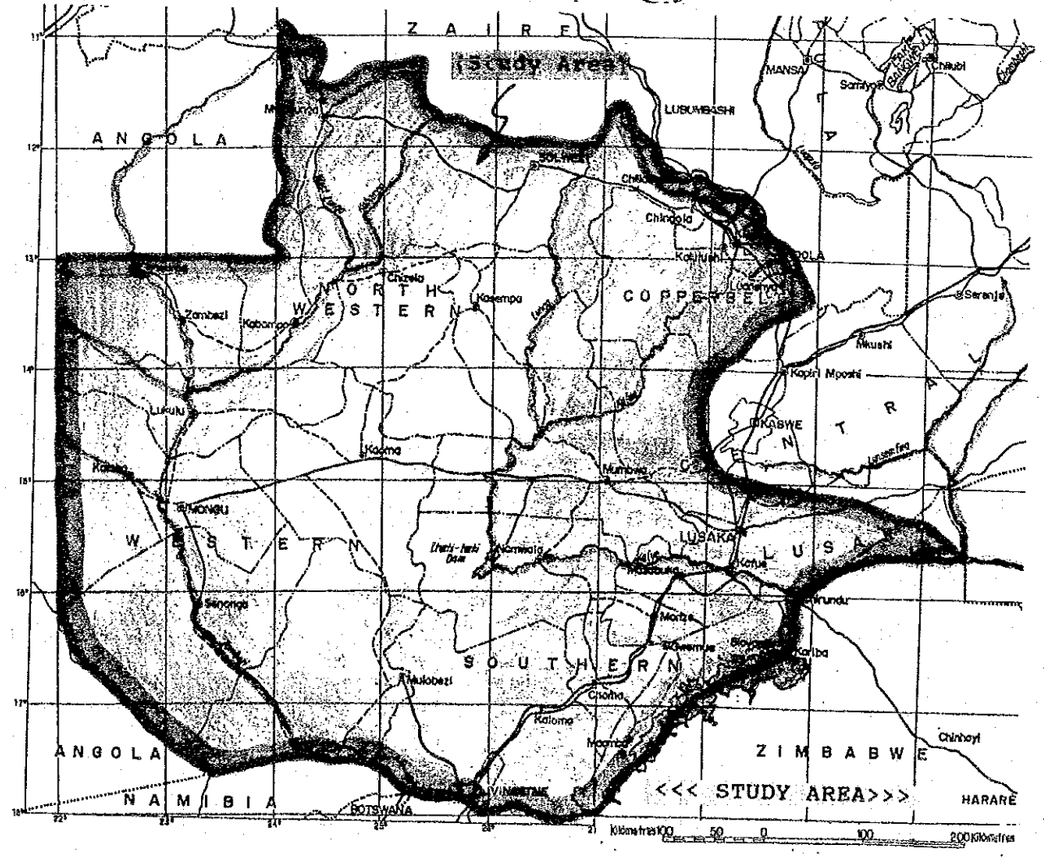
< U N I T >

km	: Kilometer, 1km = 1000m
m	: Meter, 1m = 100cm
cm	: Centimeter, 1cm = 10mm
mm	: Millimeter
f	: Feet, 1f = 12 inches = 1/3 yard = 0.3048m
km2	: Square kilometer, 1km2 = 1000m2
m2	: Square meter
m3	: Cubic meter
bcm	: Billion cubic meter, 1bcm = 1000mcm
mcm	: Million cubic meter, 1mcm = 1000000m3
m/s	: Meter per second
m3/s	: Cubic meter per second
mcm/yr	: Million cubic meter per year
mg/lit	: Miligram per litter



MAP OF STUDY AREA





1 INTRODUCTION

1.1 Outset of Study

Zambia has been dependent on copper production since the discovery of copper ore deposits. The country, however, now faces a nationwide economic difficulties due to a significant drop in copper prices in international markets since 1975. To overcome this situation, the country is seeking to diversify its domestic industries and has chosen agriculture to be the center of a national development plan. On the other hand, the population growth rate, more than three (3) percent per annum, is high and increasing rapidly. This growth rate is among the highest in the world. Such population increase will cause further serious shortage of urban and rural water. This situation requires urgent development of water resources. Existing plans of water resource development have emphasized single purpose which has been limited in scope, such as hydraulic power generation, urban water supply and irrigation. An overall scheme for developing water resources, taking into account differences in river basins, has never been produced. Regarding the hydrological observation to collect, process and archive the hydrological data for the base of water resources development plan of Zambia, the installation of most hydrometric stations was started from 1950's in technical cooperation with the foreign agencies led by the England. At the moment, more than 240 hydrometric stations are registered in Zambia. In fact, basic hydrologic data, essential to an overall scheme for water resource development, has not been sufficiently collected and analyzed, especially in a recent decade.

With this as a background, Zambia sought technical cooperation from Japan in February of 1987, to study the water resources potential in the major rivers and to prepare a master plan for developing these resources. In response to the Zambia's request, the Japan International Cooperation Agency (JICA) sent the preliminary study team to Zambia in November of 1988 to perform a preliminary survey, and the scope of work (S/W) of this study was discussed and agreed upon by the two countries. In December 1989, JICA dispatched the study team for " The Master Plan Study on Hydrologic Observation Systems of the Major River Basins in Zambia" (Study Team and Study respectively) according to the scope of work, and commenced the Study in conjunction with the counterpart agency, Department of Water Affairs (DWA), Ministry of Water, Lands and Natural Resources (present Ministry of Energy and Water Development).

1.2 Outline of Study

(1) Objectives of Study

The Study, the first step in preparation of the overall plan for water resources development in Zambia, is designed to achieve the following objectives.

1) To strengthen the hydrologic observation systems in Study Area to utilize the data for future planning of water resources development.

2) To make a rough estimation of water resources potential through the study of river flow based on existing and new hydrologic data.

In addition, this study is also designed to transfer technology to the Zambian counterparts through the execution of study.

(2) Study Area

The areas covered by Study (Study Area) are the western parts of Zambia. The total catchment area of Study Area amounts about 340,000 km2 (within Zambian territory) consisting of:

1) Catchment area of some 787,000 km2 along the mainstream of the Zambezi River (Area of 602,000 km2 is out of Zambia, this area is out of scope) as far as the confluence point with one of its tributaries, the Luangwa River, and

2) Catchment area of some 155,000 km2 along the Kafue River, another tributary of the Zambezi River.

The Zambezi River originates at the northwest corner of the county and, after passing through Angolian territory, flows southward in the western part of the Zambia. After forming a great flooding area which has 190 km in length and 40 km in average width, it reaches the boundary with Namibia. It then turns east, giving the great valley and Victoria falls (utilized for generating hydraulic power of 108 MW), flows into the Kariba Lake (big artificial lake with a total volume of 160 billion cubic meters and formed by the construction of Kariba Dam which generates as much as 1266 MW of electric power in Zambia and Zimbabwe and joins with its tributary, Kafue River, at Chiawa, downstream of Kafue Gorge. At Luangwa it accompanies another tributary, Luangwa River which originates at the country's east boundary with Tanzania and after passing through Mozanbique, flows into the Indian Ocean. The Zambezi River is an international river and its total catchment area is about 1.2 million km2. Other countries: Angola, Namibia, Botswana, Zimbabwe and Mozanbique all contain parts of the Zambezi River basin.

The Kafue River, originating from the copper belt on the boundary with Zaire, flows through the middle west portion of the country

and has a total area of about 155,000 km2 and a total length of about 1,200 km. Its whole area is contained within Zambian territory. Its catchment area contains political, economic and cultural centers of the country. One third of the whole population is concentrated in this area. The Kafue river has two big dams (the Itezhi-tezhi Dam in the middle and the Kafue Gorge Dam on its lower course) to utilize the river's water resources. The Itezhi-tezhi Dam is a regulation reservoir for Kafue Gorge Dam. The Kafue Gorge Dam can generate 900 MW of electric power, which is distributed to the capital, Lusaka, or cities in the Copperbelt to operate urban facilities.

(3) Scope and Contents of Study

The scope of this study includes systemizing and reinforcing a hydrologic observation network throughout the Study Area and clarifying the water resources potential of the Study Area.

The Study is divided into three (3) phases comprising each phase's targets as shown below. Refer to Fig.- 1.1.

<<< Phase 1 >>>
Period : Dec. 1989 - Mar. 1990

1) To establish the hydrometric reference points and hydrologic observation network.
2) To repair and/or install observation stations covered by the network. After putting facilities into place, actual observation should be made using those facilities.
3) To prepare a hydrologic database to be used for planning water resource development in the future, and feed it the necessary data.
4) To prepare a progress report (1)

<<< Phase 2 >>>
Period : May 1990 - Mar. 1991

1) To continue hydrologic observations and to transfer hydrologic techniques to Zambian counterparts. (training level)
2) To investigate water quality.
3) To analyze existing materials and observation data to comprehend the flow regime at each reference point and to study water balance of existing reservoirs.
4) To prepare an interim report summarizing the interim results, and discuss with the Zambia side.
5) To prepare a progress report (2)

<<< Phase 3 >>>
Period : May 1991 - Mar. 1992

1) To continue hydrologic observations and work to transfer hydrologic techniques to Zambian counterparts (mastery level).
2) To analyze the existing materials and observation data

to reveal river flow classified by different basins so that potential water resources can be roughly estimated.

3) To prepare a master plan for hydrologic observation systems.
4) To prepare Draft Final Report summarizing the above results, and discuss Study results with Zambia side.
5) To prepare Final Report after receiving the comments on the report from the Zambia side and submit it to Zambia.

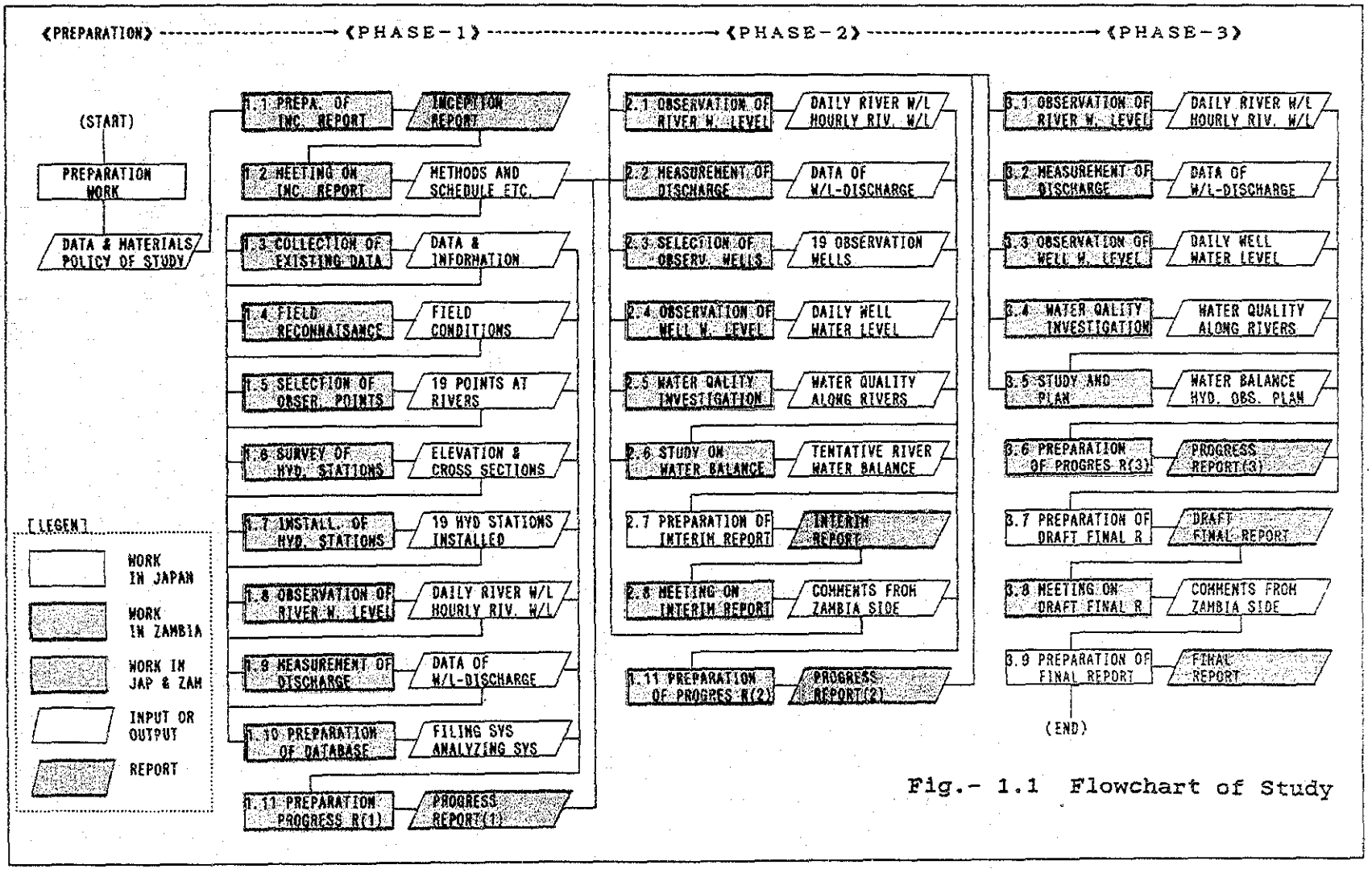
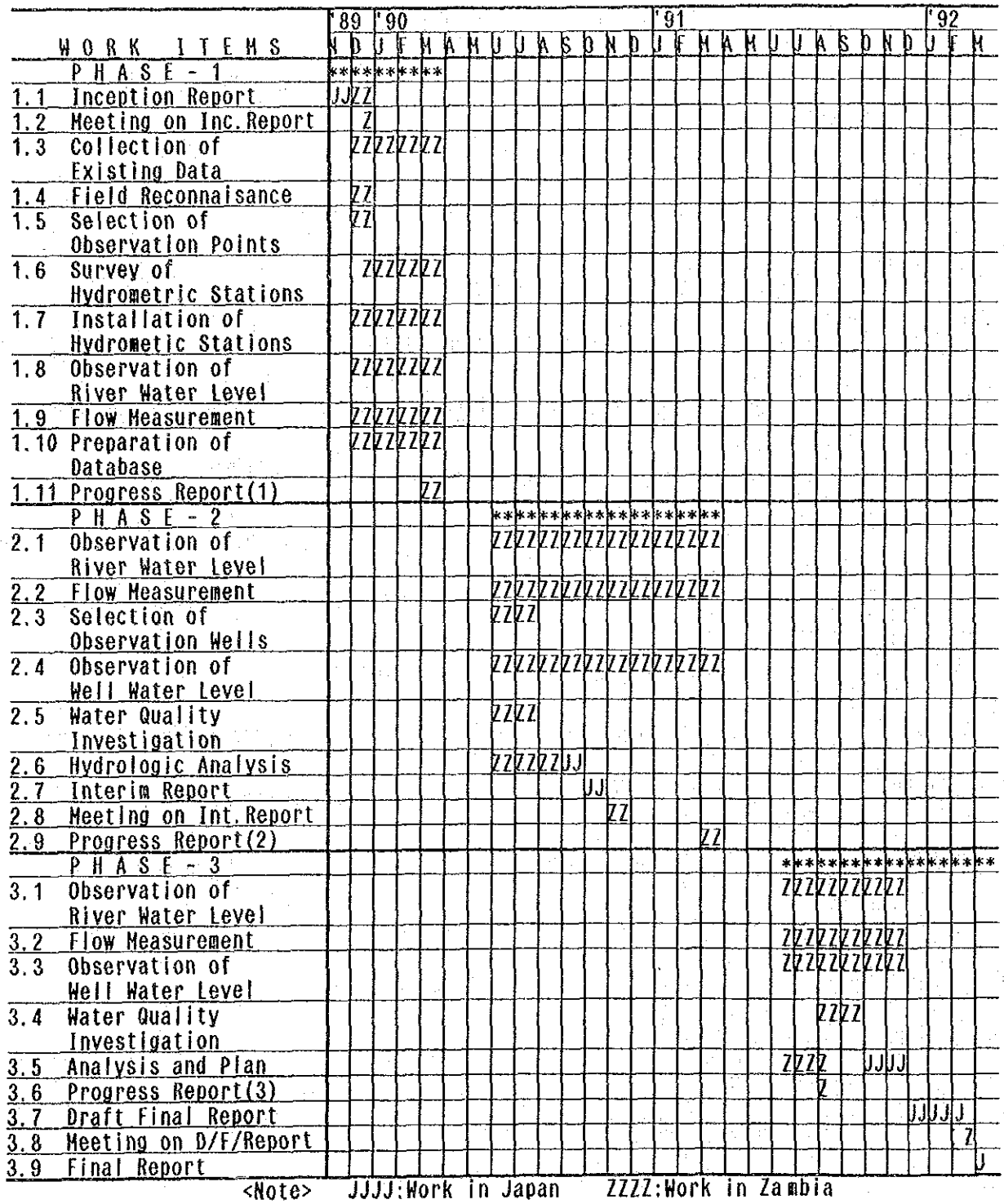


Fig.- 1.1 Flowchart of Study

(4) Work Schedule

The Study was carried out as shown in Table- 1.1.

Table-1.1 Work Schedule of Study



(6) Organization of Study

The organization of Study is as shown in Fig.-1.2.

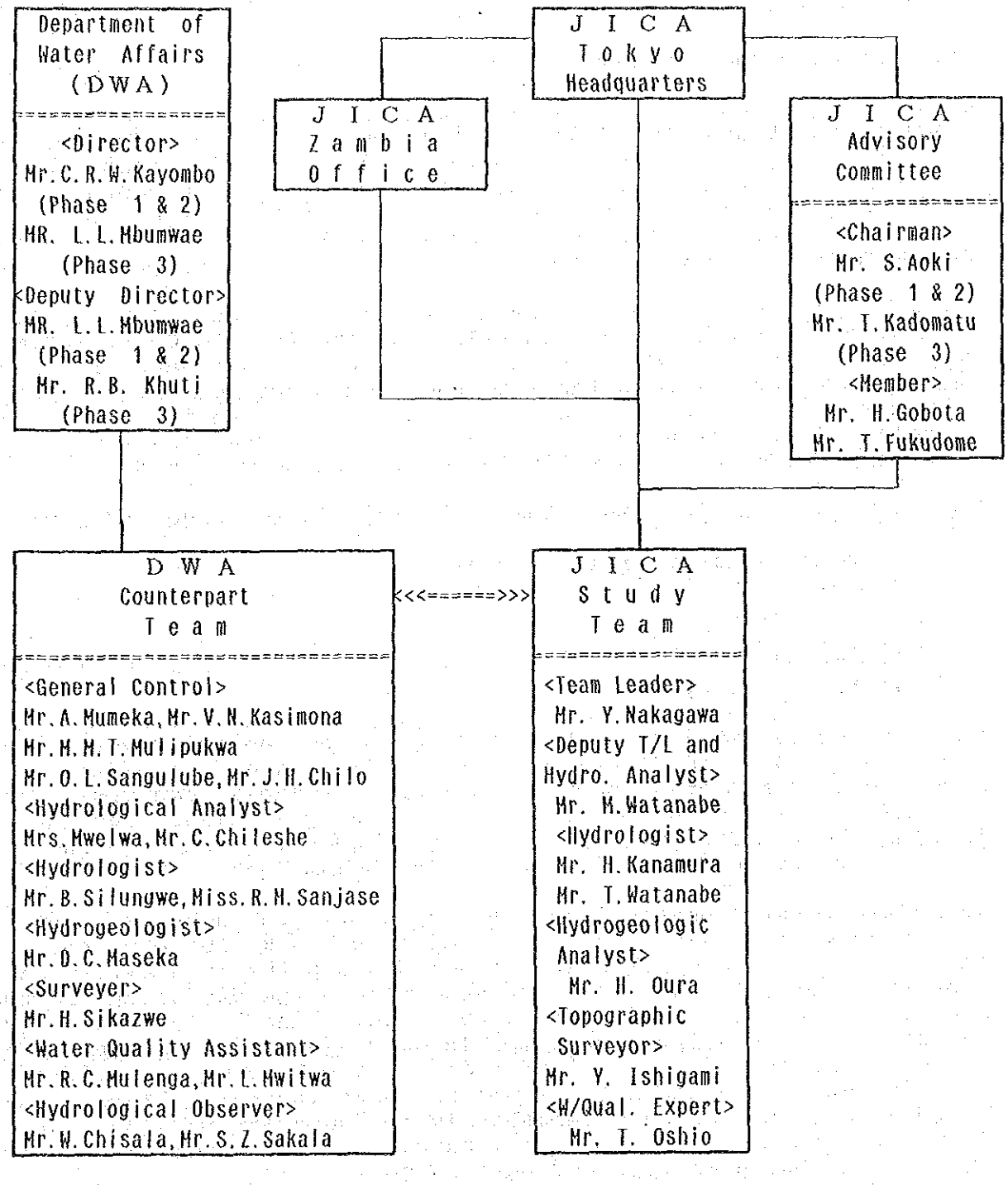


Fig.-1.2 Organization of Study

1.3 Background Information of Study

1.3.1 General Information on Zambia

(1) Geography and Geology

Zambia is located at the southern part of the African Continent, ranging from 8 deg. to 17 deg. in the south latitude and from 22 deg. to 33 deg. in the east longitude. It is a land-locked country with an area of about 753,000km2 and shares borders with Zaire and Tanzania in the north; Malawi and Mozanbique in the east; Zimbabwe and Botswana in the south; Namibia in the south west and Angola in the west.

Zambia lies mostly on the Great African Plateau with gentle undulation in the altitude generally ranging from 1000m to 1500m. The land rises toward the north and the north-east and reaches the mountain range with the altitude from 1500m to 1800m, which separates the country into Zambezi River catchment and Zaire (Congo) River catchment in the north-east of the country, and forms the border with Zaire in the north end of the country.

The country is divided into the following six (6) river basins:

1) Zambezi River (main stream)
2) Kafue River
3) Luangwa River
4) Chambeshi River
5) Luapula River
6) Lake Tanganyika

The basins 1), 2) and 3) above belong to the Zambezi River, and the basins 4), and 5) belong to the Zaire River. The Zambezi River catchment area occupies 3/4 of the whole country. The Zambezi River (main stream) and the Luangwa River cut down through the plateau to a level at about 300m at their confluence point near the border with Zimbabwe and Mozambique.

There are several physical features along rivers, such as Victoria Falls with a height difference of 108m and Kariba Dam, one of the largest man-made lakes in the world along the main stream of Zambezi River; Itezhi-tezhi Dam and Kafue Gorge Dam along Kafue River. In some section of the rivers, the channel slope is very gentle. This develops sometimes large scale flood plains and swamps, such as the Mongu flood plain in the Zambezi main stream; Lukanga Swamp and the Kafue flood plain in the Kafue River; and Bangweulu Swamp in the Chambeshi River. There are several large lakes in the northeastern area, such as Lake Bangweulu, Lake Mweru, Lake Mweru Wantipa and Lake Tanganyika.

The rocks of Zambia are mainly Pre-Cambrian in age and they are generally very stable, however, some areas are underlain with Karroo sedimentary and volcanic rocks and Kalahari sands. Refer to Table-1.2.

As for top soil, gleysol and podzol are distributed along the main stream of Zambezi River, and arrensol in the highland of the north-western and western provinces. Acrisol or Luvisol-Phaeozem are distributed in the south province.

Table-1.2 Stratigraphic Subdivisions

Stratigraphic Unit	Age	Rock Type
Alluvium/ Colluvium	Quaternary	clay, silts, sands
Igneous rocks	All ages	granites, porphyries, syenites, gabbros, volcanic
Kalahari	Pleistocene	sand, sandstones, quartzites, duricrusts
	Cretaceous	sandstones and shales
Karroo	Permo-Triassic/ Jurassic	basalts, sandstones, grits, marls, mudstones, coals
Katanga	Late Pre-Cambrian Cambrian	shales, sandstones, dolomites, quartites, limestones, conglomerates
Basement Complex	Pre-Cambrian	gneisses, schists, quartzites, conglomerates, limestones, granites, older volcanics

(2) Climate

Although Zambia belongs to the Torrid Zone, the climate is generally rather pleasant due to the high altitude of the country and it is strongly influenced by the altitude, latitude and distance from sea. Zambia has three seasons in a year, they are a cool and dry season from May to August, a hot and dry season from September to October and a warm and wet season from November to April.

The average annual temperature is about 20 deg.C, though the average monthly temperature ranges from 15 deg.C at the lowest in July to 26 deg.C at the highest in October depending on location. The Temperature changes gradually from low in the north to high in the south. Especially in the low lands along the Zambezi main stream and Luangwa River, the temperature is high and the humidity is also high, though the average annual humidity of the country is about 60%.

There are seasons in rainfall: one is rainy season from November to April and the other is dry season from May to October. In the dry season, rainfall is very little and small tributaries of rivers are sometimes dried up. The average annual rainfall ranges from 500 - 800 mm in the south to 1000 -1600 mm in the north. The annual average evaporation is observed at about 2000 mm.

(3) Population

The total population is estimated to be 7.8 million in 1990, and the current growth rate to be 3.2% (1980 - 1990) per annum (quoted from Preliminary Report of 1990 Census). This growth rate which is higher than the African average about 3% per annum, is among the highest in the world. Refer to Table-1.3 and Fig.-1.3 and 1.4.

Generally speaking, Zambia is a very sparsely settled country, however, the population is very unevenly distributed among the provinces. The population is concentrated along the old railway from Kitwe to Livingstone, thus the Copperbelt, Central, Lusaka and Southern Provinces, especially the urban area of Kitwe, Ndola Lusaka and Livingstone, are densely populated due to the fact that commercial, industrial and other economic activities are more developed and concentrated along such areas. In fact, 55% of the total population of Zambia lives in the these provinces.

Table-1.3 Population and Growth Rate in Zambia

Province	Population 1969 (Head)	Population 1980 (Head)	G. Rate 1969-80 (%)	Population 1990 (Head)	G. Rate 1980-90 (%)
Central	358,655	511,905	3.2	725,611	3.5
Coperbelt	816,309	1,251,178	3.8	1,579,542	2.3
Eastern	509,515	650,902	2.2	973,818	4.0
Luapula	335,584	420,966	2.1	526,705	2.2
Lusaka	353,975	691,054	5.9	1,207,980	5.4
Northern	545,096	674,750	1.9	867,795	2.5
N/Western	231,733	302,668	2.4	383,146	2.3
Southern	496,041	761,923	2.7	946,353	3.4
Western	410,087	486,455	1.5	607,497	2.2
<Total>	4,056,995	5,661,801	3.0	7,818,447	3.2

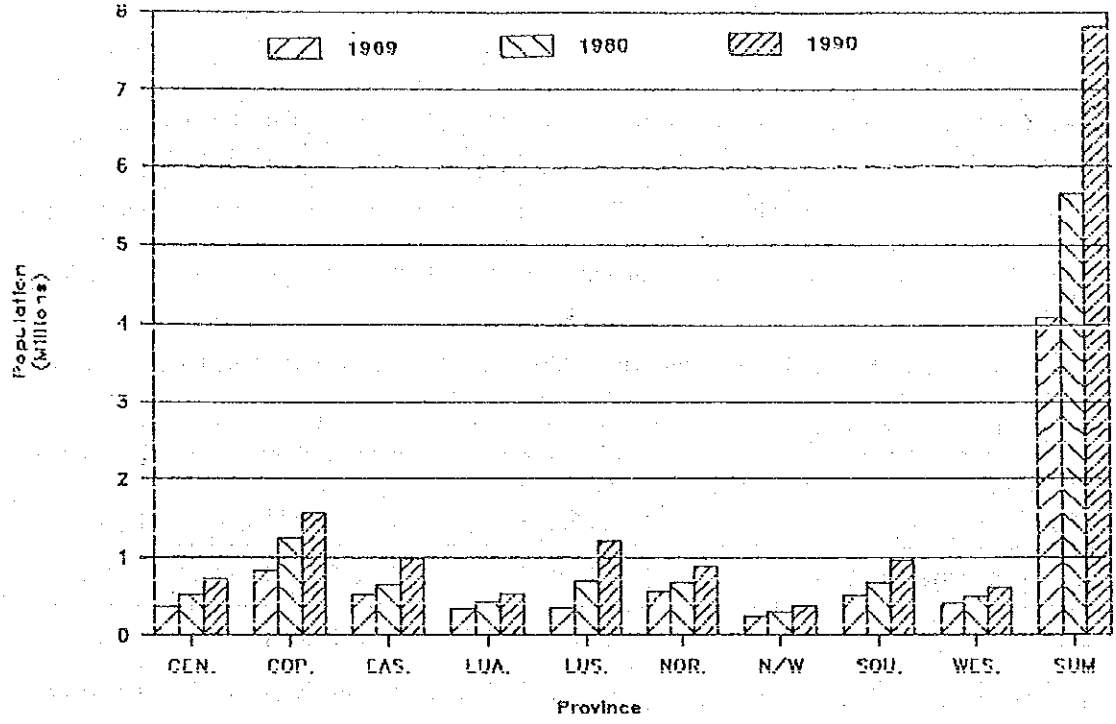


Fig.-1.3 Population of Zambia by Province

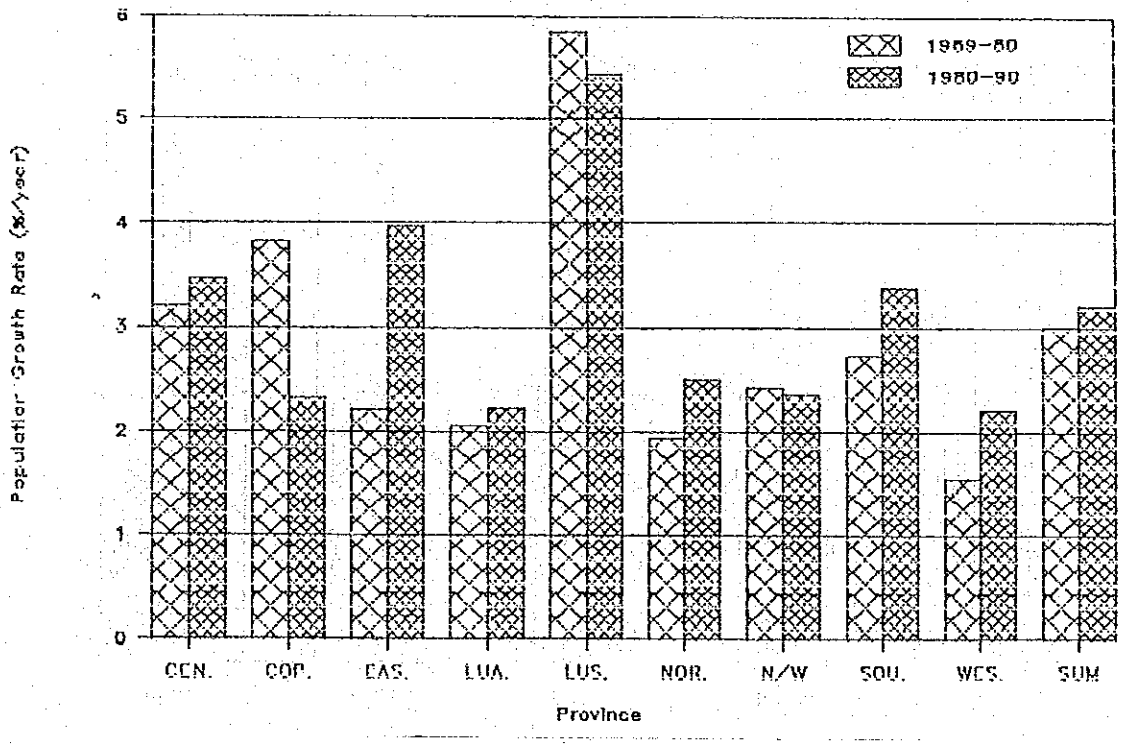


Fig.-1.4 Population Growth Rate of Zambia

(4) Economy and Industries

The figures of gross domestic product (GDP) at the current prices in 1988 and 1989 are estimated to be K.27,724.9 and K43,637.5 million respectively (quoted from Economic Report 1989). GDP per capita in 1989 is calculated to be about K.5,800(=us$290) by assuming that the total population is 7.5 million and the exchange rate is K.20 per one us$. The main industries contributed to GDP are shown in Table-1.4 and Fig.-1.5 showing each percentage to the total GDP (quoted from Monthly Digest of Statics, May - September, 1989).

Table-1.4 Main Industries and Their Percentage to GDP

Industries	1984	1985	1986	1987	1988
a) Agriculture, forestry and fishing	14.5 (%)	13.1	12.2	11.2	14.2
b) Mining and quarrying	13.7	15.6	18.2	13.7	15.0
c) Manufacturing	20.5	22.9	22.7	27.6	24.6
d) Wholesale and retail trade	10.6	10.8	12.6	14.2	12.6
e) Community, social and personal services	16.4	13.2	9.0	7.5	8.0

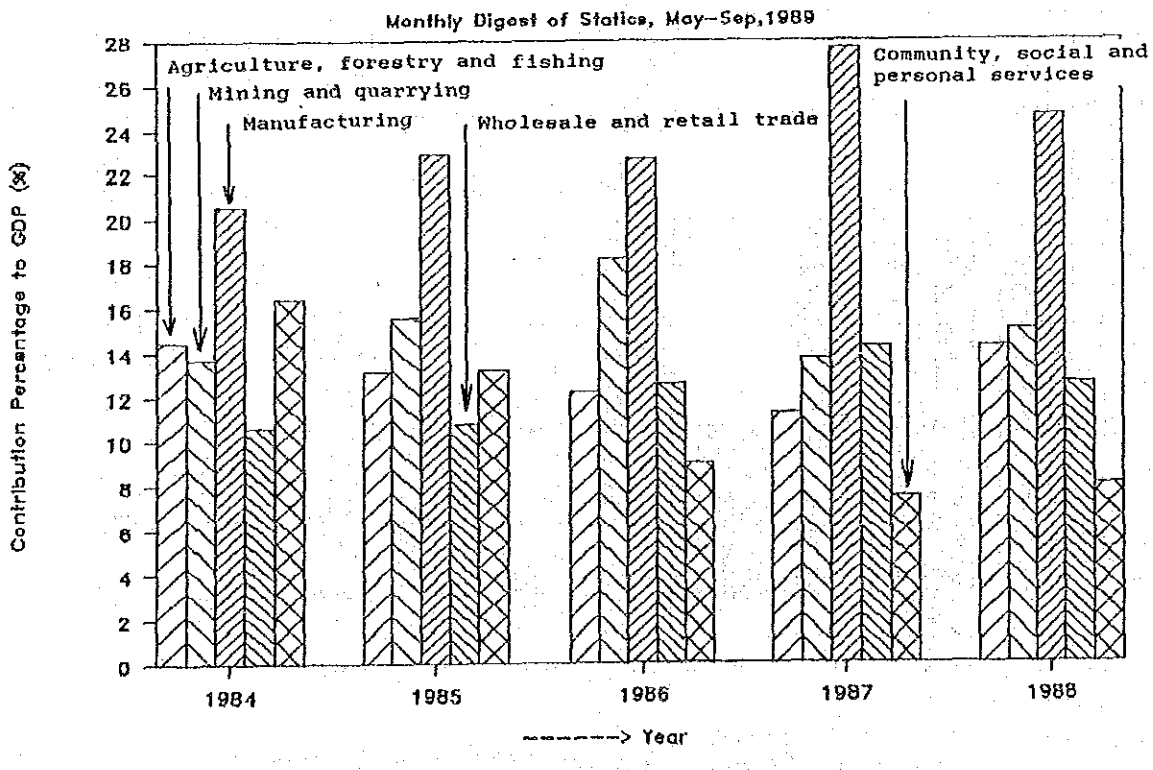


Fig.- 1.5 Main Industries of Zambia

The main products of the agriculture sector are maize, sorghum, millet, soybean, rice, tobacco etc. The maize is a staple crop in Zambia and most of Zambian live on maize. The main products of mining sector are copper, zinc, lead, coal, cobalt etc. The main products of the manufacturing sector are food, beverages and tobacco, fabricated metal products, non-metalic mineral products, chemicals, rubber and plastic products, textile and leather, paper and paper products etc.

Zambia has been famous for its copper production since 1925. However, the country has experienced a significant drop in copper price in international markets since 1975 and therefore, now is seeking to diversify its domestic industry from copper production to agricultural products.

Fourth national Development Plan, 1989-1993 explains as follows: In the budget of 1988, the total of revenue and grants is estimated to be K.5,552.0 million including external grants of K.832.0 million, while the total of expenditure and lending is K.8,283.1 million, therefore there is overall deficit of K.2,731.1 million. Refer to Fig.-1.6.

The total value of exports in 1988 was K.8,252 million. Copper export accounted for 84% of total export proceeds. Other exports included zinc, lead, cobalt and electricity. The total value of imports was K.6.043 million. Oil imports accounted for the largest portion of the total import bill. Other imports included cereals, chemical, medical products, fertilizer, dairy products and eggs etc. The balance of merchandise account in 1988 stood at K.2,209 million. Refer to Fig.- 1.7. However, during 1988 the country incurred net capital loss as a result of capital flight. As a consequence of this the overall balance of payment position worsened to a higher level of deficit of K.2,049 million in 1988.

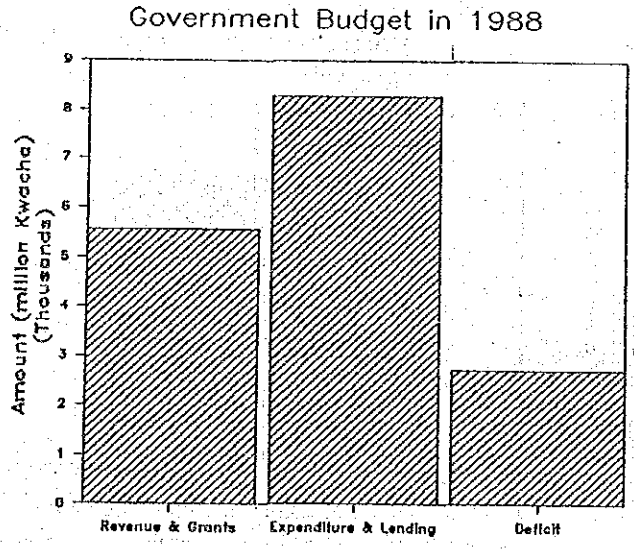


Fig.-1.6 Government Budget

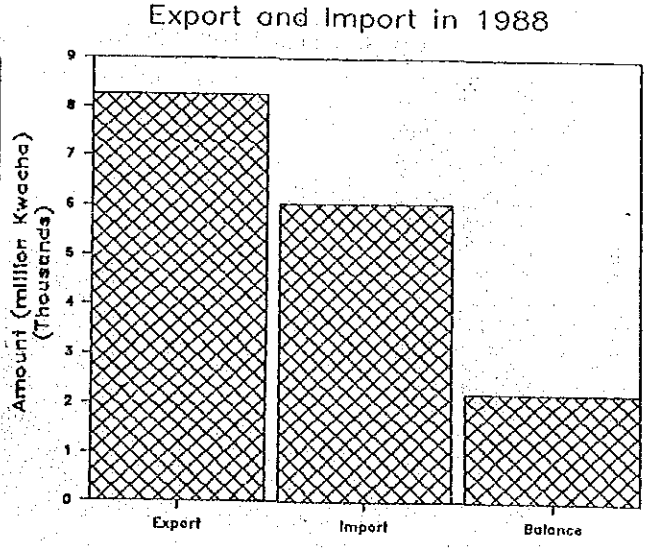


Fig.-1.7 Export and Import

(5) Transportation

As Zambia is land-locked country, transportation is a very important sector. Railways handle about 85% of the country's imports and 90% of exports and play an important role in the transportation sector. Zambia has a total main line network of 2,708 km with 848km on Zambia Railways (ZR) and 1,860 km on the Tanzania-Zambia Railway Authority (TAZARA). The route of TAZARA is from Kapiri Mposhi to Dar-es-Salam, and 833 km out of the whole length is in Zambia.

Zambia has a road network of 38,763 km of which 6,172 km are bitumen and 8,592 km are gravel. Major roads linking Lusaka with major cities such as Kitwe, Ndola, Kasama, Dar-es-Salam, Mongu and Livingstone, are paved all weather type. However, in rainy season the roads are heavily damaged and sometimes lose their efficiency. Refer to Fig.-1.8.

There are international flights from Lusaka to London, Paris, Frankfurt, Rome, Nairobi, Harare etc. several times per week. There are also domestic flights between major cities, however, they are not well developed yet.

(6) Land Use

According to FAO Production Year Book Vol. 39, 1985, only 7% of total area of 753,000 km2 is agricultural land, 47% for grazing area, 40% for forest and 6% for others. Refer to Fig.-1.9.

Taking such conditions into consideration as topography, rainfall, soil etc., Zambia has considerable potential for agricultural development. The total potential irrigation area is estimated to be about 500,000 ha.

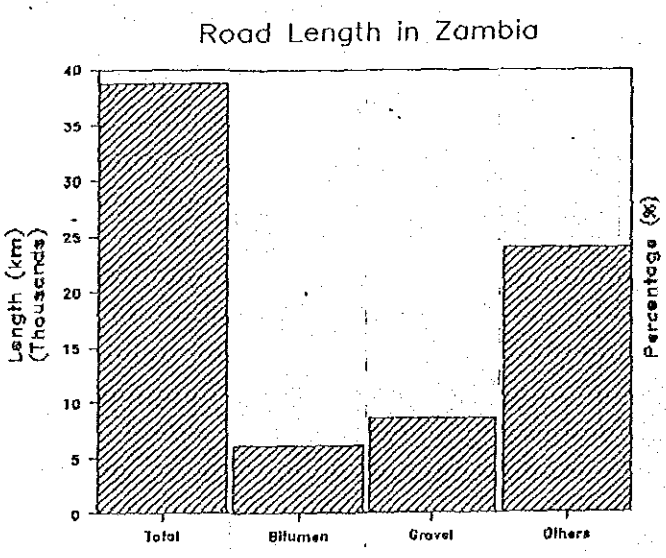


Fig.- 1.8 Road in Zambia

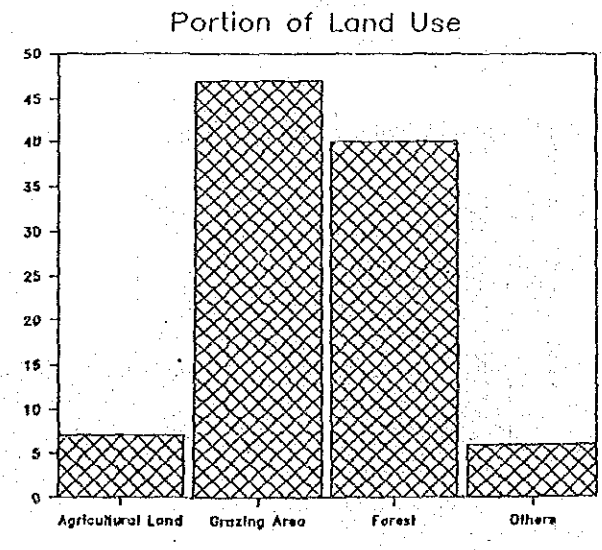


Fig.- 1.9 Land Use in Zambia

1.3.2 Water Resources Development

The water resources development for hydropower has been well advanced in Zambia. Kariba and Victoria Falls projects along Zambezi River, and Itezhi-tezhi and Kafue Gorge projects along Kafue River were already developed. Mupata Gorge, Devils Gorge, Batoka Gorge and Katombora projects along Zambezi River are proposed and some of them are under investigation.

Urban and rural water have been developed by constructing water works for surface water, and by drilling bore holes and wells for groundwater. The recent large population increase requires large scale development of surface water.

Irrigation water is relatively poorly developed in Zambia. Agriculture has been a rather neglected economic sector of the country. Rainfall is generally adequate to produce some crops without assistance of irrigation throughout almost the entire country. However, due to the Zambia's policy change of fundamental industry from copper production to agricultural production, development of irrigation water will be essential.

There has been no overall study for the development of water resources in Zambia. However, beside this Study, there have been some studies carried out in the past and present as follows:

(1) UNDP/(IDWSSD)

The International Drinking Water Supply and Sanitation Decade (IDWSSD) is a world-wide co-operative effort to provide clean water and adequate sanitation for all by the year 1990. The decade was declared by the United Nations (UN) General Assembly in response to human tragedies of enormous proportions. The decade was launched in 1981. Zambia is a signatory to the UN resolution launching the IDWSSD and fully accepts the objectives of providing safe water supply and adequate sanitation for all. National Action Committee for IDWSSD in Zambia was formed in 1980 to prepare the Zambian community to actively pursue and achieve the goals of the Decade. The Plan of Action for Water Supply and Sanitation in Zambia was published in June, 1985. The Plan of Action considers four levels of water supply as follows:

1) Provision of safe water supply to 100% of all urban and rural population by the year 1990;
2) Provision of safe water supply to 80 or 90% of total population by 1990 comprising 100% of all large and small urban areas and about 50% of all rural population;
3) Provision of safe water supply to 100% of total population in Zambia by the year 2000, and
4) Similar coverage as for 2) except that the target date is the year 2000.

Among four levels of water supply above, 1) and 2) have failed to reach their targets by the year 1990, thus efforts should be made to obtain 3) or 4).

(2) UNDP/WMO Study

Hydrologic study of the United Nations Development Program (UNDP) was commenced in November 1989 by World Meteorological Organization (WMO) and DWA, and will terminate in October 1992. This WMO Study aims at strengthening the hydrologic services of Zambia by upgrading and expanding the facilities available to the hydrologic branch of DWA and ensuring the DWA can better fulfill its role in supplying the hydrologic data. The study will be made for whole country of Zambia but concentrated on the east side of the country to avoid duplication with JICA Study.

(3) SADCC Study

Hydroelectric Hydrological Assistance Project, Phase-1 is implemented by the South African Development Coordination Conference (SADCC) for the purposes of collecting and processing hydrologic data for hydropower development under financial assistance from Canada and Portugal. Zambezi River, as international river, was studied in Phase-1.

The steering committee including 9 representatives of SADCC countries directs the associated consultants of Canada and Portugal. The counterpart agency in Zambia is the Zambia Electricity Supply Corporation Ltd. (ZESCO).

(4) Forth National Development Plan

The Government of Zambia issued the "Fourth National Development Plan, 1989-1993" in January 1989. The main objectives in the development of national water resources are:

1) To ensure permanent supplies of water of acceptable quality and adequate quantities to as many users as possible in line with IDWSSD's Plan of Action for Zambia;
2) To review the Water Act and the 1980 Local Administration Act regarding the planning, development and management of resources;
3) To review and establish appropriate level of services and coverage;
4) To establish National Water and Sanitation Authorities;
5) To strengthen and expand the present surface and groundwater resources data collection network in all seven river basins of the country, with particular emphasis to areas of deficiency in data collection;
6) To establish a computer based data bank for surface and groundwater resources aimed at acquiring a permanent system for storage, retrieval and analysis of data;
7) On the basis of items 5) and 6) above, it will be necessary to prepare and implement a National Water Master Plan, which will form a basis upon which policy decisions can be made in the development of water resources; and
8) To dredge and construct canals to facilitate water transport, drainage and fishing.

2 HYDROLOGIC OBSERVATION

2.1 Present Situation

(1) Climatology

In Zambia, about 860 rainfall stations are registered at the Meteorologic Department. Out of these stations, some 460 stations are working and observations are continued. In main cities, climatologic stations are installed and temperature, humidity, evaporation, wind speed etc. are observed besides rainfall.

In Study Area, there exist 18 climatologic stations. As seen from Fig.-2.1 and 2.2, climatologic conditions in Study Area are summarized as follows.

1) Annual climate changes of the Study Area can be divided roughly into three categories:
   * Cool dry season (May to August)
   * Hot dry season (September to November)
   * Warm wet season (December to April)
2) The mean annual rainfall amount in the Study Area is around 1000mm. Isohyetal lines are nearly paralleled to latitude. The annual rainfall is gradually increased from southern areas (800mm /year) to northern area (1500 mm/year).
3) The mean annual temperature in the Study Area is around 20 deg.C. The season from May to August is rather cool (16-20 deg.C). Other season from September to April is warm and hot (22 - 26 deg.C).
4) The mean annual relative humidity in the Study Area is around 60%.
5) The mean annual evaporation is distributed regionally from 1600 mm to 2200 mm. In the northern area, its value is low. Seasonally, Values of evaporation in the months from August to November are higher than other months.

(2) Hydrometry

In Zambia, more than 240 hydrometric stations where the river water level is observed daily and flow measurement are carried out periodically, are registered at the Department of Water Affairs (DWA) and almost all stations are working.

At each station, an observer is employed to make daily observations (twice a day) of river water level using the staff gauge installed at the station. At some stations, automatic recorders were installed, but at almost all stations, no recorder is working now.

In the Study Area, about 150 hydrometric stations are distributed. At these stations, daily observation of river water level is continued, but the frequency of periodic flow measurement has decreased in recent years.

<<< Climatologic Stations in Study Area >>>

NO	STATION NAME	CATCHMENT	LAT.	LON.	ALT.	From
0500	KABWE MET.	LUANGWA	14/25'	28/29'	-	1932
2193	LUSAKA MET. HQ	ZAMBEZI	15/25'	28/19'	1283m	1938
2375	MOUNT MAKULU MET.	KAFUE	15/33'	28/15'	1213m	1951
2525	MAGOYE MET.	KAFUE	16/02'	27/38'	-	1946
2748	MUMBWA MET	KAFUE	14/59'	27/04'	1067m	1904
3180	KASEMPA MET.	KAFUE	13/27'	25/50'	1228m	1903
3570	SOLWEZI MET.	KAFUE	12/11'	26/23'	1320m	1913
4100	NDOLA MET.	KAFUE	13/00'	28/40'	1269m	1913
4375	KAFIRONDA MET.	KAFUE	12/38'	28/10'	-	1965
5350	CHOMA MET.	ZAMBEZI	16/51'	27/04'	1313m	1948
5625	LIVINGSTONE MET.	ZAMBEZI	17/50'	25/50'	907m	1948
5800	SESHEKE	ZAMBEZI	17/28'	24/18'	1021m	1919
5979	SENANGA MET.	ZAMBEZI	16/07'	23/16'	975m	1979
6010	MONGU MET.	ZAMBEZI	15/15'	23/10'	1054m	1953
6210	KAOMA MET.	ZAMBEZI	14/48'	24/48'	1138m	1913
6415	KABOMPO MET.	ZAMBEZI	13/36'	24/12'	-	1948
6525	MWINILUNGA MET.	ZAMBEZI	11/45'	24/26'	1355m	1921
6840	ZAMBEZI MET.	ZAMBEZI	13/34'	25/06'	1085m	1921

<<< Annual Average Climatologic Values >>>

NO	STATION NAME	RAIN (mm)	TEMP. (C)	RAINY DAY	R.HUMI. (%)	EVAP. (mm)	SUNSHINE (hr/dy)	WIND S. (knot)
0500	KABWE	928	20.2	84	62	2103	8.1	5.2
2193	LUSAKA	833	20.0	84	60	2215	7.9	6.2
2375	MT.MAKULU	814	20.2	82	60	2014	7.8	4.0
2525	MAGOYE	803						
2748	MUMBWA	905						
3180	KASEMPA	1131	20.1	85	64	1723	7.5	2.2
3570	SOLWEZI	1343	19.2	49	66	1664	7.1	2.2
4100	NDOLA	1183	20.3	97	63	2046	7.5	4.6
4375	KAFIRONDA	1280	19.4	101			7.9	2.1
5350	CHOMA	808	19.0	70	64	1989	8.0	2.7
5625	LIVINGSTONE	742	21.7	77	55	2170	8.4	4.6
5800	SESHEKE	694	21.2	77	57			3.0
5979	SENANGA	819						
6010	MONGU	957	21.9	80	59		8.0	
6210	KAOMA	946	20.9	87	60			2.8
6415	KABOMPO	1065	21.2	92	63	1889	7.3	1.6
6525	MWINILUNGA	1403	19.7	141	68	1597	7.1	2.6
6840	ZAMBEZI	1065	21.4	85	62	2142	7.7	2.8
<< A V E R A G E>		984	20.4	86	62	1959	7.7	3.3

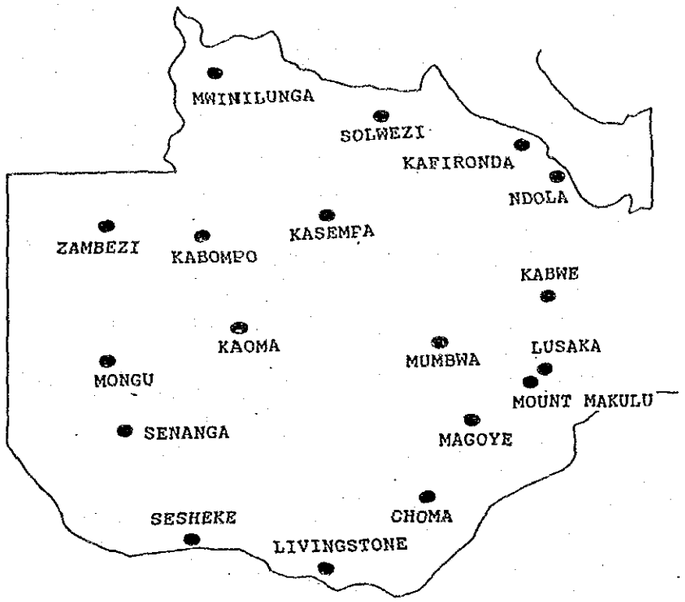
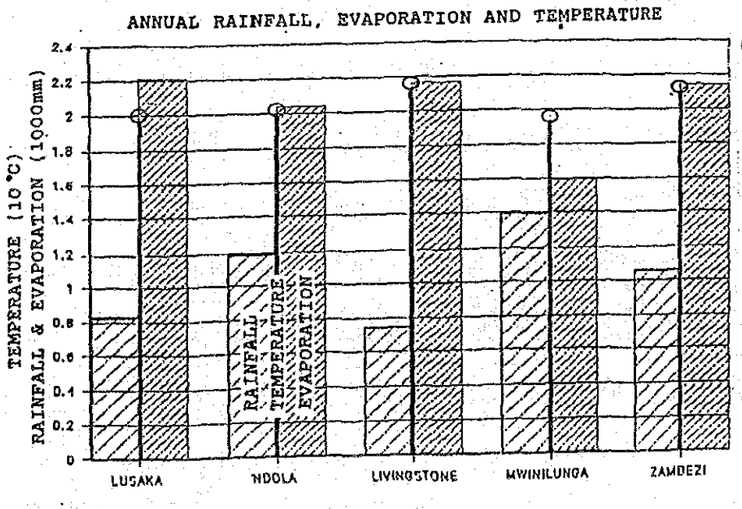
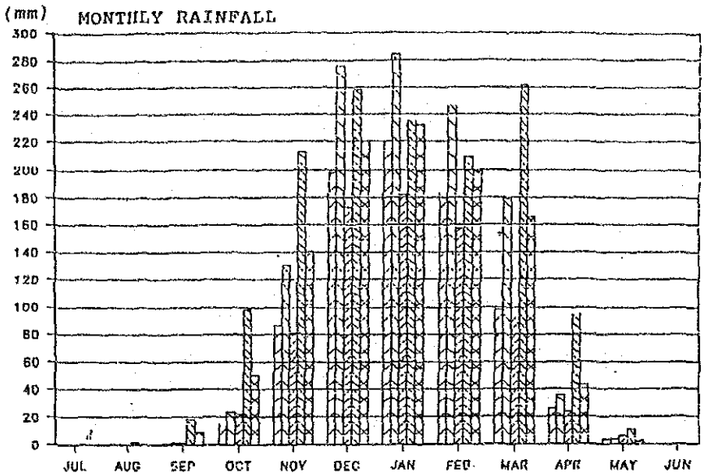
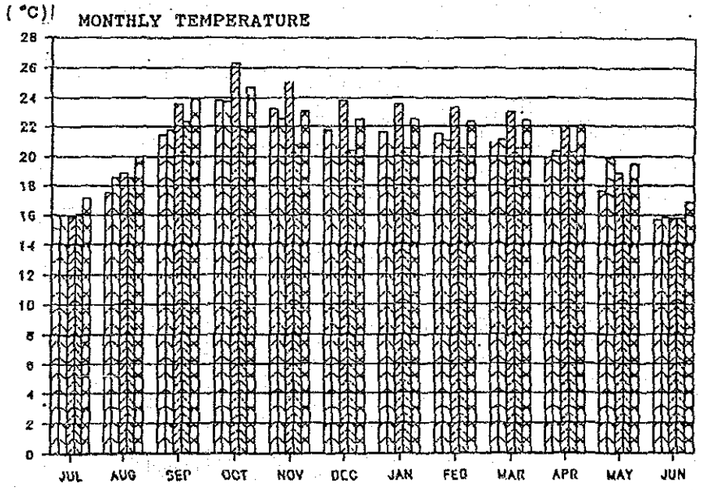


Fig.- 2.1 Climatologic Stations and Data







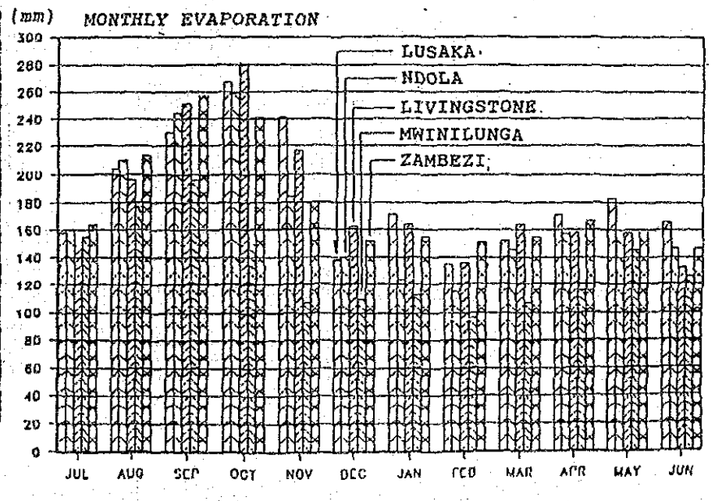


Fig.- 2.1 Climatologic Stations and Data

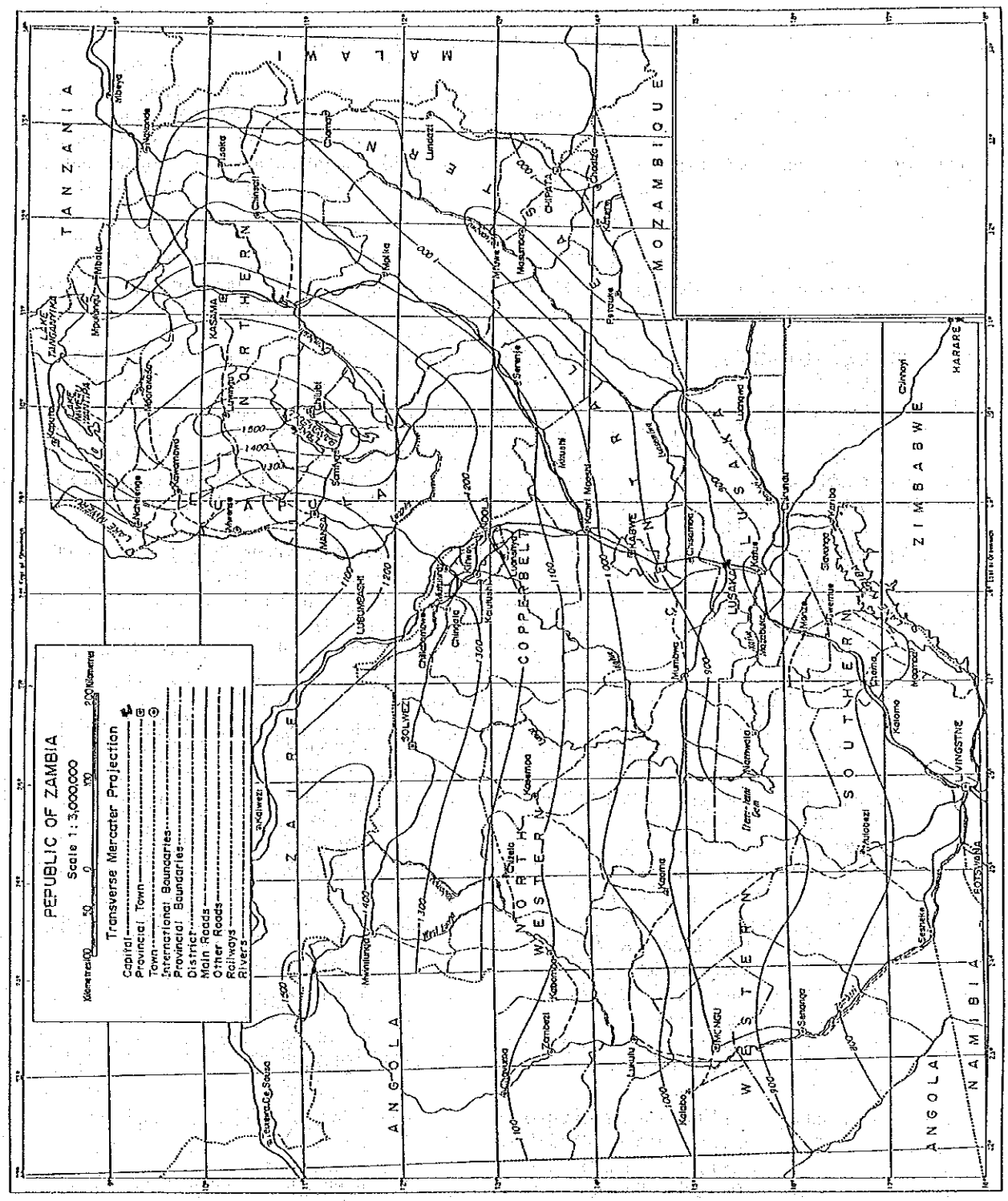


Fig.- 2.2 Annual Isohyetal Map

2.2 Installation of Hydrometric Stations

2.2.1 Selection of Hydrometric Observation Points

On the basis of the results of field reconnaissance and analysis of existing data, the mutual discussions between the Study Team and the counterpart agency DWA have been held regarding the hydrometric stations to be observed in the Study. The discussions concluded and selected the nineteen (19) hydrometric stations shown below and in Table- 2.1. Refer to Fig.- 2.3. The main points of discussion are as follows.

1) The stations are well located so as to comprehend the river flow pattern uniformly throughout Study Area, also the stations have long term observation data so that the long term flow pattern is estimated.
2) Kariba Dam, Itezhi-tezhi Dam, Kafue Gorge Dam, Sesheke, Victoria Falls and Luangwa should be reference points. However, no observation will be done at these points in the Study. This is because periodic data such as reservoir water level and gate operation etc. are recorded at each dam, and at the other three points flow measurement is difficult due to the reason that the international boundary lies on the river.
3) Water level recorders should be set at promising exploi tation point having small catchment area, .
4) To estimate the discharge at the confluence (Zambezi and Luangwa River), observation will be carried out at St.Luangwa Bridge, through it is out of the Study Area.

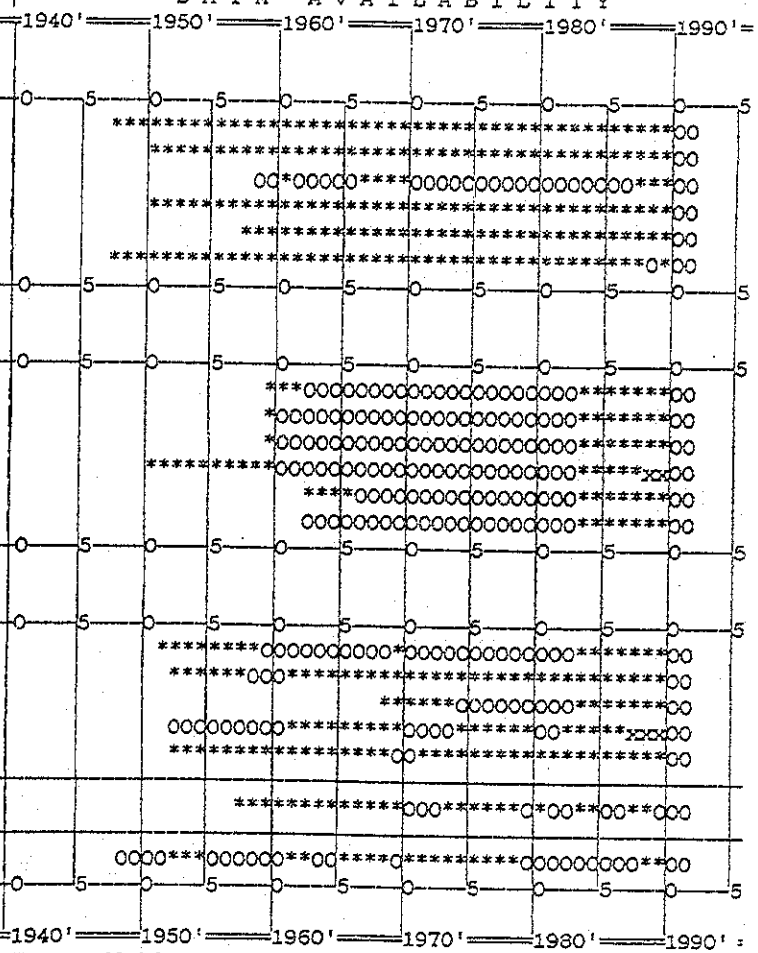
<<< Station >>>		<<<Catchment Area>>>
< Zambezi Main River Basin > ..... 7 stations		
o 1-150	Zambezi Pump House	: 82,275km2
o 1-650	Kabompo Boma	: 42,740km2
o 1-950	Watopa Pontoon	: 66,449km2
o 2-030	Lukulu	: 206,531km2
o 2-250	Kalabo	: 34,620km2
o 2-400	Senanga	: 278,298km2
* 5-030	Exchange Farm	: 67km2
< Kafue River Basin >..... 11 stations		
o 4-050	Raglam Farm	: 4,999km2
* 4-120	Mwambwashi	: 869km2
* 4-130	Smith's Bridge	: 8,599km2
* 4-200	Mpatamato	: 11,655km2
o 4-280	Machiya Ferry	: 22,920km2
o 4-350	Chilenga	: 29,008km2
o 4-450	Lubungu	: 54,442km2
o 4-560	Chifumpa Pontoon	: 21,445km2
o 4-669	Kafue Hook Bridge	: 95,053km2
* 4-941	Kaleya Dam Site	: 45km2
* 4-958	Uruaff Farm	: 140km2
< Luangwa River Basin >..... 1 station		
o 5-940	Luangwa Bridge	: 143,781km2

[Note] 1) o:Staff-gauge station *:Automatic Recording station
2) Value of catchment area includes that of foreign countries' areas.

Table- 2.1 Hydrometric Stations Selected in Study

NO	ST.NO.	AREA(km2)	RIVER	LOCATION	OPENED	CLOSED	S.G	AUT	DIS
<STATIONS COVERED BY MONGU TEAM>									
---<<< ZAMBEZI RIVER BASIN >>>---									
1	1-150	82,275	Zambezi	Zambezi Pump House	02/1947		Y	N	Y
2	1-650	42,740	kabompo	Kabompo Boma	10/1950		Y	N	Y
3	1-950	66,449	Kabompo	Watopa Pontoon	05/1958		Y	N	Y
4	2-030	206,531	Zambezi	Lukulu	10/1950		Y	N	Y
5	2-250	34,620	Luanginga	Kalabo	11/1957		Y	N	Y
6	2-400	278,298	Zambezi	Senanga	11/1947		Y	N	Y
<STATIONS COVERED BY KITWE TEAM>									
---<<< KAFUE RIVER BASIN >>>---									
7	4-050	4,999	Kafue	/ Raglam Farm	09/1959		Y	N	Y
8	4-120	869	Mwambashi	/ Mwambashi	10/1959		Y	Y	Y
9	4-130	8,599	Kafue	/ Smith's Bridge	08/1958		Y	Y	Y
10	4-200	11,655	Kafue	/ Mpatamato	12/1950	10/1987	Y	Y	Y
11	4-280	22,920	Kafue	/ Machiya Ferry	06/1962		Y	N	Y
12	4-350	34,162	Kafue	/ Chilenga	06/1962		Y	N	Y
<STATIONS COVERED BY LUSAKA TEAM>									
---<<< KAFUE RIVER BASIN >>>---									
13	4-450	54,442	Kafue	/ Lubungu	06/1951		Y	N	Y
14	4-560	21,445	Lunga	/ Chifumpa Pontoon	02/1953		Y	N	Y
15	4-669	95,053	Kafue	/ Kafue Hook Bridge	01/1968		Y	N	Y
16	4-941	45	Kaleya	/ Kaleya Dam Site	12/1952	10/1986	Y	Y	Y
17	4-958	140	Mazabuka	/ Uruaff Farm	10/1952		Y	Y	Y
---<<< ZAMBEZI RIVER BASIN >>>---									
18	5-030	107	Kapiriombwa	Exchange Farm	04/1957		Y	Y	Y
---<<< LUANGWA RIVER BASIN >>>---									
19	5-940	143,781	Luangwa	/ Luangwa RD BG	10/1948		Y	N	Y

DATA AVAILABILITY



<NOTE> S.G : Staff Gauge, AUT : Automatic Recorder, Dis : Discharge Rating Curve, Y : Available, (Y) : Previously worked,
N : Not Available, O : Water level and discharge data are available,
X : Data is not available

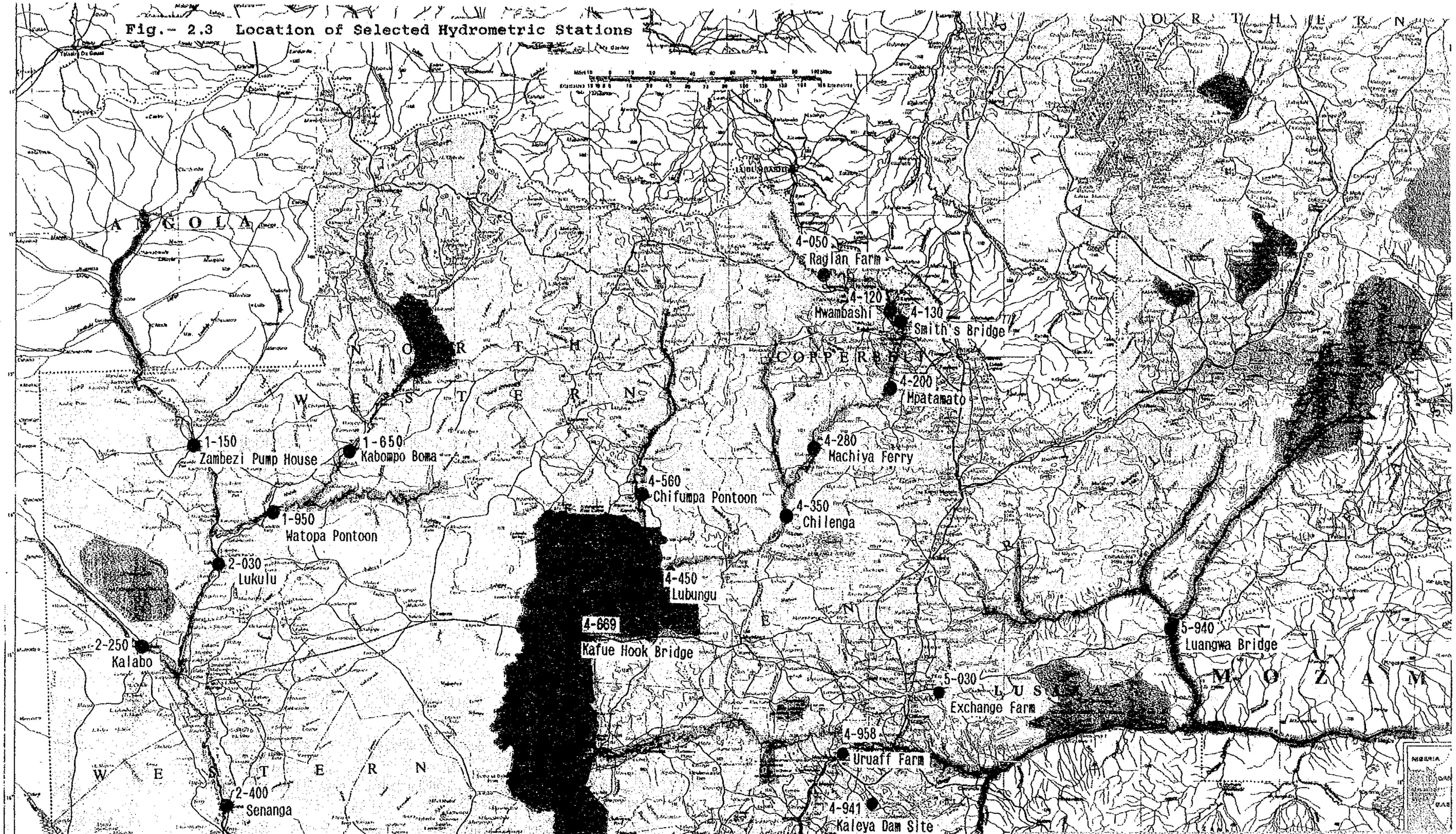


Fig.- 2.3 Location of Selected Hydrometric Stations

<<< Hydrometric Stations Observed in Study >>>

No	No. of St.	Name of Station	Basin	Name of River	Catchment Area	Starting Year & Month	Staff Gauge	Bench Mark	Auto. Recorder	Store House	Elevation of Bench Mark
(1)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1954/01	0	0		0	1010.626
(2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0		0	1053.327
(3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0			1037.048
(4)	[illegible]	Lukulu	[illegible]	[illegible]	[illegible]	[illegible]	0	0		0	1026.740
(5)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0			[illegible]
(6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1947/11	0	0		0	1000.718
(7)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0			1284.930
(8)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0		1175.185
(9)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0		1167.590
(10)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1950/12	0	0	0		1169.247
(11)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0		0	1125.174
(12)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0		0	1120.684
(13)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0		0	[illegible]
(14)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0			1118.743
(15)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0		0	[illegible]
(16)	[illegible]	[illegible]	[illegible]	[illegible]	4	1950/12	0	0	0		[illegible]
(17)	[illegible]	[illegible]	[illegible]	[illegible]	140	1962/10	0	0	0	0	[illegible]
(18)	[illegible]	[illegible]	[illegible]	[illegible]	187	[illegible]	0	0	0		[illegible]
(19)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0		0	[illegible]

2.2.2 Construction of Hydrometric Stations

Construction for nineteen (19) stations mentioned above was carried out by employing the local contractor under the supervision of the Study Team. The construction includes the following: (Refer to Table-2.2)

1) Automatic Water Level Recording Stations .... 6 Stations
2) Water Level Gauge ..... 19 Stations
3) Bench Mark and Base Point ..... 19 Stations
4) Store House at Observation Station ..... 10 Stations

Table-2.2 Installation of Hydrometric Stations

S T A T I O N S	Water/L Recorder	Staff Gauge	Bench Mark	Store House
(1) 1-150 Zambezi P/H		O	O	O
(2) 1-650 Kabompo Boma		O	O	O
(3) 1-950 Watopa Pontoon		O	O	
(4) 2-030 Lukulu		O	O	O
(5) 2-250 Kalabo		O	O	
(6) 2-400 Senanga		O	O	O
(7) 4-050 Raglam Farm		O	O	
(8) 4-120 Mwambashi	O	O	O	
(9) 4-130 Smith's Bridge	O	O	O	
(10) 4-200 Mpatamato	O	O	O	
(11) 4-280 Machiya Ferry		O	O	O
(12) 4-350 Chilenga		O	O	O
(13) 4-450 Lubungu		O	O	O
(14) 4-560 Chifumpa Pont.		O	O	
(15) 4-669 Kafue Hook Br.		O	O	O
(16) 4-941 Kaleya Dam Site	O	O	O	
(17) 4-958 Uruaff Farm	O	O	O	O
(18) 5-030 Exchange Farm	O	O	O	
(19) 5-940 Luangwa Bridge		O	O	O

(1) Automatic Water Level Recording Station

The following six (6) recording stations were installed. The schematic diagram of the station is shown in Fig.-2.4.

< Float Type Recorder Station >
Recorder Model "W-021-Z", Nakaasa, Japan
1) Mwambashi (4-120)
2) Mpatamato (4-200)
3) Kaleya Dam Site (4-941)
4) Uruaff Farm (4-958)
5) Exchange Farm (5-030)

< Pressure Type Recorder Station >
Recorder Model "W-435-Z", Nakaasa, Japan
6) Smith's Bridge (4-130)

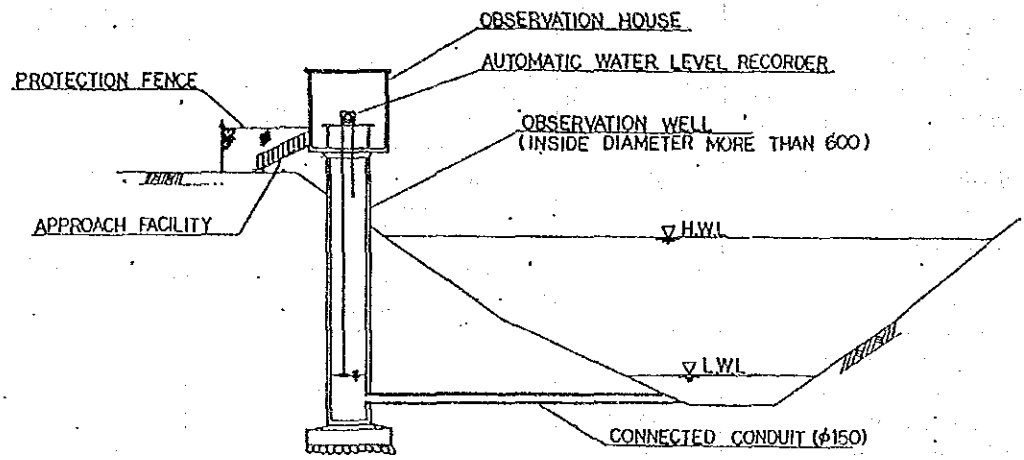


Fig.-2.4 Automatic Water Level Recording Station

(2) Water Level Gauge

A set of staff gauges (Model"W-881Z" Nakaasa, Japan) was installed at the 19 stations. This gauge is a polyvinyl chloride board, 5 feet-long graduated in 0.1 feet increments. The standard for staff gauge installation in one unit is as shown in Fig. - 2.5.

(3) Bench Mark and Base Point

One bench mark and one base point were installed at both banks of the river along cross sectional line perpendicular to river flow. In case of a wide river, another base point was installed on one side of bank along the river so that a triangle is formulated by these three points making it easy to position a boat by using a simple survey method in measurement of discharge. The standard type of bench mark and base point are as shown in Fig.- 2.5.

(4) Store House

Ten (10) store houses were constructed at the selected hydrometric stations in order to store spare parts, consumables, equipment and tools, and to arrange raw data just observed, and to take a rest during observation and measurement.

The store house was made of brick with concrete flooring and slate roofing or equivalent and with space of fifteen (15) square meters. The store house is furnished with shelves and a set of desk and chair as well as window and entrance with lock and burglar bars.

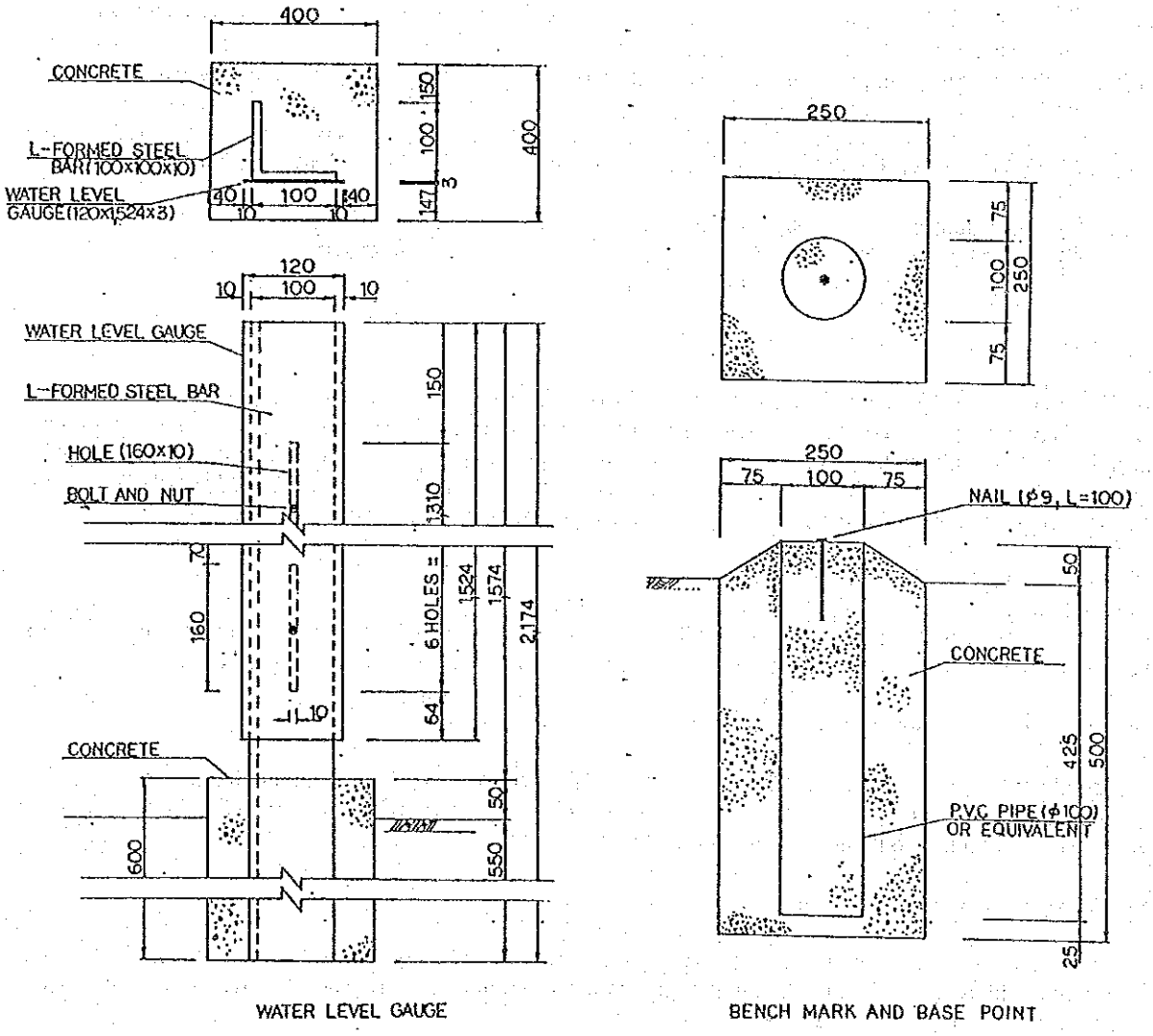


Fig.-2.5 Staff Gauge and Bench Mark

2.2.3 Topographic Survey

(1) Contents of Survey

The topographic survey for nineteen (19) stations mentioned above was carried out by the local survey company under the supervision of the Study Team. The survey includes the following:

1) Leveling Survey for Establishment of Bench Mark
2) Cross Sectional Survey of River
3) Relative Position Survey between Bench Mark & Base Point
4) Leveling Survey for Water Level Gauge

< Leveling Survey >

The leveling survey was carried out to measure the elevation of the new bench mark installed at the stations. The elevation of each new bench mark was correlated with the National Bench Mark or equivalent. The most appropriate equipment was applied according to the distance between the existing known point and the hydrometric station, from the following three (3) methods:

1) Automatic Level for short distance survey
2) Distance Meter for medium distance survey
3) Super Barometer for long distance survey

< Cross Sectional Survey >

The cross sectional survey of the river was carried out to prepare the cross section necessary for establishment of the rating curve. In cross section of each station, datum line of water level is shown. Using this cross section, the relationship between the water level and discharge area can be obtained.

< Relative Position Survey >

The bench mark and base point, installed at the stations, were surveyed to get the location and position of each point.

< Leveling Survey for Water Level Gauge >

The height of datum point of staff gauge was determined by leveling survey using an automatic level, connecting with the bench mark installed at each station.

(2) Results of Survey

The results of the leveling survey between the national Bench Mark and the new bench mark installed at each station are summarized as shown in Table- 2.6.

The cross sections of the selected 19 hydrometric stations are shown in Fig.-5.7 _ 5.25 of Chapter 5.

Table- 2.3 Result of Leveling Survey

No. of St.	National B/M Name	Elev.(m)	Leveling A1	A2	A3	B1	B2	JDG	River B/M El.(m)
1-150	T=P6	1056.230	-	41.0	-	128	80	OK	1040.626
1-650	T=TP28	1128.980	2.0	5.2	-	53	15	OK	1053.327
1-950	T=TP30	1110.380	-	-	62.0	157	76	OK	1037.048
2-030	T=P7	1032.430	-	5.4	-	46	4	OK	1026.740
2-250	B=H89	1046.000	-	7.9	-	56	55	OK	1020.800
2-400	B=17F7	1009.392	0.1	-	-	6	0	OK	1000.718
4-050	B=14M30	1321.953	1.5	16.6	-	85	83	OK	1264.930
4-120	B=KITWE	1205.831	-	-	12.0	69	0	OK	1175.285
4-130	B=RM88CL	1200.269	5.0	-	-	44	28	OK	1167.580
4-200	B=E7M165	1208.594	-	-	28.0	105	46	OK	1169.247
4-280	B=E7M120	1196.963	-	-	28.0	105	38	OK	1125.174
4-350	B=E7M75	1161.896	-	-	21.0	91	11	OK	1120.684
5-030	B=12/63	1097.606	0.1	-	-	6	0	OK	1118.198
4-450	B=12M120	1120.492	0.4	-	-	12	5	OK	1098.285
4-560	B=43M81A	1079.549	0.8	-	-	17	16	OK	1116.743
4-669	B=19/19	1147.963	-	-	36.0	120	100	OK	1072.868
4-941	B=19F1	1136.021	-	13.8	-	74	42	OK	1247.486
4-958	9/19	1125.102	0.3	-	-	10	6	OK	1027.622
5-940	B=TS289	944.570	-	-	12.0	69	9	OK	368.289
[Total]			10.2	89.9	199.0				

[Note]

A1 : Distance surveyed with autolevel (km)
A2 : Distance surveyed with distance meter (km)
A3 : Distance surveyed with super-barometer (km)
B1 : Allowable error (mm)
B2 : Actual error (mm)
JDG: Judgment of survey accuracy

2.3 Observation and Flow Measurement

(1) Observation Team

The three (3) observation teams for the Study were established as shown Fig.-2.6. The teams covered the periodic flow measurement and daily observation of river water level.

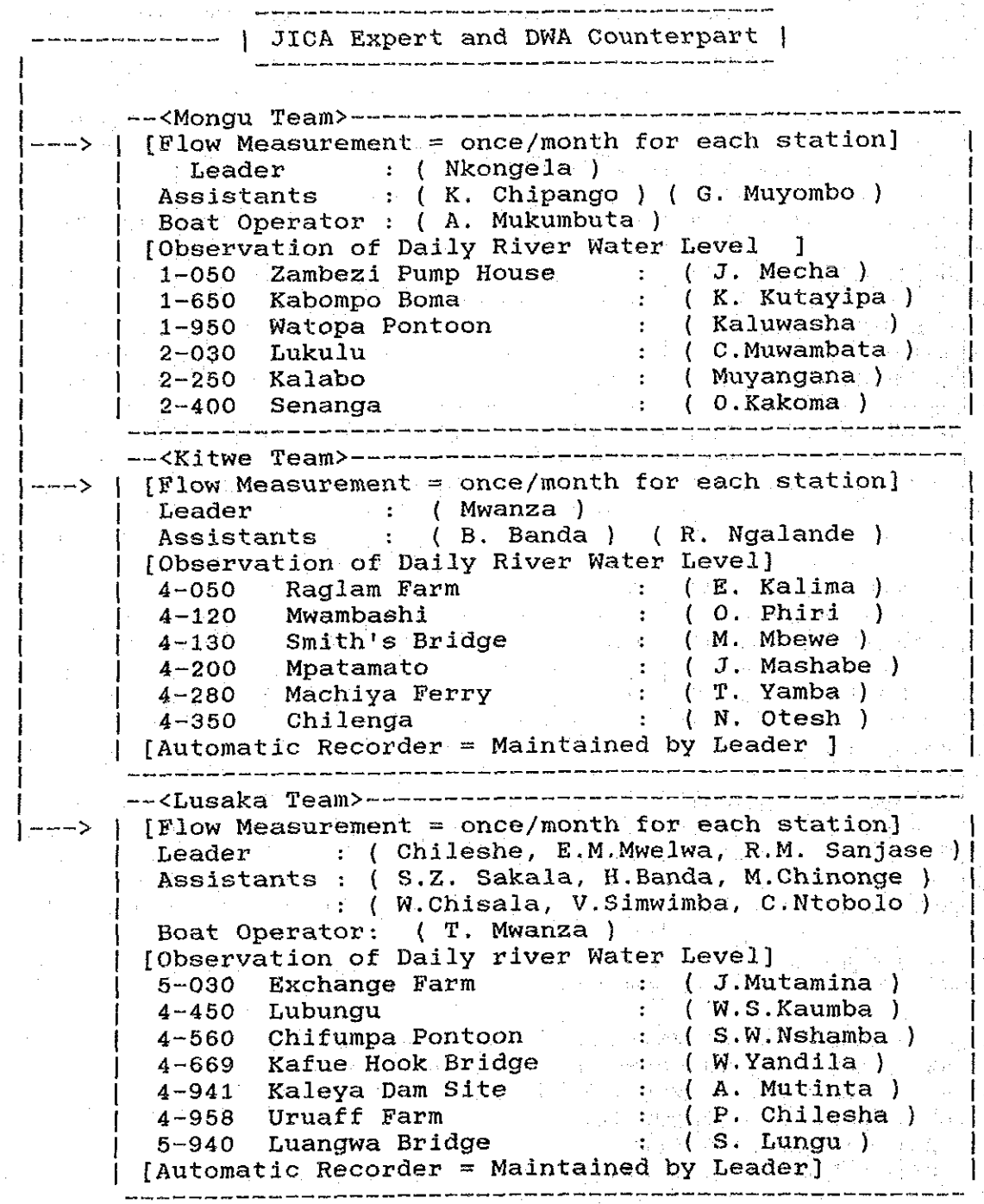


Fig.- 2.6 Hydrologic Observation Team

(2) Observation of River Water Level

The daily water level observation was carried out using staff gauge at every stations by the employed observer. The gauge reading was made twice a day, every morning (6:00) and evening (18:00). The reading data and time were filled on the format sheet. Every month this sheet was sent to the Regional Hydrological Office. The continuous water level data was recorded at the six (6) recording stations during rainy seasons.

(3) Measurement of Discharge

Generally, either one of the following methods :1) Current meter method 2) Float method 3) Weir method, is used in flow measurement. In this Study all the flow measurements were done with the current meter method. Flow measurement with current meter was done by wading or from bridge or from boat.

(4) Observation and Measurement Data

The Study Team executed successfully the hydrologic observation mentioned above and obtained the daily water level data of 19 stations and the recording water level data of six (6) recording stations. These data were converted into discharge using the rating curves established in the Study.
The flow measurement data obtained in this Study is summarized as shown in Table-2.4.

Table-2.4 Number of Flow Measurement Data

Stations	Before Study	During Study Period			
		89/90	90/91	91/92	Total
(1) 1-150 Zambezi Pump H.	0	5	7	2	14
(2) 1-650 Kabompo Boma	0	5	7	2	14
(3) 1-950 Watopa Pontoon	173	7	7	2	16
(4) 2-030 Lukulu	0	5	7	2	14
(5) 2-250 Kalabo	45	5	6	1	12
(6) 2-400 Senanga	2	4	8	2	14
(7) 4-050 Raglam Farm	127	2	8	2	12
(8) 4-120 Mwambashi	186	4	8	2	14
(9) 4-130 Smith's Bridge	226	3	8	2	13
(10) 4-200 Mpatamato	368	3	8	2	13
(11) 4-280 Machiya Ferry	261	3	7	2	12
(12) 4-350 Chilenga	220	2	6	2	10
(13) 4-450 Lubungu	216	3	7	2	12
(14) 4-560 Chifumpa Pont.	54	3	5	2	10
(15) 4-669 Kafue Hook Bri.	75	3	7	2	12
(16) 4-941 Kaleya Dam Site	15	2	5	2	9
(17) 4-958 Uruaff Farm	11	1	4	2	7
(18) 5-030 Exchange Farm	22	2	5	2	9
(19) 5-940 Luangwa Bridge	133	3	7	2	12
< Total >	2134	65	127	37	229