REPUBLIKA NG PILIPINAS
PAMBANSANG KORPORASYON SA ELEKTRISIDAD
(NATIONAL POWER CORPORATION)

REPORT
FOR
STUDY ON HYDROPOWER POTENTIALS
IN LUZON ISLAND

MAIN REPORT

AUGUST 1987

JICA

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request of the Government of the Republic of the Philippines, the Japanese Government has decided to conduct a feasibility study on Hydropower Potentials in the Luzon Island and entrusted the study to the Japan International Cooperation Agency (J.I.C.A). J.I.C.A. sent to the Philippines a survey team headed by Mr. Kazuo Sawaya of Nippon Koei Co.,Ltd. from July 1985 to January 1987. The team had discussions with the officials concerned of the Government of the Philippines and conducted a field survey in the Luzon Island. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two contries.

I wish to express my deep appreciation to the officials concerned of the Government of the Philippines for their close cooperation extended to the team.

August, 1987

Keisuke Arita
President
Japan International Cooperation Agency

STUDY ON HYDROPOWER POTENTIALS
IN LUZON ISLAND

August, 1987

Mr. Keisuke Arita
President
Japan International
Cooperation Agency

Dear Sir,

LETTER OF TRANSMITTAL

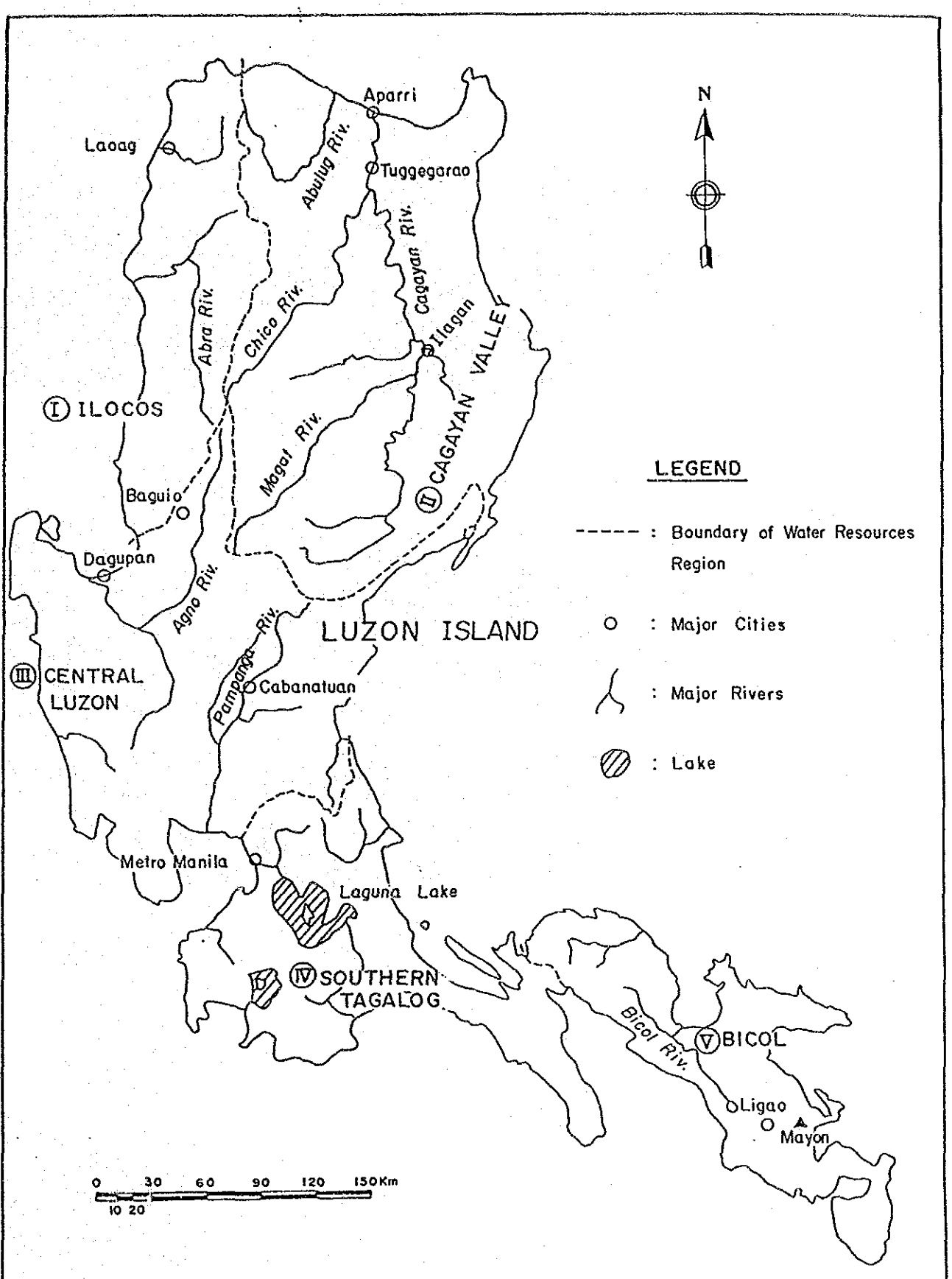
We have the pleasure to submit herewith the Final Report for the Study on Hydropower Potentials in Luzon Island, prepared for consideration by the Government of the Philippines in implementing overall hydropower potentials study in Luzon Island in line with nation's energy policy.

The Report consists of the Main Report and Appendices A, B and C. The Main Report contains review of previous studies on hydropower projects, analysis of the present situations and future prospects of power of the Luzon Grid, and master action program for orderly development of hydropower potentials. Appendices contain supporting data and technical details.

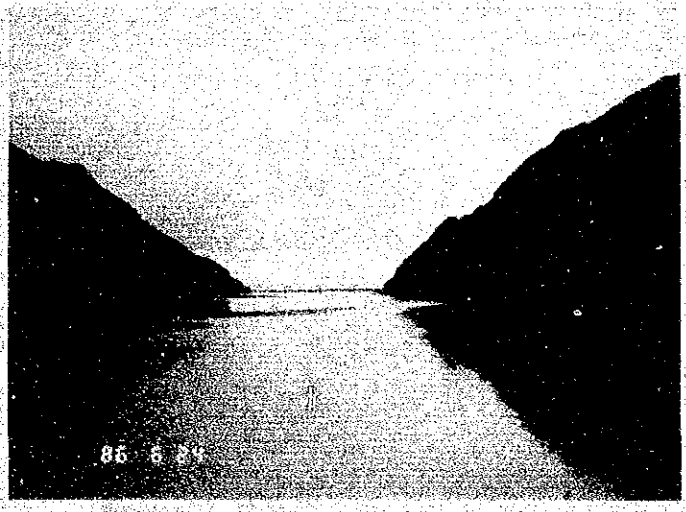
We would like to express our grateful acknowledgement to the personnel of your Agency, Ministry of Foreign Affairs, Ministry of Industry and Trade, and Embassy of Japan in Manila as well as officials and individuals concerned of the Philippines for their kind assistance/advise extended to the Study Team. We sincerely hope that the study result would contribute to the future development of hydropower potentials in Luzon Island.

Yours sincerely,

Kazuo Sawaya
Team Leader



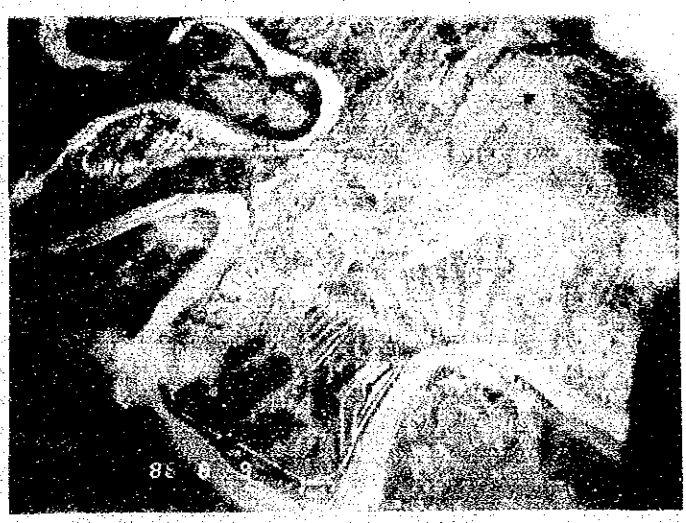
PROJECT AREA



Distant view of Banaoang damsite, from upstream side
(ID No.1-022-00-01-0)

Distant view of Wawa damsite, from downstream side
(ID No.4-115-01-01-0)

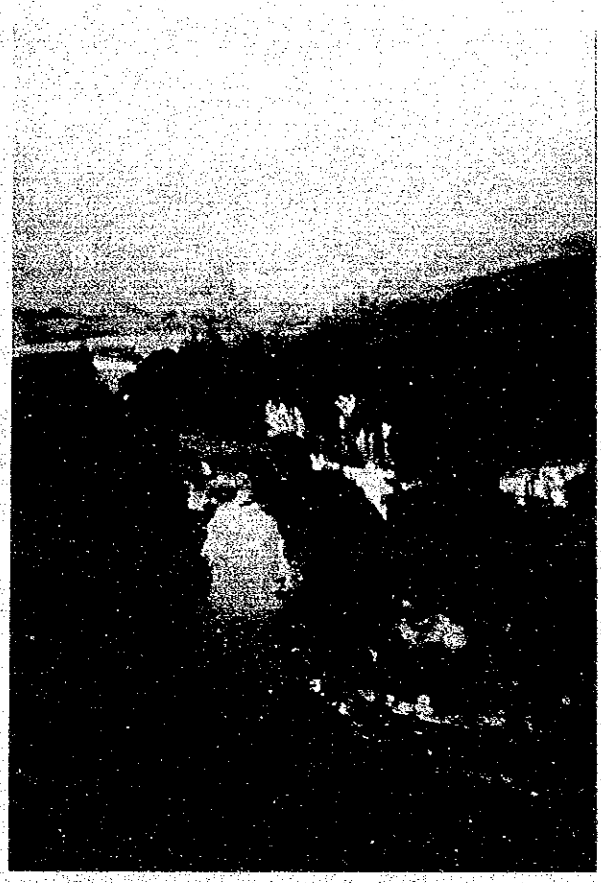
Aerial view of plain extended immediately upstream of Bantay damsite
(ID No.2-008-07-24-0)



Aerial view of diversion tunnel at Laiban damsite

Bosigon damsite,from upstream side
(ID No.5-014-01-01-0)

Confluence of the Kaliwa and the Kanan Rivers



Aerial view of Cabingatan damsite
(ID No.2-008-28-52-0)

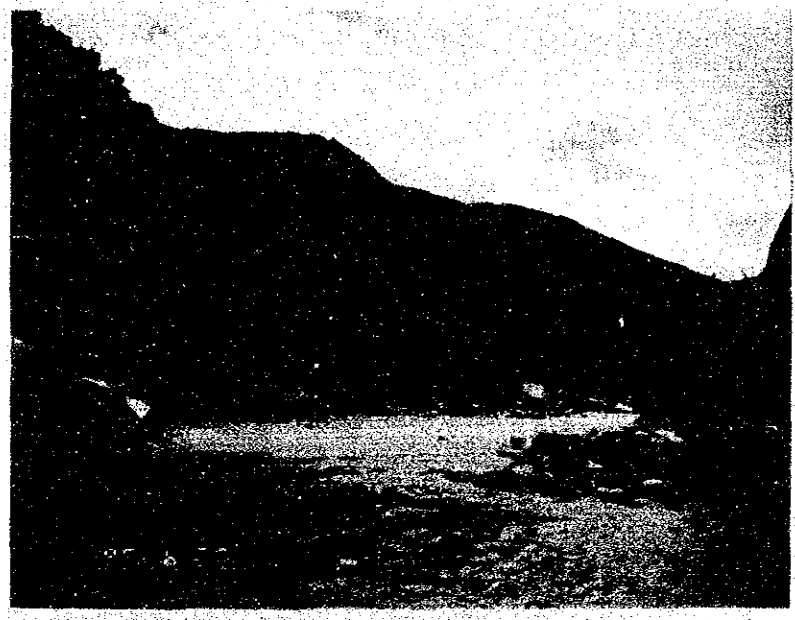
Aerial view of Alimit-2 damsite
(ID No.2-008-19-44-0)

Aerial view of Huoab damsite
(ID No.2-008-20-45-0)

Aerial view of Gadeng damsite
(ID No.2-008-29-57-0)

Aerial view of Ibulao intake weir site
(ID No.2-008-20-46-0)

Aerial view of Saltan-4 damsite
(ID No.2-008-05-14-0)



Amburayan intake weir site, from
downstream side
(ID No.1-010-01-04-0)

Aerial view of Naneng damsite
(ID No.2-008-06-19-0)

Summary

1) The main objective of the study is to formulate a hydropower potentials plan for orderly development in Luzon, in line with the energy policy of the Government of the Philippines toward:

- Reduction on dependency on imported energy, particularly crude oil energy,
- Conservation of energy use and demand to adequate level,
- Diversification of supply sources, and
- Acceleration of shifting to alternative domestic energy sources, particularly by geothermal, coal-fired and hydro sources.

Results of the study were summarized in the form of "Inventory of Hydropower Site" and the "Master Action Program for Orderly Development of Hydropower Potentials".

A team of Consultants for the study (the Study Team) was organized by Japan International Cooperation Agency (JICA) and commenced the study at the site on July 1985. The study was mainly done at the site, and the Study Team stayed there until the end of Jan. 1987. After then, the Study Team had prepared this report at Tokyo, Japan. During this period (July 1985 - August 1987), the following studies have been made to prepare the above "Inventory of Hydropower Site" and "Master Action Program for Orderly Development of Hydropower Potentials":

- Collection and review of existing data and previous studies relevant to the study,
- Preparation of inventory of the projects investigated in the previous studies,

- Preparation of inventory of the projects newly identified in map studies,
- Preliminary investigations for the identified projects,
- Preparation of hydropower potentials plan for orderly development, and
- Establishment of data base and updating programs of the development priority in accordance with hydropower potential plan.

2) The Luzon Island in the Tropics has torrential areas with 6,000 mm in annual rainfall, such as the north end of Cordillera Central Mountains and the southeastern part of the island, such heavy rains are brought by the prevailing winds, principally the southwest monsoon from July to September and the northeast moonsoon from November to February. Several typhoons hit the island every year. However, the areal distribution of rainfall is considerably orographic; the central regions such as the lower Cagayan Valley and Central Luzon Plain are relatively dry and their annual rainfalls range from 1,500 mm to 1,800 mm. Since temperature differences in the Luzon Island are comparatively slight, the meteo-hydrological conditions depend on rainfall characteristics. In this study, the Luzon Island was divided into 10 hydrological regions based on annual rainfall depth, its temporal distribution and the climate classification in the Philippines. The hydrological region denotes the area where similar hydrological characters are shared.

On the other hand, 18 streamflow stations within the island were selected as the key station, for power output calculation. The flow duration and storage-draft curves were prepared at each station on the basis of monthly streamflow data. Both curves were nondimensionalized so that the curves can be converted to the arbitrary scheme sites in the same hydrological region by proportionating to the annual rainfall volume in the catchment. High-flow analysis is carried out

to estimate design floods for spillway and river diversion works. In the first screening stage, a concept of zonal design flood curve is introduced so as to process many schemes at a time, since more than 100 reservoir type schemes are raised up. In the second stage, the design floods of 20 schemes passing the first screening are derived scheme by scheme, adopting PMP and PMF methods. For the reservoir simulation study, the sediment volume was estimated on the physical life of a scheme. The reservoir evaporation was assumed to be 3.5 mm/day to 2.5 mm/day, according to an elevation at each scheme site.

3) Luzon island lies between 119°45' to 124°13' east longitude and 12°30' to 18°45' north latitude. Luzon Island can be divided into three physiographic Provinces, namely 1) Eastern physiographic province, 2) Central physiographic province, and 3) Western physiographic province. In the Eastern physiographic province, the Miocene limestone is exposed at mostly the western portion of Northern Sierra Madre along the Cagayan River, where is made up of steep cliff and gorge. Northern Luzon of Central Physiographic province is composed of Luzon Central Cordillera and Cagayan Valley. Southern Luzon of Central physiographic province is composed of Luzon Central Plain and Southwest Luzon Uplands. The western physiographic province is subdivided into the Ilocos Lowland and Zambales Range. The geology of Luzon Island consists of broad time rock units ranging in age from Cretaceous to Holocene. The rocks underlie at the mountaion area consists of Tertiary sedimentary rocks (limestone, sandstone, claystone) volcanic rocks of Cretaceous to Paleogene and Intrusive rocks of Neogene.

The seismicity of Luzon Island is high potentially. Most of the epicenters of Luzon Island are generally shallow (less than 70 km), and situated near the Luzon Trench and Manila Trench.

4) Preliminary engineering geological assessment were made for all the identified 145 sites referring to the results of

field reconnainssance and studies of existing geological maps and reports. Geological assessments were mainly carried out on the following categories:

- geologic formation, age and structure of the scheme site,
- rock quality, permeability and overburden of dam site,
- rock quality in relation to tunneling operations,
- rock quality and overburden of powerhouse foundations,
- permeability, slope stability and sedimentation of reservoir, and
- character and location of construction materials.

5) The power output calculation was made for all the identified 145 schemes to estimate power and energy output, as well as development scale. Several alternative examination on reservoir development scale, power discharge and water level are tried for the development types of "Reservoir" and "Run-of-river". The calculation is based on the topographic and hydrological informations derived from the studies related as well as some criteria and assumptions, such as equal plant factor 0.5 and no interdependency among the schemes. Output of the above calculation was proceeded to the succeeding "Preliminary cost estimate" phase.

6) The preliminary construction cost estimate for all the 145 schemes was made succeeding to the basic design of each scheme. For evaluation of every schemes on equal basis, the design criteria was standardized for each major component of the hydropower development project. Based on the above design and result of the power output calculation, the preliminary cost calculation was tried to estimate the total construction cost and cost indices. The power development cost was estimated by means of summing up costs for major structures applying cost formulae set up through the cost study, while power transmission and access cost were based on the unit prices and quantities. The calculation was made for

the selected several alternatives out of all examined in the power output calculation. Comparing cost index and also (B-C) of each development alternative, the development scale of maximum power output or lowest index value is proposed as an optimum development one for the first screening evaluation, and information for the optimum one have been registered in the "Inventory of Hydropower Site".

7) The study have required number of computer programs consisting of 18 programs prepared for the first screening, 11 programs for the second screening evaluation and 7 for the priority ranking study. All of programs were processed by a computer VAX11-750 owned by NPC. The above programs have respective functions of data filing, analysis and data retrieval as a key component of the data bank system. The data bank system established in the study contains following six data files:

- meteo-hydrologic data file,
- hydropower scheme data file,
- cost information data file,
- existing and committed plants data file,
- inventory of hydropower site, and
- promising hydropower project catalogue.

This data bank system is required to be updated periodically and occasionally as required. The data bank system is designed for convenience of data updating. The study presents required work procedure for updating computer works basides name of data files concerned.

8) The Inventory of Hydropower Site has been established in this study in the computer system VAX11-750 owned by NPC. The optimized development scale of every identified schemes have been evaluated through the power output calculation and preliminry cost estimate. The site and development features of the above have been stored in the inventory. The

inventory provides any information stored through the computer processing of the exclusive retrieval programs. The inventory provides also hydropower potential information in Luzon Island; approximately 7,300 MW and 21,000 GWh exploitable as technically possible development, while developed potential is 1,226 MW in terms of the installed capacity and 2,956 GWh in actual energy product in 1986, respectively.

Number of schemes examined, identified and screened during this stage are tabulated below:

Region No.	Name of Region	Number of Schemes Examined	Identified	Sieved (1st screening)
I	ILOCOS	(76 + 17)	(34 + 11)	(3 + 4)
II	CAGAYAN VALLEY	(57 + 33)	(48 + 27)	(11 + 12)
III	CENTRAL LUZON	(54 + 6)	(12 + 5)	(0 + 2)
IV	SOUTHERN TAGALOG	(12 + 3)	(3 + 3)	(3 + 1)
V	BICOL	(13 + 1)	(1 + 1)	(0 + 1)
	Total:	(212 + 60)	(98 + 47)	(17 + 20)

Note: (A + B) A: Named sites
B: Newly identified sites

Schemes passed through the first screening are 37 schemes in total as shown in the above. As for selected reservoir type schemes, the maximum output ranges from 39.8 MW to 576.4 MW, and run-of-river type schemes from 9.5 MW to 64.0 MW.

9) Prior to the preparation of general layout drawings for the schemes which had passed the first screening, preliminary review was made for all the schemes from the viewpoints of technical aspects such as site geology, accessibility, socio-environment, etc. As a result, six schemes; Banaoang, Buburayan, Cabingatan, Dabba, Upper Casecnan 3, and Daraitan, were discarded because of some disadvantages. On the other

hand, two schemes, Basao and Tabu were revived for the examination of upstream storage effect, and also some schemes were studied in combination with neighboured schemes on the same river stretch. Finally 22 reservoir type schemes and 19 run-of-river type schemes were proceeded to basic design.

Basic design for those schemes was made on major dimensions of principal structure, such as dam, river diversion works, intake structure, waterway tunnel, penstock, power house, and so forth.

Based on the general layout plan prepared, the second cost estimate was performed for all the selected schemes. The cost was computed by summing up every construction work items, which were obtained by multiplying work quantity by unit price. The cost estimate was made at the price level of end-1985.

10) The second screening of selected schemes was made by the assessment of kWh cost (energy cost) to find an appropriate number of promising hydropower schemes among those of named and newly identified, and also F/S completed projects. Total number of schemes and projects studied were 51 in total.

Judging from the energy cost of alternative thermal plants such as coal-thermal, geothermal and oil-thermal, and also that of F/S completed projects, the highest limit of energy cost was determined to be 0.169 $/kWh. Taking this value as the highest limit, 45 schemes in total were finally selected as a promising scheme/project, and 6 schemes were ruled out. Breakdown of those schemes/projects are as follows:

Type of Development	Number of scheme/project		
	Studied	Discarded	Selected
- Reservoir (Named & Newly Identified)	22	6	16
- Run-of-river (Newly Identified)	19	-	19
- Reservoir (F/S Completed)	10	-	10
Total:	51	6	45

11) The Hydropower Project Catalogue has been established in the computer system owned by NPC, as one of the key component of the data bank system. The Catalogue contains features of hydropower development for the 45 promising schemes to be examined through the second screening evaluation, which schemes includes several alternative plans of basin development.

12) For the scrutinized schemes and F/S completed projects through the second screening evaluation, the priority ranking study has been made to propose the optimum orderly power development program spanning up to the target year 2005 incorporating alternative thermal plants. This study includes some preliminary studies on power demand forecast, existing and committed power plants, plant scales, and construction cost of thermal plants.

Candidates of thermal plant considered in the study were coal-fired thermal and geothermal, while nuclear power plant was not considered as candidate, and oil-fired thermal plants were only for the existing ones. Retirement of the existing plants was counted as negative installation, and the projects committed for implementation by the year 1995 were considered of which commissioning is made as scheduled in the Power Development Program updated by NPC.

The study was made for the one original plan of power and energy demand forecast which is the latest one updated by

NPC, and three alternatives which are rather conservative than the original plan:

Case	Growth of Power and Energy Demand (%)	
	1986 - 1995	1996 - 2005
A. Original	5.3	5.3
B. Alternative 1	5.3	4.0
C. Anternative 2	4.0	5.0
D. Alternative 3	4.0	4.0

The study introduced the present worth method to find the least cost development sequence introducing a simulation model applying the Dynamic Programming.

As a first step of the priority ranking analysis, formulation was made for various development sequences of coal-fired thermal, geothermal and hydropower. Those sequences consisted of combination of power generation sources, plant size and installation timing taking account of the appropriate share of each power generation source.

Then, out of various alternative sequences, several alternatives of rather low present worth of total capital cost and the operation/maintenance costs were examined to select the optimum power development program of least cost development sequence using a simulation model.

13) Through the priority ranking study, an orderly power development program which covers 20 years from the 1986 to 2005, was selected. Committed power projects such as Bacon-Manito, Calaca 2, Casecnan, etc. in the NPC's Power Development Program (May 1986) were incorporated in the program without any modification. Total number of projects to be installed during that period is as follows:

Plant Type	Nos. of Project	Total Installed Capacity (MW)
Committed, 1986-1995		
Hydropower	2	291
Coal-thermal	3	600
Geothermal	1	110
Sub-total:	6	1,001
Proposed, 1995-2005		
Hydropower	7	1,239
Coal-thermal	4	2,100
Geothermal	4	1,320
Sub-total:	15	4,659
Total:	21	5,660

As is seen in the above, total installed capacity of power plants to be newly installed during 11 years from 1995 to 2005 is almost 4,700 MW. On the other hand, total installed capacity of power plants which are scheduled to be commissioned by the year 1995 is about 1,000 MW. It means that more than four times of new installation is needed for the latter half of study horizon.

For the projects to be installed after the year 1995, fund of 6,189 x 10^6 US $ in total will be required, breakdown of which is as follows:

Plant Type	Nos. of Project	Total Capacity (MW)	Total Const Cost (10^6 US$)
Hydropower	7	1,239	1,689
Coal-thermal	4	2,100	2,520
Geothermal	4	1,320	1,980
Total :	15	4,659	6,189

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ABBREVIATIONS

BCGS	Bureau of Coast and Geodetic Survey
BMG	Bureau of Mines and Geo-Science
BPI	Bureau of Plant Industry
BPW	Bureau of Public Works
DMA-AC	Defence Mapping Agenecy Aerospace Center
ECAFE	Economic Commission for Asia and the Far East
GDP	Gross Domestic Product
GRDP	Gross Regional Domestic Product
GNP	Gross National Product
GOP	Government of the Philippines
MOE	Ministry of Energy
JICA	Japan International Cooperation Agency
MERALCO	Manila Electric Company
MPWH	Ministry of Public Works and Highways
MWSS	Metropolitan Waterworks and Sewerage System
NPC	National Power Corporation
NIA	National Irrigation Administration
NWRC	National Water Resources Council
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
NCR	National Capital Region
PNPP	Philippine Nuclear Power plant
T/L	Transmission Line
NEDA	National Economic and Development Authority
NCSO	National Census and Statistics Office
AIE	Asian Institute of Economy

UN	United Nation
IBRD	International Bank for Reconstruction and Development
ADB	Asian Development Bank
IMF	International Monetary Fund
EIU	Economic Intelligence Unit

MEASUREMENT

Time

sec	=	second
min	=	minute
h	=	hour
d	=	day
yr	=	year

Money

₱	=	Philippine Peso
US$	=	US Dollar
¥	=	Japanese Yen

Electrical Measures

V	=	volt
kV	=	kilovolt
kVA	=	kilovoltampere
kW	=	kilowatt
MW	=	megawatt
kWh	=	kilowatthour
GWh	=	gigawatthour
kWh/yr	=	kilowatthour/year
EHV	=	extra high voltage

I. INTRODUCTION

1.1 Project Background

The energy policy of the Government of Philippines sets its direction toward:

(1) Reduction on dependency on imported energy, particularly crude oil energy,

(2) Conservation of energy use and demand to adequate level,

(3) Diversification of supply sources, and

(4) Acceleration of shifting to alternative domestic energy sources, particularly by geothermal, coal-fired and hydro sources.

Supply and resources development in the power sector has been just in line with the above-mentioned policy. Among the alternative sources to the oil-based energy, development of geothermal, coal-fired and hydro resources has been promoted recently. Adding to these alternative sources, development of nuclear energy has been aimed, and the Philippine Nuclear Power Plant (PNPP) has been constructed in Bataan. However, it has abandoned to be commissioned by the Government due to some socio-environmental problems. Development of hydro resources, in particular, has been undertaken since 1945 in Luzon. As of June 1987, Luzon has 11 hydropower sources of total 1,226 MW of installed capacity. It corresponds to the share of 30% of the grid total capacity of 4,111 MW, breakdown of which is as follows:

- Geothermal	660	MW
- Coal-fired	300	"
- Oil-fired	1,925	"
- Hydro (incl. pumped storage)	1,226	"
Total:	4,111	MW

On the other hand, a number of hydropower projects have been studied, though their study depths vary project by project, in various regions where ample hydro resources are to be harnessed. However, no overall survey on hydro potentials in whole Luzon has not been carried out yet. To this end, the Government of Philippines has decided to undertake overall hydropower potentials study in whole Luzon aiming at:

(1) to obtain general view of hydropower potentials of major river basins in Luzon,

(2) to inventory techno-economically feasible project,

(3) to identify the promising project for future development, and

(4) to find guide line for programming of future expansion of energy supply and resources development.

For implementation of this study, the Government of Philippines requested the technical assistance to the Government of Japan. In February 1985, National Power Corporation (NPC) and Japan International Cooperation Agency (JICA), an official agency responsible for the implementation of technical cooperation programs of the Government, agreed to carry out the study on hydropower potentials in Luzon. A team of Consultants for the study (the Study Team) was organized by JICA and commenced the study at the site on July 1985.

1.2 Scope of Work

1.2.1 Objective of study

The main objective of the study is to formulate hydropower potentials plan for orderly development in Luzon, in line with the policy of the Government of Philippines as mentioned above. It is well known that "NPC is now endeavoring to reduce oil dependence in its power generation plan in line with the national policy. As a part of such effort, NPC places a special importance upon development of the hydropower potentials in Luzon. For attaining the objective, NPC strongly desires to

carry out the intensive study on hydropower potentials in Luzon including the review of all the previous overall studies and feasibility studies for the establishment of the development strategy and its orderly development."

1.2.2 Scope of study

As was agreed in incipient discussion between the Study Team and NPC in August 1985, the scope of study covers the following six main items.

(1) Collection and review of existing data and previous studies relevant to the study.

a) Common data

- Meteoro-hydrological data
- Topographic maps and aerial photos
- Geological data
- Electrical data
- Socio-economic data
- Other data concerned

b) Project data

- List of projects (plans) :

  information of all projects (plans) studied or named by NPC, NIA, MPWH, MWSS, and other agencies.

- Reports of project :

  such as Design Report, Feasibility Report, Pre-feasibility Report, Reconnaissance Report, and other technical report concerned.

- National and regional data :

  such as overall development / expansion programs for power generation and supply system, development plans, national and regional development plans, and other data concerned.

(2) Preparation of inventory of the projects investigated in the previous studies.

Named hydropower project of which technical informations are to be furnished by study made so far will be picked up and inventoried with the following items:

a) Name of project (plan or site)

b) Name of river

c) Location

d) Power scale (installed capacity and annual energy output)

e) Main structures with types and dimensions

f) Construction costs

g) Present status of study

h) Reports and data collected up to date

i) Technical comments

j) Economic comments

k) Other information

All the above informations and data will be sorted into "Data Bank System".

(3) Preparation of inventory of the projects newly identified in map studies.

For unsurveyed river basins, hydropower sites of which development is possible in technical viewpoint will be picked up from the map studies using 1:50,000 topographic maps. And all data and information obtained by this study will be compiled in the Inventory in the same manner as described in the preceding paragraph (2).

(4) Preliminary investigations for the identified projects.

The reconnaissance study will be made to prepare detailed inventory of hydropower potential sites and to obtain data and

informations necessary for the study. The sites which are identified through the studies of the preceding paragraphs (2) and (3), except those sites completed their feasibility studies, will be visited by the Study Team. This site reconnaissance will be made twice in the course of the study: The first visit aims at obtaining basic technical informations at potential sites idetified by map studies, and the named sites, before the first screening of projects. The second visit aims at obtaining more detailed information for the selected projects before the second screening to prepare "Hydropower Project Catalogue" which lists up the promising projects.

(5) Preparation of hydropower potentials plan for orderly development.

the development priority list will be prepared for promising hydropower projects selected from a "Hydropower Projects Catalogue" considering other alternatives such as coal-fired, and geothermal. This study will be made to meet power requirements up to the year 2005. This study will cover power demand forecast and construdtion cost survey for the promising power projects as well as those for other alternatives.

Based on the above priority study, most advantageous sequence(s) of power expansion will be prepared to meet the projected power demand. Recommendable expansion programs for hydropower development will be elaborated in due consideration of the long-term development strategy of NPC. Flow of capital cost required for the recommendable programs will be estimated in apportioning into foreign and domestic currency components. The recommended program will then be justified in term of the least-cost solution.

(6) Introduction of data base and updating programs of the development priority in accordance with hydropower potential plan (Ref.: Fig. 2.1, General Work Flow of Study).

For reviewing and analysing the collected data and reports, data processing by computer will be undertaken to the maximum extent in order to save work forces and times in economic viewpoint and to keep data in easy access files in physical viewpoint. To this end, a "Data Base" system will be introduced in the study (sub-system-I).

For analysis of development priority of projects, "Project and Cost Analysis" system (sub-system-II) will also be introduced.

Furthermore, in order to make the systems applicable continuously after the study, and to deal with renewal of the field data and modification of the given conditions whenever necessary, an "Updating System" will be incorporated with the aforesaid systems.

Programming and operation of the systems will be transferred thoroughly to engineers/analysts of NPC by the Study Team from time to time till the end of the study.

1.3 Study Works

The study works in Philippine had been made in three stages, that is, from July 1985 through March 1986, from June 1986 through January 1987, and on May 1987. The study works in Japan had also been made before and after such field works. A bar chart schedule is shown in Fig. 1.1.

Except the field investigation works, most of the study works could be done as scheduled. The Study Team met some difficulties in the field investigation works due to poor accessibility and the security problem.

1.4 Personnel Participated in the Study

Members of JICA Study Team, senior officers and counterpart officers of NPC participated in the sutdy are as listed below:

Members of JICA Study Team

MR. K.Sawaya	Team Leader	NK
MR. K.Inoue	Co-Team Leader/ Hydro planning Engineer	NK
MR. K.Tanaka	Civil Engineer	NK
NR. K.Kawamura	Hydrologist	NK
MR. S.Maruyama	Civil Engineer	NK
MR. M.Itoh	Computer Analyst	NK
MR. M.Fujinami	Geologist	NK
MR. Y.Tomiyama	Electrical Engineer	NK
MR. R.Kubota	Economist	PEI

NK : Nippon Koei Co., Lid.
PEI : Project Economiy Institute, Inc.

Senior Officers and Counterpart Officers of NPC

MR. J.T.Ramas	Vice President for Engineering
MR. M.C.Avendaño	Manager of Hydro Dept.
MR. R.C.dela Cruz	Division Manager of Hydro Dept.
MR. E.D.Marapao	Planning Manager
MR. F.A.San Pablo	Hydro Planning Engineer
MRS. T.A.Dechavez	"
MR. G.V.Valdez	"
MRS. M.B.Hornilla	Hydrologist
MR. J.T.Ujano	"
MR. C.M.Noynay	"
MR. P.P.Ybañez	Computer Analyst
MR. I.A.Blanco Jr.	"
MR. A.A.Pacpaco	Electrical Engineer
MR. G.C.Quejada	"

MR. H.T.Roque	Economist
MRS. B.T.Beltran	"
MR. P.P.Fernandez	"
MR. G.B.Gavino	"
MRS. S.C.Ladignon	"
MR. C.G.Geroso	"
MR. F.S.Baking	Geologist
MR. M.R.Crisostomo	"
MR. L.R.Cruz	System Planning Engineer
MR. L.O.Rebosa Jr.	"
MR. F.G.Guerero	Mechanical Engineer
MR. W.F.Bautista	"

II. STUDY PROCESS AND APPROACH

2.1 General Study Flow

As described in Section 1.2, the main objectives of this study are summarized in preparation of the "Inventory of hydropower sites" and the "Development master action program".

For the preparation of the inventory, the following studies are worked out:

(1) Basic data collection and review,

(2) Map study and site reconnaissance,

(3) Establishment of data bank system,

(4) Hydropower computation and preliminary cost estimate,

(5) Establishment of the inventory of hydropower sites, and

(6) Selection of promising hydropower projects.

For the preparation of the development master action program, the following works are succeeded:

(7) Site reconnaissance (2nd),

(8) Preparation of the basic layout design,

(9) Cost estimate (2nd),

(10) Establishment of the catalogue of promising hydropower projects and second screening,

(11) Priority ranking study of hydropower development including studies on system expansion plan and alternative power sources, and

(12) Preparation of the development master action program.

The general work flow showing the above procedure is presented in Fig. 2.1.

2.2 Basic Concept of Study

2.2.1 Basic criteria and assumption

Basic study criteria and assumption applied to this study are as follows:

(1) Power scale

In accordance with the Letter of Instruction No.889 dated July 23, 1979, the minimum power development scale to be conducted by NPC is limited to 5 MW. Thus, the minimum power scale to be identified in this study is defined to be 5 MW in terms of the maximum installed capacity with assumed plant factor. The scale of 5 MW is deemed to be probable limit of accuracy in the larger scale maps available in the whole study area.

In accordance with the above criteria, all of the hydropower sites of which potential seems to be more than 5 MW were preliminarily investigated in the whole Luzon.

(2) Category of projects

The study covers all hydropower potential sites including existing ones. The following six categories are applied in this study:

Category 1 : Existing,

Category 2 : Under construction and committed for installation,

Category 3 : Projects of feasibility study level,

Category 4 : Projects of pre-feasibility study or reconnaissance level,

Category 5 : Named sites identified through previous study, and

Category 6 : Newly identified schemes in this study.

Of the above, projects of Category - 2 are deemed as the authorized project which will be stuck on future power expansion program according to their commissioning schedules. No further reviews are made for these projects. Projects of Categories - 4 to - 6 above are those to be examined and scrutinized in this study. Projects in Category - 3 are not subject to further alternative studies.

It is duly expected that, even in scaled projects, the engineering informations of those projects vary by the previous study grade as well as the maps and hydrological data utilized. In the process of the study, these projects are updated from technical and socio-economical points of view and by site reconnaissance.

(3) Study on other water resources development

Water use for hydroelectric power is, in most cases, not mutually competitive with water use for other purposes, only excepted the water use for irrigation which sometimes conflicts with hydropower in instream use where the irrigation water is dominant. Out of 283 schemes studied, 271 schemes are planned exclusively for hydropower generation.

If there are particular projects involving other water uses, especially proposed project by NIA, a preliminary review is made to derive the most practical allocation of instream water uses among the sectors. This study is conducted for multipurpose project in the second screening.

2.2.2 Computerization

Most of study data collected and derived are compiled in the computer system to establish a computerized data bank system. As for the analyses and calculations required, it is tried as much extent as possible as one of the key function of the data bank system.

2.2.3 Technology transfer

Technology transfer relating to the study approach and methodology is performed to NPC personnels concerned from time to time during the study period, as well as the transfer on technique of computer use and operation of data bank system. To perform a technology transfer, the following measures are undertaken:

(1) On-the-job training by respective expert,

(2) Seminar on specific topics, and

(3) Documentation.

2.3 Zoing of Study Area

The study covers the main land area of Luzon Island excluding any surrounding islets which belong to the Luzon administratively. The study area is divided into five (5) zones identical to the water resources regions defined by NWRC as shown in Fig 2.1. These water resources regions generally correspond to the existing administrative regions with slight deviation. Each administrative region consists of several provinces as referred to Fig. 2.1.

Each water resources region is further divided into a number of river basins identified on the topographic maps of 1:250,000 and/or 1:500,000 scale. The numeric code numbering is developed systematically in this study, which numbering system is independent to those by NWRC or NPC. Fig. 2.2 shows all the river basins in Luzon Island with river names and code number. Those river basins are presented in tabular form of river code, name and catchment area in APPENDIX A. The number of rivers in each water resources region are summarized below:

Water Resources Region	Nos. of rivers
I	52
II	55
III	79
IV	115
V	121
Total:	422

All of the river basins above are studied preliminarily. However, a number of river basins are omitted from the site identification due to their apparent minor potentials, less than 5 MW attributable to low-lying location and small drainage area.

2.4 Establishment of Inventory of Hydropower Sites and First Screening

Out of 422 river basins described in Section 2.3 above, all of hydropower potential sites identified in the 122 river basins are studied to establish the inventory of hydropower sites and examined in the first screening evaluation.

2.4.1 Data preparation

Prior to the hydrological analysis and hydropower computation, data collection and compilation are made for topographic and geological maps, rainfall and streamflow records including storm and flood, cost information, existing previous study reports. Most of collected data and information are arranged and stored in the data files which is a component of the data bank system. The details are discussed in Chapters III and XVI.

2.4.2 Hydrological analysis

Due to limited runoff information, available discharge at each potential site is processed by the average discharge and storage-draft/flow duration curves at the selected streamflow gauging stations, which are confirmed to be reliable through the

hydrological study. Besides, isohyetal map covering whole Luzon Island is prepared to estimate the average annual rainfall on the catchment of selected streamflow gauging stations and identified hydropower potential sites. The hydrological study are worked out to obtain:

(1) Isohyetal map,

(2) Determination of hydrological region,

(3) Selection of representative streamflow gauges and preparation of the storage-draft/flow duration curves,

(4) Evaporation and denudation rates to be applied, and

(5) Determination of flood regions and specific flood discharge.

The hydrological analysis is discussed in detail in Chapter IV.

2.4.3 Identification of hydropower sites

For all the schemes identified in the previous studies, the site identification is made as well as for newly identified sites in this study. The identified schemes are comprised of those classified into the Categories - 4 to - 6, which are described in Paragraph 2.2.1. Identification is made on the topographic maps of 1:50,000 scale.

Prior to the map study, the site location of each scheme previously identified is confirmed and adjusted according to topographic condition around the proposed site. Some schemes are discarded due to wrong and/or doubtful information. In this study, the scheme scale is limited over 5 MW as described in Paragraph 2.2.1. Several schemes are also discarded through the preliminary estimation of power output since those schemes are not expected to exploit hydropower potential over 5 MW.

The data extracted from the map are location, water levels to be specified, reservoir capacity, river cross section, waterway length, information on transmission line, access road

and other technical findings. It is discussed in Chapter VII on the identification of hydropower potential sites.

2.4.4 Cost study

Based on the cost information provided by several previous project reports, reference books and NPC, the cost formulae for each major component are formulated. The cost formulae used in this study are to be referred to Chapter IX.

2.4.5 Field reconnaissance

Prior to the establishment of hydropower site inventory, schemes in Categories - 4 to - 6 are visited for site reconnaissance as many as possible. The objective of reconnaissance are principally to confirm the site condition especially on geology. The findings by site reconnaissance are arranged in standardized form as one of the information to the inventory. The matter is described in Chapter X as well as an engineering assessment.

2.4.6 Power output calculation and preliminary cost estimate

Based on the hydrological and topographical data obtained through the studies precedingly described, power output calculation on the condition of individual scheme is conducted to get the following output information for all the identified schemes:

(1) Installed capacity (MW),

(2) Annual energy (GWh),

(3) Scheme feature and development alternatives.

Scheme with installed capacity of less 5 MW, which capacity was expected to be over 5 MW in the preliminary estimate, are discarded. The preliminary cost estimate for all the schemes identified excluding preliminarily discarded ones follows the power output calculation. The cost estimated consists of those for power development, transmission line and access road, including engineering and administration cost as well as

physical contingencies. The above calculations are conducted by application of cost formulae which were establised specifically based on the criteria for the preliminary estimate.

2.4.7 Inventory of hydropower sites

The project feature of hydropower schemes, successfully passed through the power output and cost calculation, are stored in the inventory of hydropower sites. The inventory is set up in the computer file to retrieve any information by several computer programs.

Based on the inventoried information, estimate of hydorpower potential such as those by region or development type is made as described in Chapter XI.

2.4.8 First screening evaluation

The first screening evaluation aims at to select promising projects out of schemes identified and stored in the inventory of hydropower sites. The evaluation of each hydropower scheme is made in two steps. Firstly the index of construction cost per annual energy is compared with those of competitive alternative thermal plants such as oil-thermal, coal-thermal and geothermal. Secondly the optimum scale of each scheme is checked in terms of (B-C) by changing plant factors. At this evaluation, schemes which have apparent technical problems for implementation are discarded.

2.5 Preparation of Promising Hydropower Project Catalogue and Master Action Program

For the selected hydropower projects passed through the first screening evaluation, the second screening evaluation is tried. After then the priority raking study of hydropower projects is made to propose the development master action program.

2.5.1 Data preparation

Data required for this study stage are:

- data on flood and storm,
- data on site conditions such as geology, accessibility, land use, etc.
- cost data of end-1985 price level, and
- data on power demand forecast and future power expansion plan.

Those data are collected, analysed and arranged in the data bank system.

2.5.2 Hydrological analysis

The hydrological analysis principally made in this stage is to datermine the spillway capacity. The study includes flood discharge analysis and flood routing analysis. The spillway capacity is datermined according to the degree of effect of flood regulation by the catchment area and reservoir storage capacity.

2.5.3 Field reconnaissance and basic layout plan

Prior to the preparation of basic layout plan of each selected scheme, the second field reconnaissance are attempted.

(1) Field reconnaissance

The second field reconnaissance are carried out basically for all the selected hydropower sites which have passed the first screening evaluation, however, some sites hardly be visited due to security problems. The field reconnaissance has purposes to confirm and find site condition including geological one, accessibility, land use and so on.

(2) Preparation of basic layout plan

Firstly, the basic layout plan is prepared for each selected scheme based on the optimized development plan formulated in the first screening stage. Findings are also incorporated to the plan formulation, which findings are obtained through the above site reconnaissance. Some alternative development plan on major structures are considered in the layout plan, such as earthfill type or concrete type dams, whereas only rockfill type dam is considered in the preliminary layout for the equal comparison of first screening stage.

Secondly, it is tried to find the optimum development plan in one river basin, in which several schemes are considered independently. Such river basins are Abra, Abulog, Chico, Agno and Agos. The optimum scale of each scheme is determined taking an effect of regulated flow from upstream reservoirs into consideration.

2.5.4 2nd cost estimate

The second cost estimate is carried out using data on work quantity from the basic layout drawing and cost data such as unit prices on each major work item. This cost estimate is more detailed one than the preliminary one which was estimated by using cost formulae. The total construction cost is estimated by summing up costs for each major work item, and also engineering and administration cost, and physical contingency.

Updating of the construction costs for F/S completed projects is made referring to the foreign exchange rate and the wholesale price index. Price level to be considered is set as of end-1985.

2.5.5 Promising hydropower project catalogue

Project features of the schemes examined in Sub-sections 2.5.3 and 2.5.4 as well as those of scheme of Category - 3 are arranged in the computer file as the promising hydropower

project catalogue. All of major information obtained up to the second cost estimate are stored in the catalogue.

The catalogue file provides all information through individual retrieval program and to the succeeding priority ranking study.

2.5.6 2nd screening evaluation

For the selected schemes, the second screening evaluation is tried basically applying an index of the annual energy cost. Besides above evaluation, each scheme is reviewed in technical aspects of geological condition, land acquisition and so forth, more in detail.

2.5.7 System expansion plan and alternative power source

The target year of hydropower development in this study is assumed to be the year 2005. The power demand forecast up to the year 2005 is basically made based on the projection framed by NPC, data prepared by NEDA and other relevant data.

The alternative power sources to be incorporated are basically coal-fired thermal plant and geothermal plant. As to oil-fired thermal plant, existing plants are considered to retire with NPC's retirement schedule.

2.5.8 Priority ranking study and master action program

Selected promising projects by the second screening are nominated as candidates for the priority ranking study. The priority ranking analysis is tried to get a least cost sequence of well-balanced power development up to the year of 2005 applying two alternatives, geothermal and coal-fired thermal, aiming minimum cost development.

The development master action program is proposed with investment and installation plans taking account of alternatives applied in the priority ranking study.

2.6 Data Bank System

Data bank system usually designed consists of the source and processed data files and appropriate functions of data retrieval components. Not only computerized data, but also documents are included in the system with a well-ordered arrangement in another way.

The data bank system established in this study consists of the above components and analytical and computing functions as well as the Inventory and Catalogue. Thus, it could be said that the system is a data processing and analysis system for hydropower development.

Updating system is introduced to get a latest information at any time from the above data bank system. For this purpose, updating of basic data and computer processing are expected to be made in the future by NPC, in accordance with the flow chart showing the updating procedure to be arranged in this study.

III. BASIC STUDY DATA

3.1 Previous Study on Hydropower Development

3.1.1 Exisitng plants

Up to date, 11 hydropower plants in total have been constructed in the Luzon Island, and all of those plants are still under operation. The oldest one is "Caliraya" hydropower plant commissioned in 1945 and the latest, "Magat" and "Kalayaan" hydropower plants in 1983 as shown below. Inventory data for those plants were collected as much as possible, however, some data are lacking. Inventory data collected are compiled in APPENDIX C.

Name of Power Station	Number of Unit	Installed Capacity (MW)	Commis-sion Year	No. of Water Resources Region
1. Caliraya	4	32	1945	IV
2. Botocan	3	17	1948	"
3. Ambuklao	3	75	1956	III
4. Buhi-Barit	1	1.8	1957	V
5. Cawayan	1	0.4	1959	"
6. Binga	4	100	1960	III
7. Angat	8	228	1967	"
8. Pantabangan	2	100	1977	"
9. Masiway	1	12	1981	"
10. Magat	4	360	1983	II
11. Kalayaan1/	2	300	1983	IV
Total:	33	1,226		

1/: pumped storage

3.1.2 Committed plants

According to the latest NPC's power development program (May, 1986), the following hydropower plants are planned to be

commissioned by the year of 1994, and 1995, respectively. Inventory data for those plants are also compiled in APPENDIX C.

Name of Power Station	Number of Unit	Installed Capacity (MW)	Commission Year	No. of Water Resources Region
1. Panty	2	23	1993	IV
2. Casecnan[1/]	6	268	1995	II/III
Total:	8	291		

1/: It includes the extension of existing Pantabangan (2 nos. x 50 MW) and Masiway (1 no. x 12 MW) power plants.

3.1.3 Feasibility study

Feasibility studies for the promising hydropower potential sites have been made by foreign consultants from time to time, the total number of which is counted to be 10. Feasibility study reports for those schemes have been collected and reviewed to obtain the main features and the construction cost of each project. Inventory data collected are also compiled in APPENDIX C.

Name of Scheme	Installed Capacity (MW)	Study Year	No. of Water Resources Region
1. Apayao-Abulog	600	1979	II
2. San Roque	390	"	III
3. Palsiguan	42	1980	I
4. Chico-4	360	"	II
5. Diduyon	352	"	"
6. Agos	140	"	IV
7. Tina-Gasgas-Cura	5.6	1982	I
8. Matuno	180	1983	II
9. Balog-Balog	33	"	III
10. Binongan	175	1984	I
Total:	2,277.6		

3.1.4 Pre-feasibility study

The hydropower potential sites for which the prefeasibility study has been made are many, however, study level varies project by project. Project information obtained from collected reports were reviewed for reference as such schemes are to be studied again this time together with another named and newly identified hydropower potential sites. Until now, the pre-feasibility study has been made for the following schemes.

Water Resources Region	Name of Scheme Pre-F/S Completed
I - ILOCOS	Tineg-1, Tineg-2, Tineg-3, Malanas, Eteb, Luya, Upper Bucnit, Suysuyan, Bucnit, Dayapan, Taping, Caliaban, Naina, Naglibacan, Supo, Amluagan, Upper Boyan, Magyepyep, Tibunec, Toqueng, Labong
II - CAGAYAN VALLEY	Sisiritan, Nababalayan, Tamauini-1 Naneng, Sadanga, Bantay, Ballasang, Dabba, Agbulu, Aoan, Tabuk, Pastor, Basao, Maliano, Cabingatan
III - CENTRAL LUZON	Kalipkip, Lubas, Agopop, Sta. Rosa, Tayum, Cabangan, Balintingon, Tabu, Botolan, Villa Botolan, Camiling-2, Lubingan, Puncat Mt., Baler, Umiray
IV - SOUTHERN TAGALOG	Wawa, Rosario, Pagbilao, Daraitan, Kanan
V - BICOL	(None)

3.1.5 Water resources inventory

National Water Resources Council (NWRC) issued a report titled "SURVEY/INVENTORY ON WATER IMPOUNDING RESERVOIRS" in 1978, in which significant information on the status and prospects of water impounding projects in the Philippines are

well compiled. Relevant data for the hydropower potentials study of this time were extracted and used for the study. Hydropower potential sites identified in this report are referred to as "Named Power Project Site" in the study, and are listed in Table .3.1.

3.2 Topography and Geology

3.2.1 Topographic maps

Topographic maps available for the study are shown below and their indices are presented in Fig. 3.1.

Scale	Nos. of available maps	Issued by:
1:1,000,000	1	BCGS
1:500,000	2	DMA-AC
1:250,000	15	BCGS
1:50,000	87 x 4	BCGS

Rem: BCGS : Bureau of Coast & Geodetic Survey
DMA-AC : Defence Mapping Agency Aerospace Center

The topogtaphic maps shown above are being kept and used by NPC and the Study Team. The maps available were almost useful for the study. Road maps of 1:1,000,000 scale and of 1:250,000 scale were also used for the study, mainly for the study of access road to each scheme site.

3.2.2 Geological maps and aerial photographs

The geological information available consists mainly of the geological maps (scale 1:250,000 and 1:1,000,000) prepared by Bureau of Mines and Geo-Science (BMG), Manila. And also some aerial photographs are available in the Abra, Abulog, Agos and Casecnan river basins. These available lists are shown in Figs. 3.2 and 3.3, Tables 3.2 and 3.3, respectively.

3.2.3 Previous geological studies

Geological investigation of the Luzon Island was carried out by the BMG, and many private mining or oil companies.

During the past several years, engineering geological studies for dam projects were carried out in feasibility study or pre-feasibility study level on some parts of the Luzon Island, particularly in the river basins of Agno, Abra, Magat, Chico, Cagayan, and Agos.

Identified geological assessment study for the dam sites in the Cahayan Valley was done by MPWH and Philtech in 1983, where most named sites in Region II are included. And other identified geological assessment study for the hydropower potential study in the Luzon Island was done by NPC and Lahmeyer International in 1977. Both studies were carried out in surface geological survey only and no subsurface survey was carried out. The latter study involved over-flight inspection due to the limited time and restricted access.

3.2.4 Regional physiography of the Luzon Island

The Luzon Island lies between 119°45' to 124°13' east longitude and 12°30' to 18°45' north latitude.

It is bounded on the north by Babuyan Channel, on the south by the Sibuyan Sea, on the west by the South China Sea, and on the east by the Philippine Sea. The total land area of the Luzon Island is about 104,700 square kilometers. It can be divided into three physiographic provinces, namely: 1) Eastern physiographic province, 2) Central physiographic province, and 3) Western physiographic province as shown in Fig. 3.4.

(1) Eastern physiographic province

Eastern physiographic province is composed of physiographic high belt bounded on the east by the Luzon Trench and the Philippine Trench. On the west, it is bounded by lowland and trough. This province is divided into three subprovinces:

Northern Sierra Madre, Southern Sierra Madre, and the Bicol Peninsula.

The Northern Sierra Madre subprovince is composed of the numerous ranges which lie between and along the East Luzon Coast and the Cagayan Valley. Its length of more than 300 km trends roughly north-south. The main drainage is the northerly flowing Cagayan River and its tributaries. The Miocene limestone is exposed at mostly the western portion of Northern Sierra Madre along the Cagayan River, where is made up of steep cliff and gorge.

The Southern Sierra Madre is characterized by a rather low mountain range compared with the Northern Sierra Madre. It is bounded on the north by the Philippine Fault, on the west by the Luzon Central Plain, on the east by the Philippine Sea, and on the south by the Lanon Bay. The major drainage system of the area consists of the Agos River and its tributaries.

The Bicol Peninsula forms southeastern part of Luzon Island. Several cone-shaped Quaternary volcanos are along the eastern part. Mt. Mayon (2469 m), and active composite volcano, is the most prominent landmark in this area. The main stream system of this area consists of the Bicol River and its tributaries.

(2) Central physiographic province.

Central physiographic province is composed of Cordillera, mountains, plains, and uplands between East and West province. It is divided into six subprovinces: Luzon Central Cordillera, Cagayan Valley, Caraballo Mountains, Luzon Central Plain, Southwest Luzon Uplands, and Bondoc Peninsula.

The Luzon Central Cordillera extends from Kalinga Apayao Province to the northern border of Caraballo Mountains. The range is composed of the Cretaceous-Paleocene rocks and Neocene intrusive clastic and volcanic rocks which form the 320 km long and 85 km wide mountains regions. The main drainage of the Cordillera are the Agno, Magat, Chico, Abulog, and Abra Rivers.

The Cagayan Valley is dominated by a broad expanse of alluvial plain covering the area of about 240 km long and 85 km wide which is the widest in the Philippines. The Cagayan Valley is drained principally by the Cagayan, Ilagan, Chico, and Magat Rivers. The upstream reaches of these rivers are characterized by rapids and waterfalls.

The Caraballo Mountains separate the Cagayan Valley from the Luzon Central Plain. The headwater originates at Caraballo Mountains, and it flows northward through the Cagayan Valley, and then empties into the Babuyan Channel.

The Luzon Central Plain, between Caraballo Mountains, Zambales Range and Southern Sierra Madre, is the largest plain in the Philippines. The plain is drained by three main rivers and their tributaties. The Agno river is flowing the northern part of the plain and emptying into the Lingayen Gulf. The Pampanga and Angat Rivers are flowing the sluthern part of the plain and emptying into the Manila Bay.

Southwest Luzon Uplands locate southern part of the Luzon Central Plain. The Tagaytay Ridge, the prominent range of hills in the Southwest Luzon Uplands lies on the northern part. The most prominent lakes in the Philippines are the Laguna de Bay and the Taal Lake located in the southern part of uplands. The Laguna de Bay is drained by the Pasig River which empties into the Manila Bay. The Taal Lake is drained by the Pansipit River which empties into the Balayan Bay. The famous Taal volcano is located at the center of Taal Lake.

The Bondoc Peninsula extends from the Laoan Bay to the Sibuyan Sea. No big scale srainage system exists in the peninsula.

(3) Western physiographic province

Western physiographic province is composed of ridges and lowland which is parallel to the Manila Trench. The province is subdivided into the Ilocos lowland and Zambales Range.

Ilocos lowland is locating along western flank of the Luzon Central Cordillera, which streches from south of Vigan to Posaleg. This lowland consists of coastal plain in the lower foot hills of the Luzon Central Cordillera.

Zambales Range is about 95 km long 40 km wide at its widest, existing from the Lingayen Gulf on north to the Bataan Peninsula on the south. The range consists of high peak (2,037 m) and rugged ridges. The northeastern part of range is bordered by a fault which merges with the Luzon Central Plain.

3.2.5 Regional geology of the Luzon Island

The geology of the Luzon Island is briefly discussed by BMG in "Geology and Mineral Resources of the Philippines, vol. 1, Geology (1982)". This book was well referred to this study.

Regional geology of the Luzon Island as shown in the geologic map (Fig. 3.5) are adopted from "Geology and Mineral Resources of the Philippine and Geologic Map" (1:1,000,000 and 1:2,500,000) published by BMG.

The stratigraphy of the Luzon Island consists of broad time rock categories which were previously recognized by BMG and earlier investigators. The stratigraphy is outlined in Table 3.4. The rock formations in the Luzon Island are represented by time rock units ranging in age from Cretaceous to Holocene.

(1) Sedimentary Rocks

"Cretaceous Sedimentary Rocks": (k)

Extensive, transgressive graywacke-shale sequence intercalated with spilites. The rocks underlie at the center part of Southern Sierra Madre.

"Paleocene to Oligocene Sedimentary Rocks": (Pg)

Rocks of this unit are limited in exposure at Southern Sierra Madre, Ilocos lowland and near the Caraballo Mountains.

"Early to Middle Miocene Sedimentary Rocks": (N1)

Rocks of this unit consist of the most extensive rocks which fringe the eastern and western flanks of the Central cordillera along its entire extent. Representative rock formation by this time rock unit are the Zigzag Formation in the Central Cordillera.

"Upper Miocene Sedimentary Rocks": (N2)

The upper Miocene sedimentary rocks are exposed at relatively limited area along a narrow, irregular belt fringing the western falnks of Sierra Madre (Cabangan and Callao Formation), the eastern and western flanks of Luzon Central Cordillera (Klodyke and Kenon Formation) and also flanks of Zambales Range (Sta. Cruz Formation and Zambales Formation).

"Pliocene to Pleistocene Sedimentary Rocks": (NQ)

This time rock unit consists of sedimentary formation in the Cagayan Valley (Ilagan Formation).

the Laoag Formation is composed of sandstone and interbedded siltstone and claystone with occasional limestone in Ilocos lowland. Recent terrace gravel is disposed on capping Ilocos lowland. Recent terrace gravel is disposed on cappng ridges in Zambales and western Luzon Central Plain.

The limestone is thickly bedded to massive coralline, whito to pink and cliff-forming in Southern Bicol Peninsula (Ligao Formation).

"Quaternary Alluvium": (Q)

Quaternary alluvium thickly and widely cover the sequence of Miocene to Pliocene rocks in the Luzon Central Plain.

(2) Volcanic Rocks

"Cretaceous Volcanic Rocks": (K)

The Cretaceous Volcanic Rock consists of metavolcanics essentially spilitic basic flows, usually intercalated with graywackes. And it is exposed on western part of South Sierra Madre.

"Undifferentiated Cretaceous to Paleocene": (Kpq)

Rocks belonging to this unit are the most widespread in the Luzon Central Cordillera and Caraballo Mountains. They consists of folded and faulted alteration of basalt-spilite, andesite-keratopyre, dacite and diabase (The Caraballo and Licuan Group). These sequences of rocks are intruded by the diorite complex along the western flank of Sierra Madre.

"Paleocene to Oligocene Volcanic Rocks": (Pq)

Essentially keratophyre and andesite flows often with pyroclastics and chart of volcanic origin. Limited dacite and andesite flow and dikes, generally intercalated with and/or intrude Eocene clastics. This time rock unit is exposed on small area of the Bicol Peninsula.

"Oligocene-Miocene Volcanic Rocks": (N1)

This time rock unit is composed of mostly submarine andesite and/or basalt flows, intercalated with pyroclastics and clastic sedimentary rocks and/or reef limestone lenses. A limited extent of the rocks was noted near Cagua volcano in northern Sierra Madre and the Ragay Formation consists of andesitic volcanic flows in the Southern Bicol Peninsula.

"Upper Miocene-Pliocene Volcanic Rocks": (N2)

A limited extent of the rocks was noted near Iriga at the Caramoan Peninsula. The rock consists of massive and porphyritic dacite.

"Pliocene, Pleistocene and Recent Volcanic Deposits": (NQ)

This time rock unit formed volcanic plain and volcanic piedmont deposits. And the rock consists of volcanic cones generally phroxene-andesite and dacite and/or andesitic plugs. The formation is the most extensive, especially in the Bataan Peninsula and Luzon Southeast Uplands.

"Quaternary Volcanics": (Q)

Active volcanos are Mt. Taal in Luzon Southeast Uplands and Mt. Mayon in the Bicol Peninsula. Non-active cones (generally pyroxene andesite) as isolated cone shaped plugs of andesitic to dacitic composition are disposed mainly along fractures in the Luzon Central Cordillera, southern parts of Zambales Range, and in the Luzon Central Plain such as Mt. Arayat.

Intrusive Rocks (‡ ‡)

The intrusive rock consists of quartz diorite, granodiorite, andesite porphyry and its related phases.

The diorite complex is laterally exposed in a NE-SW orientation and largely intruded the Cretaceous-Paleocene and early to middle Miocene rocks in the Luzon Central Cordillera Mountains.

Basic to Ultrabasic Rock (¬┐¬)

The ultramafic complex underlying the eastern seaboard of Isabela Province in northern Sierra Madre consists predominantly of pyroxene periodotite with pyroxenite dunite and their serpentinized equivalents. Undifferentiated ultramafic and mafic plutonic rocks, predominantly periodotite associated with late gabbro and/or diabase dikes, are exposed in the Zambales Range.

Metamorphic Rocks (⌒≈⌒)

This time rock unit is defined a relatively narrow, and irregular belt in the eastern part of Isabela Province in

Northern Sierra Madre. The belt trending almost north-south is exposed from Dinapiqui Point at the southern boundary of Isabela Province and is continuously traceable up north to Palanan. The rock formation consists of undifferentiated schist and quartzite.

(3) Structures

Earthquakes and bolcanic activety, both very prevalent in the Philippines, are the most perceptible evidences of on-going processes of structural development. They are of important concern in Philippine tectonics. General geologic structure of the Luzon Island is shown in Fig. 3.4.

Three major trenches surrounding Luzon Island are Philippine Trench to the southeast of Bicol Peninsula, East Luzon Trench at the sea of east coast of northern Luzon, and Manila Trench at the sea of west coast of the Luzon Island.

The Philippine Trench extends from east of Bicol Peninsula at about 15°N latitude to east of Halmahera at about 4°N latitude. It is 1,400 km long with an average width of 60 km and an average depth of 8,000 m. The Trench is the narrowest and the deepest at east of Mindanao, where it exceeds of 10,000 m in depth. Seismic activity has mostly occurred in the zone between the Philippine Trench and the Philippine Fault. East Luzon Trench is a flat-floored depression, the northern extension of the Philippine Trench. It extends about 250 km from 17°N and 123°E to 15°N and 122°E, with 25 km wide in average and about 5,000 m deep or more. Earthquake epicenters are concentrated along the west of East Luzon Trench. Manila Trench is situated about 100 km from the west coast of the Luzon Island. It extends from the Bassy Channel to the Mindoro Island with about 100 km long and 30 km to 70 km wide. Its deepest part is about 5,000 m below sea level and about 1,000 m below the rim of the South China Sea abyssal plain. This trench system has east subduction, its beginning somewhere between the Late Oigocene and Middle Miocene. The epicenters of Manila Trench are concentrated near the Mindanao Island.