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EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA · NICARAGUA

NATIONAL POWER STUDY
1978 - 1988

PREFEASIBILITY INVESTIGATION

PHASE II REPORT

INTRODUCTION
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS
CHAPTER I, HYDROLOGY AND METEOROLOGY
CHAPTER II, GEOLOGY
CHAPTER III, TECHNICAL EVALUATION
CHAPTER IV, ASSUMPTIONS AND CRITERIA
CHAPTER V, GENERATION EXPANSION PLANS
CHAPTER VI, POWER PURCHASES VIA INTERCONNECTIONS
CHAPTER VII, TRANSMISSION SYSTEM EXPANSION PLANS
CHAPTER VIII, ECONOMIC EVALUATION

IECO
INTERNATIONAL ENGINEERING COMPANY, INC.
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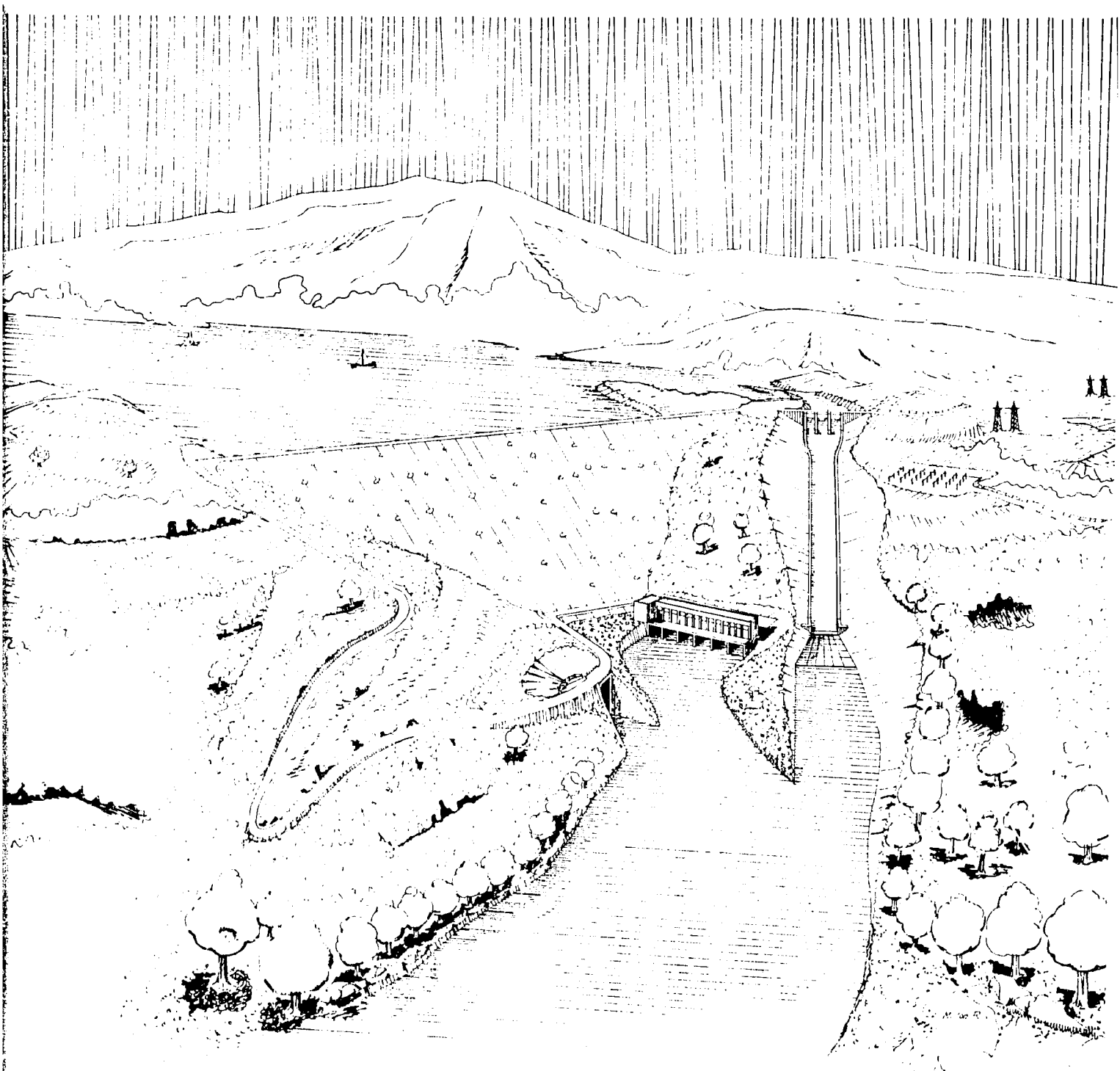
MANAGUA D.N. NICARAGUA

AUGUST 1975



PROYECTO COPALAR PRESA ALTA
COPALAR PROJECT HIGH DAM

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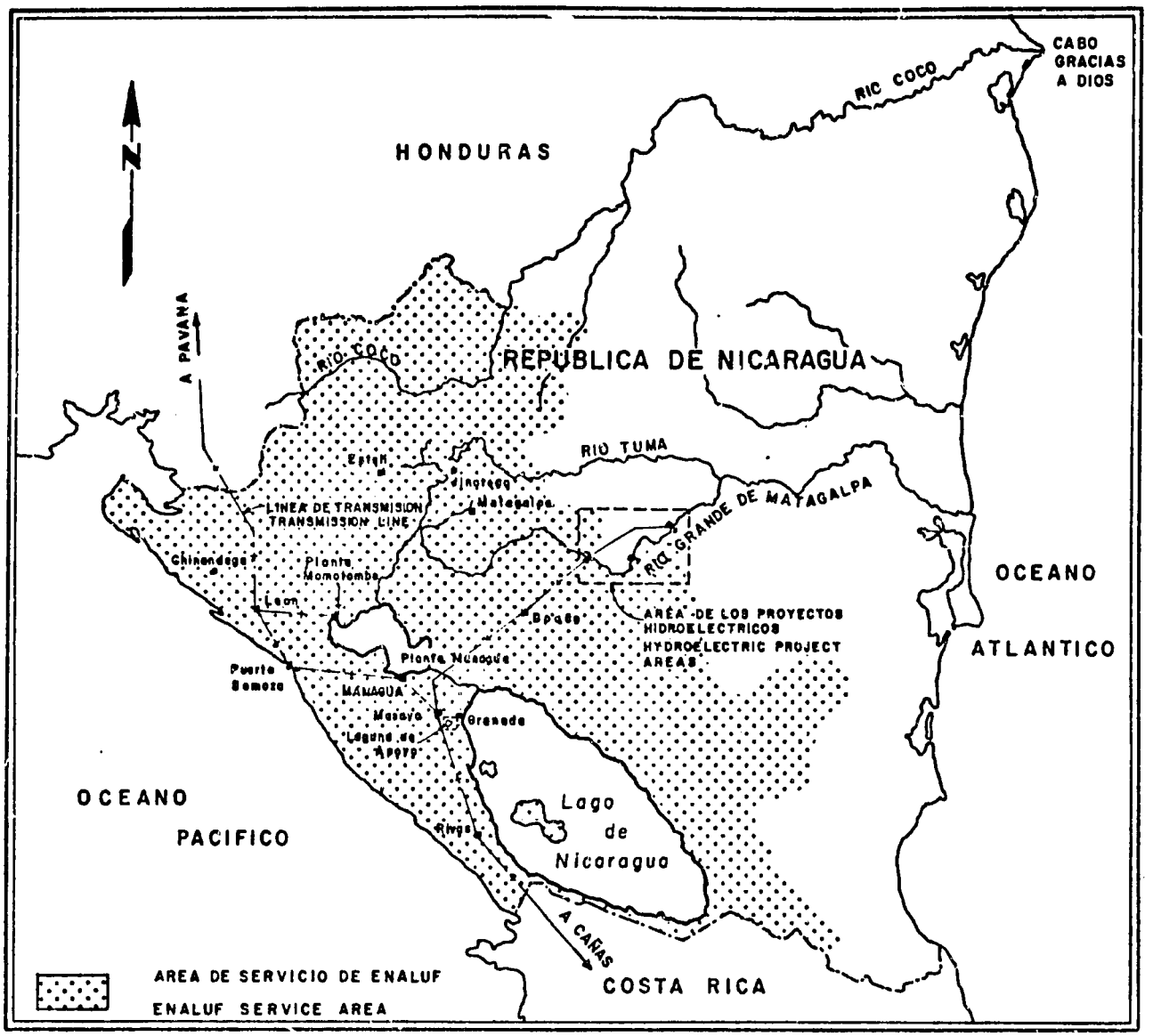
ESTUDIO DE POTENCIA PARA NICARAGUA
NICARAGUA POWER STUDY
1978 - 1988



MAPA DE UBICACION - Location Map

Desde el presente hasta el fin del año 1990, el crecimiento de la economía hará que la demanda de energía se quintuplique. Este informe presenta los planes para el dessarrollo futuro del sistema de ENALUF, que permitan extender los beneficios de la electrificación a los habitantes de Nicaragua, a todo lo largo y lo ancho del territorio de servicio del Sistema Interconectado Nacional.

From the present to the end of the year 1990, the growth of the economy will increase the demand for power five-fold. This report presents plans for the future development of the ENALUF power system, to enable the benefits of electrification to be extended to the Nicaraguan people, over the length and breadth of the service territory of the National Interconnected System.

P R O L O G O

Este informe ha sido preparado en ambos idiomas, español e inglés. Originalmente, fue escrito en inglés y luego traducido al español, que se considera la versión oficial del informe. Se hicieron todos los esfuerzos posibles con el objeto de que ambos textos fueran idénticos, sin embargo, durante la traducción se encontró que era conveniente y necesario hacer cambios menores en el formato, el arreglo y la terminología en parte del texto. Se dió especial énfasis a la traducción de la terminología técnica en relación a sus equivalencias al español que fuese mejor aceptado y más usual en Nicaragua; es posible que ésto no se haya logrado a cabalidad, debido a que varias traducciones tienen esencialmente el mismo significado, pero sin embargo varían un poco en su uso actual. Se espera, sin embargo, que los cambios hechos y las expresiones técnicas usadas no alteren en forma alguna el significado o intención del texto en español.

F O R E W O R D

This report has been prepared in both the Spanish and English languages. It was originally written in English and translated into Spanish, which is considered to be official version of this report. Every possible effort has been exerted to make both texts identical; however, it was found expedient and necessary to make minor changes to the format, arrangement and terminology of some of the text material during the translation. Special emphasis was placed on translating technical terms into the Spanish equivalents which are most acceptable to and frequently used in Nicaragua. This may not have been accomplished in all cases because of several translations that have essentially the same meaning, but vary slightly in actual usage. Nevertheless, it is intended that none of the changes made or technical expressions used alter the meaning and intent of the Spanish text in any regards.

NATIONAL POWER STUDY; 1978-1988

PHASE II REPORT DIRECTORY

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INTRODUCCION

INTRODUCTION

GENERAL

This report contains the results of an intensive technical and economic evaluation at the prefeasibility level, of the power capacity and energy requirements of the ENALUF National Interconnected System, for the decade of development from 1978 to 1988 and the most economical system expansion to satisfy the growth potential. The investigation was subdivided into two independent, but interrelated phases. Phase I comprised the preparation of a load forecast for the development decade, the investigation of numerous hydroelectric projects that could be considered for supplying the forecasted load and the selection of the best and most economical projects from those studied for further investigation during Phase II. The Phase I work was performed between June 1974 and March 1975.

The Phase II work comprised a more thorough investigation of the hydroelectric projects selected during Phase I and the integration of those projects into a comprehensive system plan which was formulated during Phase II. The Phase II system planning consisted of the technical and economical evaluation of the generation and transmission facilities required for expansion of the ENALUF system, including transmission interconnection with the ENEE system of Honduras and the ICE system of Costa Rica. This phase of the work was performed between April and August 1975.

This final report presents the results of the Phase II technical and economic prefeasibility study. It contains brief discussions of the Phase I investigations, descriptions of the work performed during Phase II and recommendations for future investigations. It establishes the Copalar Project as the most technically and economically feasible of all of the hydroelectric projects studied and sets it in context of a fully developed plan for the utilization of indigenous resources in Central America.

AUTHORITY

The authority for the performance of the work is contained in the Contract dated February 13, 1974 between Empresa Nacional de Luz y Fuerza (ENALUF) and International Engineering Company, Inc. (IECO). ENALUF was created under the laws of Nicaragua on October 14, 1954 as an autonomous agency of the Republic. International Engineering Company Inc. is a private consulting engineering firm chartered under the laws of the State of Nevada in the United States of America.

Financing for this study was provided by the United States of America, Agency for International Development (U.S. AID), from Loan Program AID No.524-L-024 between the Government of Nicaragua and U.S. AID. The Letter of Credit under which the work was performed was issued on June 14, 1974 and actual work began on June 24, 1974 upon receipt of the formal Notice to Proceed.

SCOPE

The overall scope of the study includes a forecast of power demand and energy requirements for the National Interconnected System over the period between 1978 and 1988 and the determination of the most economical expansion plan to supply long-range power system growth. It emphasizes the importance of utilizing indigenous hydroelectric and geothermal power to the maximum possible extent, together with power transfers over transmission interconnections with the power systems of Honduras and Costa Rica.

The specific scope of the Phase I investigation included the following work:

I.1 Study of national economic trends, together with load statistics pertaining to the ENALUF service area of the National Interconnected System, to prepare a range of high, average and low energy projections which could be related to a definitive load forecast for the 1978-1988 development period.

I.2 Selective analysis of all possible hydroelectric projects sites over a 220 kilometer reach of the Rio Grande de Matagalpa, between the confluence of Quebrada el Jicaro and the Rio Okawas, together with a 62 kilometer reach of the Rio Coco between Cano Namasli and Quebrada El Corozal.

I.3 Review of existing studies of the Nicaragua Project and Rafael Mora site on the Rio Viejo.

I.4 Study of a pumped-storage project at Laguna de Apoyo.

I.5 Selection of the most promising hydroelectric projects and alternative river basin developments for study during Phase II.

The specific scope of the Phase II investigation includes the following:

II.1 Detailed study of the most promising hydroelectric sites selected during Phase I.

II.2 Preparation of a long-range expansion program for the generation and transmission facilities of the ENALUF system, including interconnections with the adjacent systems of Honduras and Costa Rica.

II.3 Determination of the most economical power system expansion plan, using the present worth method of analysis.

II.4 Selection of the most favorable hydroelectric project for feasibility study and preparation of a program of geological investigations that must be performed early in the first phase of the feasibility study.

All parts of the foregoing scope of services have been fully investigated during the performance of the work.

ACKNOWLEDGEMENTS

International Engineering Company, Inc. wishes to express sincere appreciation for the valuable cooperation and assistance given by individuals and organizations during the performance of this investigation. Without such help, particularly that received from numerous Nicaraguan organizations, it would have been virtually impossible to complete this study in its present form within the available time.

The invaluable assistance provided by the officials and staff members of the Empresa Nacional de Luz y Fuerza (ENALUF) is gratefully acknowledged. Their cooperation, assistance, advice and guidance throughout the performance of this investigation contributed significantly to the successful completion of a highly important study.

In addition, sincere appreciation is expressed for the generous contribution to the work made by the Banco Central de Nicaragua (Central Bank of Nicaragua), Instituto Centroamericano de Administración de Empresas (INCAE), Naciones Unidas Proyecto Hidrometeorologico de Nicaragua and Agency for International Development (U.S. AID).

It is virtually impossible to include the names of all organizations and individuals who gave generously of their time and effort during the course of this study. However, we wish to express our deepest gratitude to the ENALUF executive, management and technical personnel listed below, who contributed so extensively to the success of this project.

Dr. Luis Manuel Debayle Sacasa	Executive President
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We also wish to express our regrets to anyone who cooperated in the work but is inadvertently excluded from the list. We assure them that their contributions are equally well appreciated as those whose names are mentioned.

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CONCLUSIONS AND RECOMMENDATIONS

S.1 SYNOPSIS

The results of the prefeasibility study of hydroelectric projects within a general expansion plan for the National Interconnected System over the period 1978 to 1988, point to the definitive selection of the Copalar Project on the Rio Grande de Matagalpa, as the logical choice for in-depth study at the feasibility level. As careful scheduling to take full advantage of seasonal conditions requires the continuation of field surveys and exploration drilling immediately following the 1975 wet season, it is recommended that the feasibility study be started in November of this year.

The selection of Copalar as the most promising site for hydroelectric power development has been based on detailed technical and economic evaluation of alternative basin developments, with principal long-range alternatives concentrated on either a high dam at the Copalar site regulated from an upstream development at Paso Real or a low dam at Copalar with successive regulation by two upstream developments at El Carmen and Paso Real. These two main alternatives were termed the two and three dam developments, these being evaluated at the system level to determine the most economic basic plan for independent power system expansion. The two dam scheme was selected largely on the basis of the energy differential between the high and low dams at the Copalar site, which greatly affected the dispatch of supporting thermal plant on the ENALUF system. When this energy differential is analyzed in terms of the equivalent oil-fired generation which is displaced by the additional hydroelectric energy from the High Dam at Copalar, the cost of the oil displaced over the 50-year life of the facility, at current posted oil prices, effective October 1, 1975, is sufficient to cover 106 percent of the total estimated capital investment required for the entire Copalar Project.

The following summary of costs, power capacity and energy values is relevant to the High Dam at the Copalar site, these values being stated at 1975 cost levels.

Capacity and Energy:	Total Construction Cost:	Total Capital Cost:
Number of Units - 6 x 55 MW	$203,382,000	$273,672,000
Installed Capacity - 330 MW	Unit Cost - $616/kw	Unit Cost - $829/kw
Annual Generation - 1418 GWH	Unit Cost - 14.3 Mills/kwh	Unit Cost - 19.3 Mills/kwh

The annual generation of 1418 GWH of electrical energy is equivalent to an annual fuel-oil consumption for thermal generation of 2.8 million gallons of Bunker C. At current posted prices for fuel oil, the undiscounted payout period for the project resulting from the displacement of equivalent fuel oil would be 7.6 years, or 15 percent of the 50-year service life.

The final recommendation for interconnected system expansion over the decade of development ending in 1988, is for the implementation of the Copalar Project in conjunction with the purchase of firm power from Honduras and off-peak energy from Costa Rica. The High Dam at Copalar should be developed as a single source, augmented by importations of hydroelectric energy from the ENEE and ICE systems.

The utilization of the indigenous resources of the region for utility system supply will require that an alternative use be found for existing thermal plant and the committed units at the new Puerto Somoza Thermal Plant. A proposal for the establishment of an Energy Center at Point Tiscucu for supply to a fertilizer process plant and industrial complex is contained in Section S.5 of this Summary.

S.2 HYDROELECTRIC PROJECT EVALUATION FOR RIO GRANDE DE MATAGALPA

S.2.1 PROJECTS AND RIVER BASIN DEVELOPMENTS

The hydroelectric projects selected from the Phase I investigation for further analysis during Phase II include the Copalar High Dam Project, Copalar Low Dam Project, El Carmen Project and Paso Real Project on the Rio Grande de Matagalpa. These projects were investigated individually and later combined into alternative river basin developments; one consisting of two dams and the other consisting of three dams. The Copalar High Dam and Paso Real comprise the two dam alternative and Copalar Low Dam, El Carmen and Paso Real comprise the three dam alternative. Paso Real is the same for both alternatives. The two alternatives were analyzed because of the different investment schedules that apply to each and because of a topographic uncertainty that could limit the height of the Copalar Dam. The retention of both alternatives for the Phase II evaluation assures that a suitable solution is available regardless of the outcome of the topographic uncertainty. The two dam alternative has the higher total investment cost and requires that larger capital investments be made at an earlier date than the three dam alternative. However, the installed capacity and energy generated by the two dam solution is considerably more than that of the three dam solution and justifies the larger and earlier capital investments. The economic comparisons of these alternatives are discussed in Section 8.2 of Chapter VIII.

A pumped-storage project at Laguna de Apoyo was also included in the Phase II investigation, this being one of the projects recommended in Phase I. This was done in recognition of the possible need for a source of peak power generation relatively near Managua, the major load center. However, the seismic, geologic, volcanic and environmental problems at this site are of such a magnitude that it was eliminated from further consideration and is not discussed further in this summary.

S.2.2 HYDROLOGY AND METEOROLOGY

Project hydrology was investigated during Phase I for all projects considered at that time. The Phase II investigation concentrated on the hydrological and meteorological conditions of the Rio Grande de Matagalpa basin. All previous work was thoroughly reviewed and updated. The discharges were revised to include additional data that were collected since the Phase I study was completed. Inflows to the reservoirs were estimated for the construction flood and for spillway design. This data was used in establishing the size and capacity of the project facilities.

The data available during this study was sufficient for this level of prefeasibility investigation; however, additional data and studies are required during the feasibility study and final project design. Discharge records must be updated to incorporate the latest data available and every possible means must be investigated for extending the existing 11-year record at the Paiwas gage. More frequent and accurate discharge measurements must be made, staff-gage readings must be made more frequently and recording gages must be more strictly maintained and observed. Additional stream gaging stations must be installed nearer the proposed damsites to more accurately determine the discharges and water level variations for use in subsequent design of project facilities. Construction flood estimates must be improved and firmer estimates made of the spillway design floods based on additional data and studies.

S.2.3 GEOLOGY

Surface geology was inspected at each site on the Rio Grande de Matagalpa and at Laguna de Apoyo. Surface geology maps were prepared and evaluation made of subsurface conditions. Nothing detrimental was found during geological investigations to preclude construction at the proposed sites.

The availability of construction materials for the dam and concrete aggregates was investigated for each damsite and acceptable materials were located within reasonable distance of the sites. Only limited quantities of natural concrete aggregates were located during this investigation and they will have to be crushed and processed from suitable quarry material, if additional quantities of natural aggregates are not successfully located during future investigations.

A surface and subsurface geological investigation program was prepared for both the Copalar Low Dam and Copalar High Dam due to the site topography uncertainty previously mentioned and because technical and economic analyses indicate that Copalar is the best of all projects considered, regardless of the dam height finally adopted. An investigation of the geological conditions will have to be performed only for the final dam height selected. The preliminary program recommended for the Copalar High Dam consists of 17,000 meters of seismic profiles, 48 drill holes with a total length of 1,800 meters and 73 test pits. A similar program for the low dam would require only slightly less work than the high dam. These quantities are those estimated as being required to verify conditions at the structure sites and the quality and quantity of the materials in each of the quarries and borrow areas. The proposed program must be constantly modified as work is performed in accordance with conditions actually encountered. The investigation must be supervised by a qualified engineering geologist and performed by experienced organizations in the particular fields of exploration, in order to ensure that the geological data required to support the design of project features is accurate and complete.

S.2.4 ECOLOGY

An environmental impact reconnaissance was conducted as part of a general evaluation of the entire ENALUF service area and to a lesser extent, the Republic of Nicaragua. Inspections of the proposed damsites on the Rio Grande de Matagalpa and Laguna de Apoyo were included within the scope of the general evaluation. This permitted the application of general environmental criteria to the hydroelectric projects under consideration, thereby providing a more in-depth study at the prefeasibility level. The general conclusion reached from this reconnaissance is that environmental problems related to the proposed project do exist, but that they are generally minor, both in nature and magnitude and can be easily and economically solved or mitigated with proper planning and foresight. Favorable environmental conditions are also recognized and some of these outweigh the adverse effects. The major environmental points of concern are public health, relocation of displaced inhabitants of the reservoir areas, archaeological patrimony, watershed protection and community development. Carefully designed and detailed recommendations to mitigate environmental problems are contained in Chapter III, Technical Evaluation and in Appendix B., Environmental Impact Reconnaissance. Conscientious compliance with these recommendations will ensure that the most adverse effects can be completely avoided.

S.2.5 HYDROELECTRIC PROJECT DESCRIPTIONS

The following brief descriptions apply to the four projects on the Rio Grande de Matagalpa mentioned in Section S.2.1. All are similar in general concept and consist of a diversion tunnel, main dam, spillway, power conduit, and powerhouse. Transmission lines and substations, including the sending-end plant substation near the powerhouse, are summarized in Section S.3.4.

A. DIVERSION TUNNELS

The diversion tunnels for all projects are located in one of the abutments in accordance with topographic configurations, geologic conditions and the location of other project features. Tunnels were adopted because the valleys at the sites are generally very narrow and the type of dam selected places limitations on the use of other methods of diversion. All tunnels are designed to discharge the inflow to the site for a flood with a 15-year recurrence interval.

Part of the Paso Real diversion tunnel will also be used as part of the power tunnel, but all other tunnels will serve for diversion only. All tunnels will be closed with a concrete plug when no longer required for diversion. The diversion tunnel size, length and discharge capacity are shown in the following summary:

PRINCIPAL DIVERSION TUNNEL DATA

PROJECT	INTERNAL DIAMETER	LENGTH	DISCHARGE CAPACITY
	m	m	m^3/s
Copalar - High	17.0	750	4,700
Copalar - Low	17.0	670	4,700
El Carmen	13.5	360	3,125
Paso Real	9.9	450	1,625

B. DAMS

All dams are of the rockfill type with a central impervious core, filters on both sides of the core, two qualities of rockfill outside of the filters and riprap on the reservoir face. Other types of dams were considered, but a rockfill type was adopted because of seismic activity in Nicaragua, availability of suitable construction materials and the status of data regarding foundation strength. The following summary shows the principal data for the dams:

PRINCIPAL DAM DATA

PROJECT	MAXIMUM HEIGHT	CREST LENGTH	TOTAL VOLUME OF EMBANKMENT
	m	m	$m^3 \times 10^6$
Copalar - High	140	630	10.5
Copalar - Low	92	350	3.7
El Carmen	59	310	1.2
Paso Real	72	330	1.5

C. SPILLWAYS

The spillways are also located in one of the abutments for the same reason as the diversion tunnels. All spillways consist of an inlet channel, crest control section with radial gates, inclined chute and a flip bucket energy dissipator. The crest control section has a standard ogee shape to obtain maximum discharge efficiency. The size of the radial gates is eight meters high by twelve meters wide for all projects. The number of gates required was established by flood routing studies for each project using the estimated inflows to the reservoirs. The reservoirs were assumed to be at their normal maximum levels when the floods occur and were permitted to rise above that level during the flood.

The chutes are located downstream of the crest control sections and are inclined at a sufficient slope to prevent backwater effects from reducing the maximum spillway discharge capacity. The flip buckets are located at the end of the chute and throw the discharge from there into the river at a sufficient distance downstream of all structures that there is no danger of retrogression endangering them. Flip bucket energy dissipators were adopted because they normally are less expensive than other types where conditions permit their use. The following summary shows the principal spillway data:

PRINCIPAL SPILLWAY DATA

PROJECT	NUMBER GATES	MAXIMUM RESERVOIR INFLOW	MAXIMUM SPILLWAY DISCHARGE	MAXIMUM RESERVOIR LEVEL
		m^3/s	m^3/s	m
Copalar - High	3	15,300	2,440	207.4
Copalar - Low	3	15,300	3,530	160.3
El Carmen	4	10,250	4,760	210.4
Paso Real	2	6,200	1,300	272.0

D. POWER CONDUITS

The power conduit comprises all facilities required to convey the water from the reservoirs to the powerhouses. They include an inlet channel, intake structure, power tunnel, penstock and penstock manifold just upstream of the powerhouse. These facilities are located in the left abutment of the dam for all projects. Separate power tunnels are provided for all projects, except Paso Real where the upstream portion of the diversion tunnel serves for this purpose. The intake structure for Paso Real is located near the inlet portal of the diversion tunnel, this being an exception to intake structures for other dam sites, which are located at the upstream portal of the power tunnels. Except for Paso Real, the penstocks slope down the hillsides and are buried in a trench. The penstock for Paso Real is a steel pipe installed in the downstream portion of the diversion tunnel. A short power tunnel is required between the diversion tunnel and the penstock manifold. The manifolds provide branch penstocks for each unit in the powerhouse. Power tunnel and penstock design capacities, lengths and diameters are shown in the table entitled Principal Power Conduit Data, at the top of the following page.

PRINCIPAL POWER CONDUIT DATA

PROJECT	DISCHARGE	POWER TUNNEL		PENSTOCK	
		LENGTH	DIAMETER	LENGTH	DIAMETER
	m^3/s	m	m	m	m
Copalar - High	308	220*	9.5	280	9.5
Copalar - Low	454	170**	11.4	170	11.4
El Carmen	208	180#	7.5	130	7.5
Paso Real	107	30##	5.5	200	5.5

* 190 meters steel lined
** 100 meters steel lined
\# 90 meters steel lined
\#\# 30 meters steel lined

E. POWERHOUSES

The powerhouses are located on the left bank of the river downstream of the main dam. Each powerhouse contains the required number of unit bays and a service and control bay. Each unit bay contains an inlet valve, turbine, governor, generator, switchgear and all required auxiliary mechanical and electrical equipment. The service and control bay contains the control room, office and supporting facilities to make each plant self sustaining. All turbines are the reaction type (Francis) and are directly coupled to the generators. The areas upstream of all powerhouses are backfilled to provide a parking and service area for each plant. The step-up transformers are located in this area immediately upstream of the powerhouse wall and high voltage lines extend from them to the switchyards located on the hill behind the powerhouse. The principal powerhouse data is summarized as follows:

PRINCIPAL POWERHOUSE DATA

PROJECT	INSTALLED CAPACITY MW	NUMBER UNITS	UNIT CAPACITY MW
Copalar - High	330	6	55
Copalar - Low	275	5	55
El Carmen	70	2	35
Paso Real	50	2	25

F. DIKES

One dike is required at El Carmen and four are required at Copalar High Dam for the maximum reservoir water levels at these sites. They are constructed to the same cross section as the main dams. Future investigations should consider these sites for fuse plug, or emergency, spillways; thereby permitting a smaller service spillway than presently provided. Some of these sites could also be considered for locations for the service spillway. The dike at El Carmen contains about 50,000 cubic meters of material and the four dikes at Copalar High Dam contain a combined total of about 700,000 cubic meters.

G. ACCESS ROADS

Access roads are provided for all sites. They are two lane gravel surfaced roads for primary access to the sites and one lane gravel surfaced roads for secondary access to saddle dikes and certain project structures. Maximum sustained grades are limited to 10 percent and minimum curve radius to 50 meters. Bridges, drainage structures and related facilities are included.

The Copalar project is scheduled to be constructed first, for both the two dam and three dam alternatives, which will necessitate construction of the major portion of the required access roads at the same time. The road alignment was selected in conjunction with the transmission line route and crosses the Rio Grande de Matagalpa on a bridge located a very short distance downstream of Paso Real. Consequently, there is almost no access road required for that project. Only a relatively short access road is required from the Copalar Project access road to El Carmen damsite.

S.2.6 POWER CAPACITY AND ENERGY GENERATION

A. RESERVOIR OPERATION STUDIES

Reservoir operation studies were conducted on a monthly basis for individual project sites and the two river basin development alternatives using generated discharges for a 50-year period. The computer program, HEC-3, Reservoir System Analysis developed by the U.S. Army Corps of Engineers was used. This program requires the assumption of the installed capacity at each plant as part of the input data and computes the average monthly power using the available discharge and the corresponding head for the month. The installed capacities for these analyses were assumed large enough that the peak output of each plant was unlimited. The installed capacities assumed were 1,000 MW for Copalar High Dam, 600 MW for Copalar Low Dam and 200 MW for El Carmen and Paso Real. The more important results of these studies are shown in a table entitled Reservoir Operation Studies, Summary Results of Computer Analysis, which immediately follows Figure S.1.

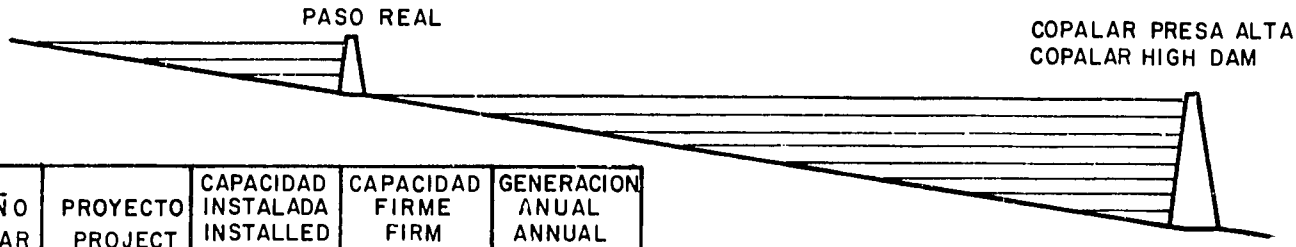
B. AVERAGE MONTHLY POWER GENERATION

The installed capacities used in the computer analysis for the reservoir operation studies served the purpose for which they were intended. However, other investigations established installed capacities which were more consistent with system planning concepts. Therefore, the 50-year average power generation was recomputed for each month of the year, using a limited installed capacity of 330 MW for Copalar High Dam, 184 MW for Copalar Low Dam, 70 MW for El Carmen and 50 MW for Paso Real. The installed capacity for Copalar Low Dam was subsequently increased to 275 MW. The resulting average power generation is shown in the summary of the reservoir operation studies. The 12-one month intervals were subsequently converted to 13-four week periods for use in system planning. These are given in Tables D.6 and D.7 of Appendix D.

Summaries of annual energy generation, together with other data relating to alternative hydroelectric power developments on the Rio Grande de Matagalpa, are given in the tabulations on Figure S.1. These summary tabulations are pertinent to the two and three dam schemes for independent system expansion, together with the Copalar High Dam as a single dam alternative for interconnected system expansion, with power purchases from Honduras and Costa Rica.

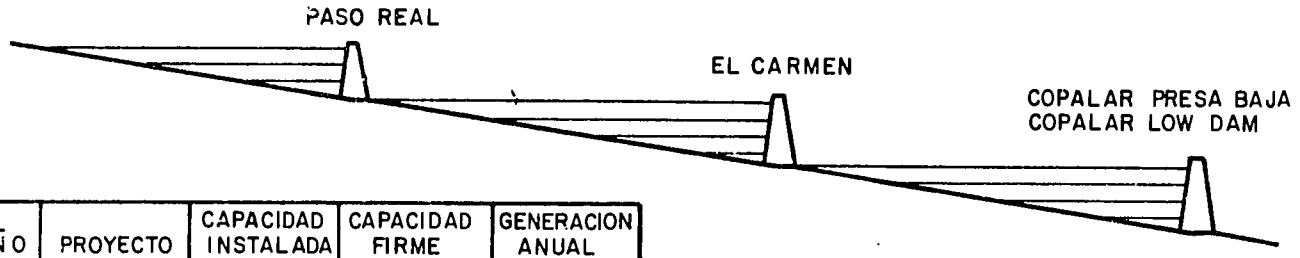
DESARROLLOS HIDROELECTRICOS ALTERNATIVOS EN EL RIO GRANDE DE MATAGALPA
ALTERNATIVE HYDROELECTRIC DEVELOPMENTS ON THE RIO GRANDE DE MATAGALPA

ALTERNATIVA DE DOS PRESAS PARA LA EXPANSION DEL SISTEMA INDEPENDIENTE
TWO DAM ALTERNATIVE FOR INDEPENDENT SYSTEM EXPANSION



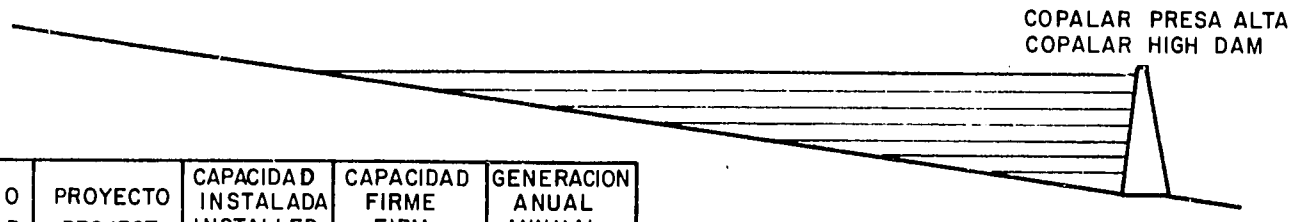
AÑO YEAR	PROYECTO PROJECT	CAPACIDAD INSTALADA INSTALLED CAPACITY	CAPACIDAD FIRME FIRM CAPACITY	GENERACION ANUAL ANNUAL GENERATION
1982	COPALAR	110 MW	–	–
1983	COPALAR	220 MW	60 MW	526 GWh
1984	COPALAR	330 MW	90 MW	788 GWh
1985	COPALAR	330 MW	158 MW	1418 GWh
1989	COPALAR	330 MW	160 MW	1413 GWh
1989	PASO REAL	50 MW	21 MW	196 GWh
1989	TOTAL	380 MW	181 MW	1609 GWh

ALTERNATIVA DE TRES PRESAS PARA LA EXPANSION DEL SISTEMA INDEPENDIENTE
THREE DAM ALTERNATIVE FOR INDEPENDENT SYSTEM EXPANSION



AÑO YEAR	PROYECTO PROJECT	CAPACIDAD INSTALADA INSTALLED CAPACITY	CAPACIDAD FIRME FIRM CAPACITY	GENERACION ANUAL ANNUAL GENERATION
1982	COPALAR	110 MW	–	–
1983	COPALAR	165 MW	70 MW	792 GWh
1986	COPALAR	165 MW	72 MW	800 GWh
1986	EL CARMEN	70 MW	17 MW	285 GWh
1989	COPALAR	275 MW	82 MW	850 GWh
1989	EL CARMEN	70 MW	28 MW	317 GWh
1989	PASO REAL	50 MW	21 MW	199 GWh
1989	TOTAL	395 MW	131 MW	1366 GWh

ALTERNATIVA DE UNA PRESA PARA LA EXPANSION DEL SISTEMA INTERCONECTADO
SINGLE DAM ALTERNATIVE FOR INTERCONNECTED SYSTEM EXPANSION



AÑO YEAR	PROYECTO PROJECT	CAPACIDAD INSTALADA INSTALLED CAPACITY	CAPACIDAD FIRME FIRM CAPACITY	GENERACION ANUAL ANNUAL GENERATION
1984	COPALAR	110 MW	–	–
1985	COPALAR	220 MW	60 MW	526 GWh
1986	COPALAR	330 MW	90 MW	788 GWh
1987	COPALAR	330 MW	158 MW	1418 GWh
1989	TOTAL	330 MW	165 MW	1418 GWh

RESERVOIR OPERATION STUDIES
SUMMARY RESULTS OF COMPUTER ANALYSIS

ALTERNATIVE AND PROJECT	INSTALLED CAPACITY MW	POWER GENERATED 100% CAPACITY FACTOR FIRM CAPACITY MW	50-YEAR AVERAGE MW
TWO DAM ALTERNATIVE			
Copalar	1,000	158.0	165.1
Copalar + Paso Real			
Copalar	1,000	159.8	163.9
Paso Real	200	21.0	23.9
TOTAL	1,200	180.8	187.8
THREE DAM ALTERNATIVE			
Copalar	600	69.6	104.2
Copalar + El Carmen			
Copalar	600	72.0	104.8
El Carmen	200	16.8	40.6
TOTAL	800	88.8	145.4
Copalar + El Carmen + Paso Real			
Copalar	600	82.4	104.4
El Carmen	200	28.2	39.3
Paso Real	200	21.0	23.9
TOTAL	1,000	131.6	167.6

C. REDUCED CAPACITY DURING RESERVOIR FILLING

The Copalar High Dam reservoir requires three years to fill completely. Therefore, reservoir filling will begin during the wet season preceding the completion of dam construction and continue through the following wet season; at which time, power will be required. However, the reservoir will be only two-thirds full at that time and output will be less than full capacity. An analysis was made of the reduced capacity that could be produced and still completely fill the reservoir in a reasonable period of time. The results of that analysis showed that an annual average of 60 MW of power could be produced during the first year and 90 MW during the second year of operation when the reservoir would be full. These reduced capacities were used in system planning for the years to which they apply.

S.2.7 PROJECT COSTS

A. GENERAL

Two types of costs were computed for this investigation. The first are total construction costs which are also called total direct costs. These costs are the same as a construction contractor would bid for constructing the projects and exclude interest during construction, engineering, administration, land procurement and resettlement. The second is total capital cost which is the total investment required to construct the project, including those cost items listed above as excluded from total construction costs.

B. TOTAL CONSTRUCTION COST

Total construction costs were obtained from unit price estimates; quantity estimates; manufacturer's quotations; price catalogs; experience curves; values from other recently estimated projects of a similar nature, size, and condition and other available unit price data. Lump sum amounts were used for some items of lesser values and are based on experience for similar costs. The price estimates were prepared during April, May and June 1975 and no escalation since that time has been used. A contingency of 10 percent was used to allow for minor cost items that were not estimated and to allow for items that may have been underestimated. All estimates are in conformity with usual and standard practices for prefeasibility studies and are as accurate as required for this level of investigation.

C. TOTAL CAPITAL COST

Total capital costs were estimated by adding the excluded cost items mentioned in Paragraph A to the total construction cost. Interest during construction was estimated on a simplified basis, using an eight percent interest rate for the period of major project expenditures increased by one-half year to allow for lesser expenditures at other times. This resulted in interest during construction being 26 percent of total construction costs for Copalar High Dam, 18 percent for Copalar Low Dam and 14 percent for El Carmen and Paso Real. Engineering and administration were combined and assumed to be 10 percent of total construction costs. Land acquisition and resettlement is a relatively minor cost item for all projects, because of the remoteness of the project areas, low population density and the type of structures in the reservoir areas. Land was assumed to cost an average of C$700 per hectare and resettlement was included as a slightly different lump sum amount for each project depending on the reservoir size.

D. SUMMARY OF CONSTRUCTION AND CAPITAL COSTS, POWER AND ENERGY VALUES

Summary Table S.1 on the following page shows total construction costs, total capital costs and the corresponding values per kilowatt of installed capacity and kilowatt hour of energy generated. This summary shows costs by project and by river basin development. The summary is not intended to be an economic evaluation of the projects and river basin alternatives. Economic evaluation is summarized in Section S.3, from the detailed analysis of Chapter VIII.

S.2.8 PROJECT SELECTED FOR FEASIBILITY STUDY

The results of the investigations, completed during the prefeasibility study, definitely establish the Copalar Project as the best and most economical of all projects considered. It can be economically constructed either as a high dam in the two dam alternative, or a low dam in the three dam alternative. The summary of costs in the preceding paragraph indicate and other evaluations confirm that the high dam is the most economical of the two alternatives. Therefore, it is recommended that the high dam scheme for Copalar Project be studied at the feasibility level. It is further recommended that the feasibility study be started at the earliest practicable date so that completion of the project can be assured by the time it is needed. It is essential to maintain momentum in a project of this magnitude and importance to the future growth of the national economy. The development of indigenous hydroelectric energy resources is the only certain way to secure autonomy of national energy supply, by reducing dependence upon the importation of fuel oil.

TABLE S.1
SUMMARY OF COSTS
POWER CAPACITY AND ENERGY VALUES
FOR
ALTERNATIVE DEVELOPMENTS ON THE RIO GRANDE DE MATAGALPA

TWO DAM ALTERNATIVE

ITEM	COPALAR	COPALAR + PASO REAL
CAPACITY AND ENERGY		
Installed Capacity - MW	330	380
Energy per year - GWH	1418	1610
TOTAL CONSTRUCTION COST	203.382	247.022
Cost per KW	616	650
Cost per KWh	14.3	15.3
TOTAL CAPITAL COST	273.672	329.806
Cost per KW	829	868
Cost per KWh	19.3	20.5

THREE DAM ALTERNATIVE

ITEM	COPALAR	COPALAR + EL CARMEN	COPALAR + EL CARMEN + PASO REAL
CAPACITY AND ENERGY			
Installed Capacity - MW	275	345	395
Energy per year - GWH	850	1167	1366
TOTAL CONSTRUCTION COST	143.152	194.589	238.299
Cost per KW	521	564	603
Cost per KWh	16.8	16.7	17.4
TOTAL CAPITAL COST	185.188	249.695	305.829
Cost per KW	673	724	774
Cost per KWh	21.8	21.4	22.4

NOTES:

Total Construction Cost and Total Capital Cost in million U.S. Dollars; Cost per KW in U.S. Dollars;Cost per KWh in U.S. Mills.

Total Annual Cost Assumed to be equal to 10 percent of Total Construction Cost.

S.2.9 INTEGRATION OF COPALAR PROJECT IN ENALUF SYSTEM EXPANSION PLANS

The Copalar Project has emerged as the most technically viable and economically sound hydroelectric development to be selected for feasibility analysis, as the prime source of future energy supply to the ENALUF National Interconnected System serving the Pacific, North and Central Zones of Nicaragua. To a great extent it will be the fixed polar axis around which long-range plans for system expansion will revolve, including firm plans for interconnection of the ENALUF system with the ENEE system of Honduras and the ICE system of Costa Rica. Copalar, together with power purchases from Honduras and Costa Rica, will provide the ENALUF system with sufficient capacity and energy to meet forecast load growth from 1982 to the end of 1989.

The firm power capability of Copalar will improve overall generation reliability to a great extent and enable low system risk levels to be attained that will provide a firm foundation for stable economic growth, uninterrupted by generation outages causing direct losses to the economy. The integration of the Copalar Project within general plans for power system expansion can be accomplished relatively easily, with a minimum of disturbance to rapid, continuous system growth, which is characteristic of a utility system the size of ENALUF.

Copalar will provide an indigenous energy source for intermediate-range supply, to complement the base-load energy provided by geothermal resources. The magnitude of the hydroelectric energy from the Copalar Project will serve to reduce the need for future importations of fuel oil for generation purposes. Depending upon the optimum height of dam selected during the feasibility study, the annual displacement of imported fuel could range from 1.7 to 2.8 million barrels, these amounts corresponding to the low and high dam alternatives, respectively. The topography may limit the dam crest to a level that permits reservoir storage to an elevation at approximately 190 meters and would result in an annual fuel oil saving of at least 2.6 million barrels per year. This oil would be worth $30.3 million per year to ENALUF at the current purchase price, which over the 50-year service life represents approximately $1.5 billion.

The selective utilization of power allocations, made available for annual purchases from the ENEE system of Honduras and the ICE system of Costa Rica, will achieve one of the prime purposes of the study, in that future use of fuel oil for system generation purposes will be minimized. The high dam at Copalar, together with power purchases made during the entire development decade 1978-1988, will result in minimal thermal plant dispatch during the period 1978 through 1981 and almost negligible thermal energy generation between 1982 and 1988. The benefits from this extended period of displacement of imported fuel oil by indigenous hydroelectric resources, represents one of the most portentous effects of the future implementation of plans for the introduction of the Copalar Project to the ENALUF system.

The discussion of detailed plans for integration of the Copalar project in the generation and transmission system expansion of the National Interconnected System is given in the following section. To summarize, the Copalar Project represents the key to system growth in the future transmission grid embracing the three countries of Honduras, Nicaragua and Costa Rica. Once the Copalar High Dam is set in place, its intrinsic stability will enable the economic integration of Central America to accelerate with an impetus gained from a source of dynamic energy, entirely within the autonomous control of the central government of Nicaragua, through ENALUF as the operating agency responsible for national power supply.

S.3 BASIC PLANS FOR INDEPENDENT POWER SYSTEM EXPANSION

The principal evaluation of alternative power system developments has been made by technical and economic comparison of comprehensive plans for both independent and interconnected expansion of the ENALUF National Interconnected System. A basic plan for long-range development of indigenous hydroelectric resources was selected following a detailed technical and economic evaluation of alternative hydroelectric sites on the Rio Grande de Matagalpa. Combinations of two and three dam development schemes, together with their respective transmission systems, were compared to select the most advantageous basic plan for independent expansion.

Contingency plans were prepared for short-range generation expansion, to substitute alternative generating plant in the event that geothermal power development does not materialize fully, according to present anticipated levels, or is delayed for any reason during the extended period of exploration, testing, feasibility studies, production drilling, plant design and construction. Viable alternatives were examined to substitute different types of thermal generation for geothermal plant and an economic comparison was completed on this basis.

S.3.1 LONG-RANGE GENERATION EXPANSION PLANS, 1982-1988

The main alternatives evaluated for long-range development of hydroelectric resources comprised the two and three dam development schemes on the Rio Grande de Matagalpa. These were evaluated both technically and economically at the system level.

A. TWO DAM DEVELOPMENT FOR SYSTEM EXPANSION PLAN A1

The combination of the Copalar high dam and Paso Real, described in Section S.2, was examined in context of a comprehensive plan for system development, comprising generation, transmission line and substation elements, this being designated Plan A1 for independent system expansion.

A summary tabulation of generation plant additions for the two dam development scheme of Plan A1 is given in Table S.2. The relationship of generating plant capacity to peak load demand on the ENALUF system is shown on Figure V.1 of Chapter V and the corresponding energy generation of the Rio Grande de Matagalpa developments, together with other components of system generation, is shown on Figure S.2.

A summary of the unit introduction schedule and forced outage rates determining the loss of load carrying capability for Plan A1 is given in Table V.1 of Chapter V, together with a summary of the loss of load probability (LOLP) indices, which indicate generation reliability risk levels on a period and annual basis.

The conclusions reached from the generation reliability study of Plan A1, confirm that the unit additions at the Copalar and Paso Real power plants will provide most adequate levels of generation reliability for secure system expansion to the end of the development decade in 1988. Thereafter, new generating plant additions will be required in 1989 to maintain acceptable levels of generation reliability.

TABLE S.2

EMPRESA NACIONAL DE LUZ Y FUERZA
NATIONAL INTERCONNECTED SYSTEM
N I C A R A G U A
GENERAL EXPANSION PLAN A1
1978 - 1988

TWO DAM DEVELOPMENT ON RIO GRANDE DE MATAGALPA
F O R
INDEPENDENT SYSTEM EXPANSION

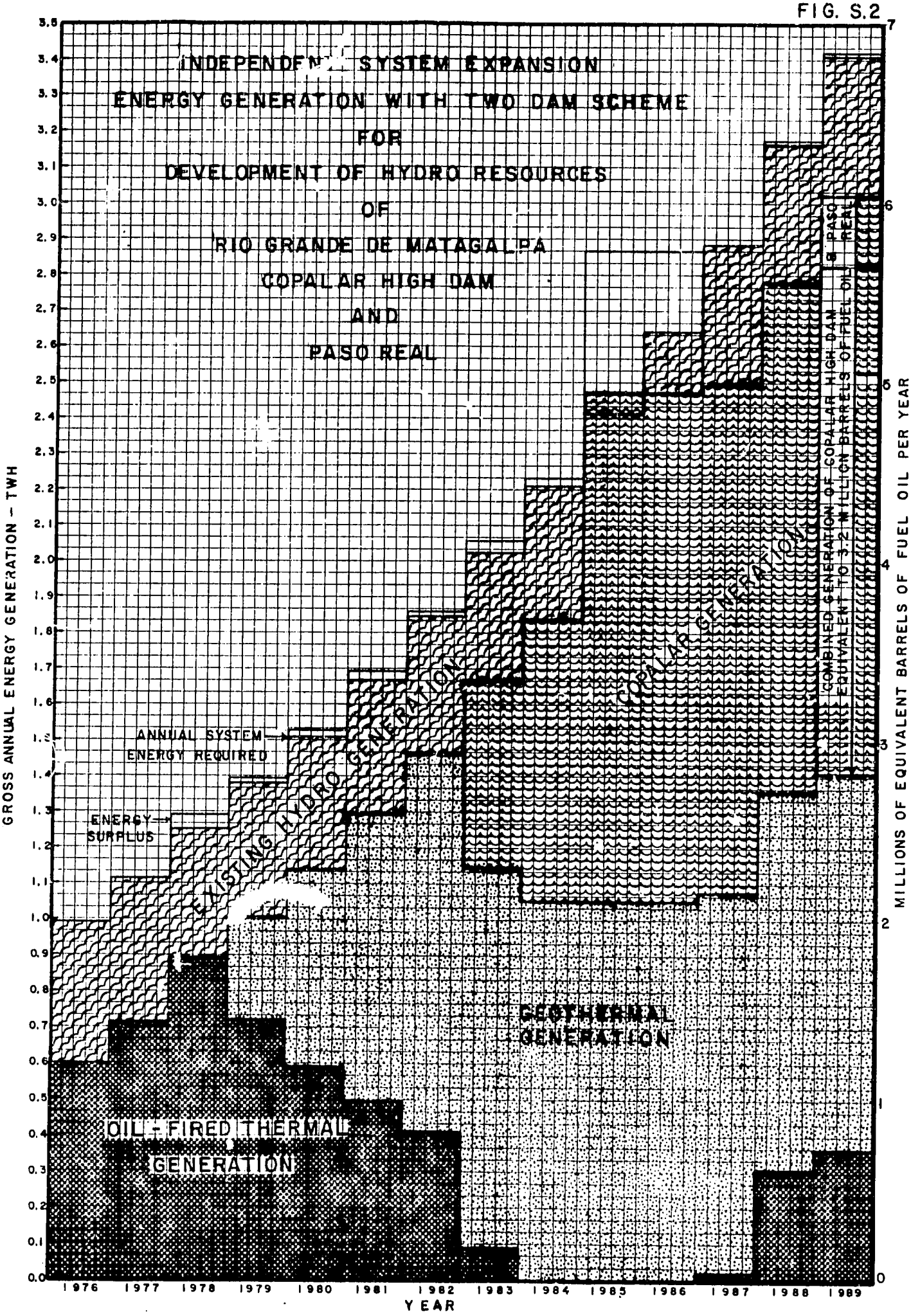
YEAR	GENERATING PLANT ADDITIONS SOURCE	UNIT	TYPE	MW	GWH	TOTAL EFFECTIVE OPERATING CAPACITY OF SYSTEM RESOURCES MW	TOTAL FIRM ANNUAL ENERGY FROM RESOURCES GWH	SYSTEM PEAK DEMAND MW	SYSTEM GROSS ENERGY GENERATION REQUIRED GWH	NOMINAL SYSTEM RESERVE MW	%	GWH	INSTALLED RESERVE MARGIN AFTER LOSS OF LARGEST RISK %	MW	%	LOSS OF LOAD PROBABILITY (RISK LEVEL INDEX) DAYS/YEAR
1978	Existing Plants Plus Thermal Units Installed at Puerto Somoza Plant					283	1,640	220	1,253	63	29	387	31	13	6	1.18
1979	Momotombo	1	G	45	350	328	1,990	241	1,374	87	36	616	45	37	15	0.94
1980	Momotombo	2	G	45	350	373	2,340	266	1,508	107	40	832	55	57	21	0.62
1981	Momotombo	3	G	45	350	418	2,690	295	1,668	123	42	1,022	61	73	25	0.87
1982	Copalar	1	H	55		END OF FIRST RESERVOIR FILLING SEASON - LIMITED OPERATION IN 1982										
	Copalar	2	H	55												
	Total Additions			110	-	528	2,690	326	1,837	202	62	853	46	147	45	1.02
1983	Copalar	3	H	55		OPERATION DURING 2ND YEAR OF RESERVOIR FILLING - 37% OF NORMAL ANNUAL ENERGY										
	Copalar	4	H	55												
	Total Additions			110	526	638	3,216	361	2,027	277	77	1,189	59	221	61	0.01
1984	Copalar	5	H	55		OPERATION DURING 3RD YEAR OF RESERVOIR FILLING - 56% OF NORMAL ANNUAL ENERGY										
	Copalar	6	H	55												
	Total Additions			110	262	748	3,478	394	2,210	354	90	1,268	57	299	76	0.0
						COPALAR RESERVOIR FULL - FIRST YEAR OF NORMAL ENERGY GENERATION IN 1985										
1985	No Unit Additions			-	630	748	4,108	431	2,411	317	74	1,697	70	262	61	0.0
1986	No Unit Additions			-	-	748	4,108	472	2,635	276	58	1,473	56	221	47	0.0
1987	No Unit Additions			-	-	748	4,108	518	2,884	230	44	1,224	42	175	34	0.02
1988	Paso Real	1	H	25		IN-SERVICE END OF YEAR (NOVEMBER) LIMITED OPERATION IN 1988										
	Paso Real	2	H	25												
	Total Additions			50	-	798	4,108	568	3,160	230	40	948	30	175	31	0.79
1989	No Unit Additions			-	196	798	4,299 R/	615	3,413	183	30	886	26	128	21	*/ 2.30 +/

Note: R/ Copalar Regulated by Paso Real

*/ LOLP Index Exceeds Reliability Criteria Level

+/ Generating Plant Additions Required

FIG. S.2



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B. THREE DAM DEVELOPMENT FOR SYSTEM EXPANSION PLAN B1

The second alternative of the Copalar low dam, El Carmen and Paso Real, as described in Section S.2, was also examined at the system level within a comprehensive plan for generation and transmission system expansion, designated Plan B1. A summary tabulation of generating plant additions for the three dam development scheme of Plan B1 is given in Table S.3. The generating plant capability in relation to system peak load demand is shown on Figure V.2 of Chapter V and the corresponding energy generation for all components of Plan B1 is shown on Figure S.3. It should be noted that the dispatch of supporting thermal generation for Plan B1, during the period 1983 through 1989, is much greater than for Plan A1 over the same time period. The additional production cost for thermal generation associated with the three dam development Plan B1 is the main economic factor determining the selection of Plan A1.

A summary of the generating unit introduction schedule and forced outage rates determining the loss of load carrying capability for Plan B1 is given in Table V.2 of Chapter V,together with an annual summary of the LOLP indices for each of the 13 four-week periods and the entire year. Although the annual risk levels for the generation of Plan B1 are in general higher than for Plan A1, they do not exceed the acceptable levels for maintenance of adequate generation reliability, defined in Section 4.2 of Chapter IV. Quite adequate levels of generation reliability are attained for secure system expansion, from the introduction of the first two Copalar units in 1982 through the end of the period of development for the three dam scheme in 1988. In the following year, 1989, new generating plant additions are required to maintain acceptable levels of generation reliability, similar to Plan A1.

C. COMPARISON OF ALTERNATIVE LONG-RANGE DEVELOPMENT PLANS

The technical and economic evaluation of the alternative hydroelectric developments, considered for long-range independent expansion of the ENALUF system, resulted in the selection of the two dam scheme for development of the hydro resources of the Rio Grande de Matagalpa. The selection is definitive, with a clear and decisive advantage in favor of the combined development of the high dam at the Copalar site, together with Paso Real.

A technical comparison of the two hydroelectric developments results in a close assessment of the relative merits of the alternative plans for independent system expansion, based on available indigenous energy resources. Both developments can provide reliable sources of power and energy, within prescribed limits governed by generation reliability criteria, defined during the course of the study. The advantage of the two dam scheme,in terms of reliability, is that it provides a more secure system during the period of expansion 1982-1988, with 15 megawatt of installed capacity less than the three dam development. The following tabulation provides a comparison of reliability for the two plans:

INDEPENDENT SYSTEM EXPANSION
COMPARATIVE GENERATION RELIABILITY

		Loss of Load Probability (LOLP) - Days/Year						
Plan	Description	1982	1983	1984	1985	1986	1987	1988
A1	Two Dam Scheme	1.02	0.01	0.00	0.00	0.00	0.02	0.79
B1	Three Dam Scheme	1.02	0.01	0.01	0.19	0.11	0.07	0.48

TABLE S.3

EMPRESA NACIONAL DE LUZ Y FUERZA
NATIONAL INTERCONNECTED SYSTEM
N I C A R A G U A
GENERATION EXPANSION PLAN B1
1978 - 1988

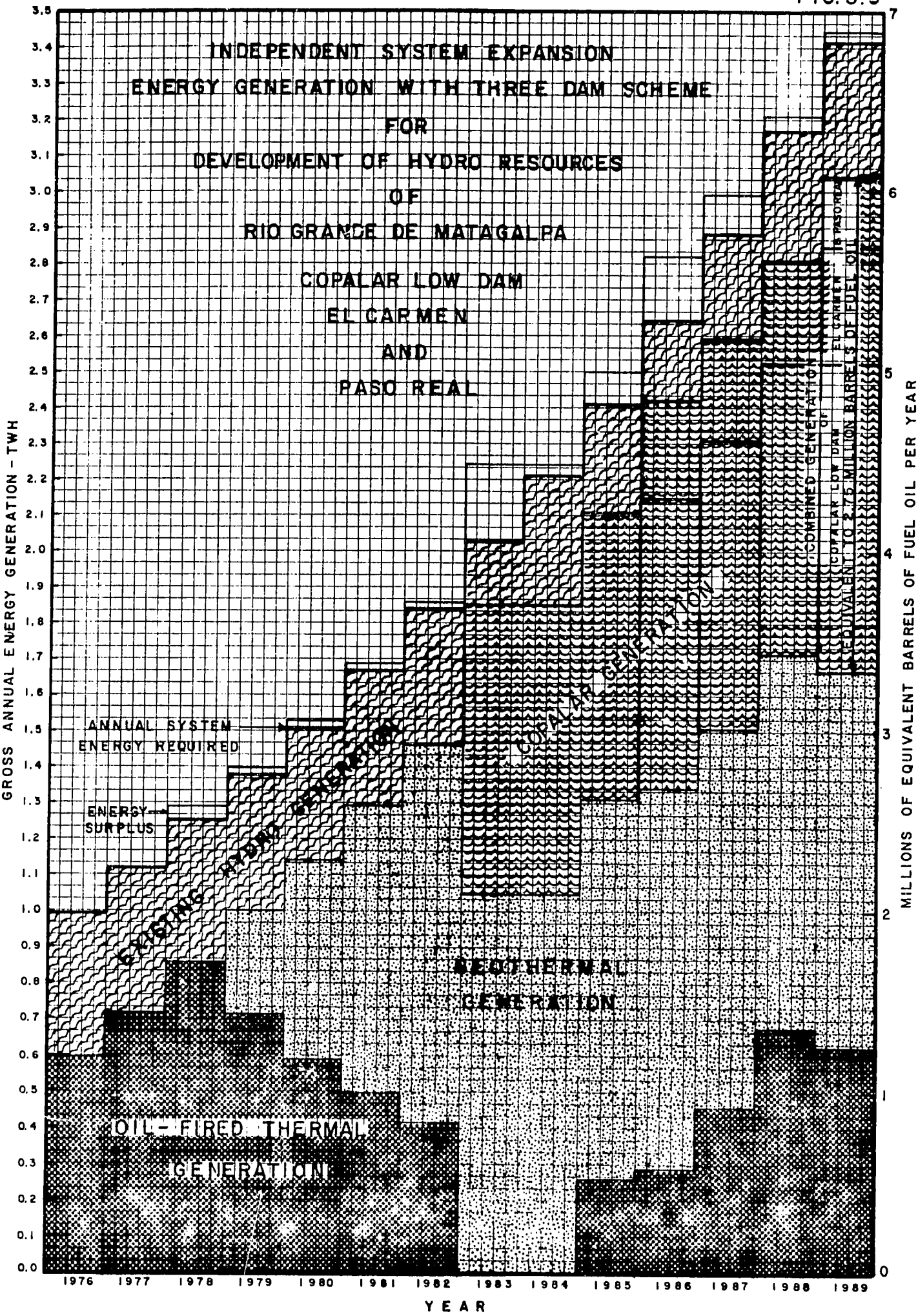
THREE DAM DEVELOPMENT ON RIO GRANDE DE MATAGALPA
F O R
INDEPENDENT SYSTEM EXPANSION

YEAR	GENERATING PLANT ADDITIONS					TOTAL EFFECTIVE OPERATING CAPACITY OF SYSTEM RESOURCES	TOTAL FIRM ANNUAL ENERGY FROM RESOURCES	SYSTEM PEAK DEMAND	SYSTEM GROSS ENERGY GENERATION REQUIRED	NOMINAL SYSTEM RESERVE			INSTALLED RESERVE MARGIN AFTER LOSS OF LARGEST RISK			LOSS OF LOAD PROBABILITY (RISK LEVEL INDEX)
	SOURCE	UNIT	TYPE	MW	GWH	MW	GWH	MW	GWH	MW	%	GWH	%	MW	%	DAYS/YEAR
1978	Existing Plants plus Thermal Units Installed at Puerto Somoza Plant					283	1,640	220	1,253	63	29	387	31	13	6	1.18
1979	Momotombo	1	G	45	350	328	1,990	241	1,374	87	36	616	45	37	15	0.94
1980	Momotombo	2	G	45	350	373	2,340	266	1,508	107	40	832	55	57	21	0.62
1981	Momotombo	3	G	45	350	418	2,690	295	1,668	123	42	1,022	61	73	25	0.87
1982	Copalar	1	H	55												
	Copalar	2	H	55			IN SERVICE END OF YEAR (NOVEMBER) LIMITED OPERATION IN 1982									
	Total Additions			110		528	2,690	326	1,837	202	62	853	46	147	45	1.02
1983	Copalar	3	H	55	792	583	3,482	361	2,027	222	61	1,455	72	167	46	0.01
1984	No Unit Additions			-	-	583	3,482	394	2,210	189	48	1,272	58	134	34	0.01
1985	No Unit Additions			-	-	583	3,482	431	2,411	152	35	1,071	44	97	23	0.19
1986	El Carmen	1	H	35												
	El Carmen	2	H	35			IN-SERVICE BEGINNING OF YEAR (JANUARY) NORMAL OPERATION IN 1986									
	Total Additions			70	285	653	3,775R1/	472	2,635	181	38	1,140	43	126	27	0.11
1987	Copalar	4	H	55												
	Copalar	5	H	55												
	Total Additions			110	-	763	3,775	518	2,884	245	47	891	31	190	37	0.07
1988	Paso Real	1	H	25												
	Paso Real	2	H	25			IN-SERVICE END OF YEAR (NOVEMBER) LIMITED OPERATION ONLY IN 1988									
	Total Additions			50	-	813	3,775	568	3,160	245	43	615	19	195	34	0.48
1989	No Unit Additions			-	199	813	4,056R2/	615	3,413	198	32	643	19	143	23	*/ 1.48 +/

Note: R1/ Copalar Regulated by El Carmen
R2/ Copalar Regulated by El Carmen and Paso Real

*/ LOLP Index Exceeds Reliability Criteria Level
+/ Generating Plant Additions Required

FIG. S.3



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It may be observed that the two dam scheme maintains almost 100 percent system reliability over the period 1984 to 1986, but both sets of risk level indices are well within the range of 0.6 - 1.0 day/year, established as part of generation reliability criteria in Chapter IV, Section 4.2. In terms of the installed cost of the reserve margin, more security of supply is obtained with the two dam development for the lowest incremental plant cost, both in absolute magnitude and expressed as an installed cost per unit.

In 1989, both schemes for independent development will require additional unit capacity to maintain reliability levels, so the LOLP indices for 1989 given in Tables V.1 and V.2, are only relative in magnitude. Their ratio of 1.55:1 is indicative that either larger capacity or additional units will be required to continue the generation expansion comprising the two dam development.

One noteworthy difference between the two alternative developments is related to the generation reliability criteria. A two-stage construction program was required for the low dam at Copalar, in order to minimize overlap between the construction schedules for Copalar, El Carmen and Paso Real. The extremely tight scheduling of the three projects could only be achieved by limiting the initial installation at Copalar to three 55 MW units and remobilizing construction forces to install an additional two units in 1987. The additional units are required for maintenance of system reliability levels and the resultant plant capacity factor is correspondingly reduced from approximately 55 to 35 percent. This also serves to illustrate the principal factor bearing on project selection, that of storage capability for pondage hydro generation. In this aspect, the limited storage of the low dam results in a total energy generation potential which is 60 percent of the equivalent generation potential of the high dam, with regulation.

The resulting production costs for the two and three dam alternatives are greatly influenced by the much larger energy component of the high dam development. The economic comparison of the two alternative plans A1 and B1 is discussed in Chapter VIII, Section 8.2, with the comparative present worth analysis of cash flow given in Appendix E, Annexes E-1 through E-18. Analysis was completed for both unescalated 1975 cost levels and over a range of escalation profiles for investment, fuel costs and O & M.

The most graphic illustration of the relative merits of the high and low dam developments at the Copalar site may be gained from a comparison of the equivalent displacement of oil-fired generation by each of the two alternatives. Figures S.2 and S.3 show the components of system generation over the period 1976 through 1989, the first year of constant operation for Paso Real in either the two or three dam schemes. The energy scale is graduated in terawatt-hours (kwh x 10^9) and a conversion is made to millions of equivalent barrels of fuel oil (Bunker C) consumed per year for energy generation. This conversion was made based upon actual production costs for ENALUF system generation, utilizing the most efficient Puerto Somoza thermal units as the prime source of thermal energy.

The tabulation at the top of the following page will serve to illustrate the impact of indigenous hydroelectric resources development on the national balance of payments.

INDEPENDENT SYSTEM EXPANSION
COMPARISON OF POTENTIAL SAVINGS IN IMPORTED FUEL OIL
FOR
ALTERNATIVE DEVELOPMENTS ON THE RIO GRANDE DE MATAGALPA

A. Two Dam Development Scheme:

	Copalar	Paso Real	Total
Annual Energy Generation - TWH	1.413	0.196	1.609
Equivalent Fuel Oil Usage - M.BBL/yr	2.80	0.40	3.20
Equivalent Usage over 50 Year Life - M.BBL	140.0	20.0	180.0
Saving at Current Prices ($11.65/BBL) - $M	1,613	233	1,864

B. Three Dam Development Scheme:

	Copalar	El Carmen	Paso Real	Total
Annual Energy Generation - TWH	0.850	0.317	0.199	1.366
Equivalent Fuel Oil Usage - M.BBL/Yr	1.70	0.65	0.40	2.75
Equivalent Usage over 50 Year Life - M.BBL	85.0	32.5	20.0	137.5
Saving at Current Prices ($11.65/BBL) - $M	990	379	233	1,602

It can be appreciated what effect future oil price escalation will have on the tabulated values, when with mid-year 1975 oil price levels applied to the equivalent fuel consumption over the normal 50-year service life of the hydroelectric power developments, the differential between the two alternatives, $262,000,000, would be 96 percent of the capitalized cost of the Copalar high dam development.

The following comparison is made using the summary of costs given in Table S.1:

INDEPENDENT SYSTEM EXPANSION
COMPARISON OF FUEL COST SAVINGS WITH CAPITAL COSTS
FOR
ALTERNATIVE DEVELOPMENTS ON THE RIO GRANDE DE MATAGALPA

(Equivalent to Application of Mid-Year 1975 Oil Price Levels)
Bunker C - $11.65 per Barrel

A. Two Dam Development Scheme:

	Copalar	Paso Real	Total
Total Capital Cost - $M	273.672	56.134	329.806
Equivalent Fuel Oil Usage - M.BBL/Yr	2.80	0.40	3.20
Savings per Year at Current Oil Prices - $M	32.620	4.660	37.280
Undiscounted Pay-Out Period-Years	8.4	12.0	8.85
Proportion of Service Life - %	17	24	18

B. Three Dam Development Scheme:

	Copalar	El Carmen	Paso Real	Total
Total Capital Cost - $M	185.188	64.507	56.134	305.829
Equivalent Fuel Oil Usage M.BBL/Yr	1.70	0.65	0.40	2.750
Saving per Year at Current Oil Prices - $M	19.810	7.570	4.660	32.040
Undiscounted Pay-Out Period-Years	9.3	8.5	12.0	9.5
Proportion of Service Life - %	19	17	24	19

S.3.2 CONTINGENCY PLANS FOR SHORT-RANGE GENERATION EXPANSION

Although geothermal field development at Momotombo is proceeding well and several other good prospects are currently being appraised for future development, sound power system planning requires contingency plans for alternative options should actual development fall short of present estimates for reservoir capacity, or delays be sustained to scheduled introductions of geothermal generating plant.

Two contingency plans were evaluated to examine the relative economic merits of alternative short-range generating plant additions to substitute thermal for geothermal plant, in the event that geothermal power development has to be supplemented by additional thermal plant for base-load supply. These contingency plans are discussed in Section 8.3 of Chapter VIII and are summarized as follows:

A. PLAN C1 FOR ADDITIONAL 50 MW UNIT AT PUERTO SOMOZA PLANT

On the assumption that the equivalent of a single 45 MW geothermal unit would be required for commissioning in 1980, prior to commercial operation in 1981, one solution would be to install a third 50 MW unit at the Puerto Somoza thermal plant. A cost estimate was made for the unit addition based on segregated costs for Unit 2 obtained from construction account records and the most recent engineering estimates made for the total cost of the plant. A unit cost of $300 per kilowatt was used to represent the total cost of a third unit at mid-year 1975 price levels. This total included the cost of the main transformer and substation equipment required for the addition of a third unit at Puerto Somoza.

The production costs for equivalent annual generation to that of the 45 MW geothermal unit at the Momotombo Plant were calculated based on an average plant heat rate of 9,400 BTU per kwh and a basic cost of $11.52 per barrel of fuel oil (Bunker C) delivered to the plant, at 1975 cost levels. A heating value of 140,000 BTU per gallon was assumed for production cost calculations. The annual geothermal energy generation was taken to be 350 GWH, this being equivalent to a 45 MW geothermal plant capacity factor of 89 percent, or a 50 MW thermal plant capacity factor of 80 percent, on base-load supply.

Thermal plant operation and maintenance costs, corresponding to mid-1975 fixed and variable O & M costs developed for Puerto Somoza Units 1 and 2, were used to calculate plant O & M expenses for Unit 3 at Puerto Somoza. An economic comparison was made with a second geothermal contingency plan.

B. PLAN C2 FOR 50 MW (4 x 12.5 MW) DIESEL PLANT AT MASAYA

An alternative thermal solution was examined, consisting of a multiple diesel engine generator unit installation, to provide a total plant output of 50 MW continuous rating for base-load supply. Relatively recent design innovations in diesel-engine technology enable a high thermal efficiency to be attained with large capacity units, to achieve low operating costs coupled with levels of investment cost comparable to steam-electric generating units with ratings between 40 and 100 MW.

A four unit installation formed the thermal equivalent of the Puerto Somoza Unit 3, each unit having a continuous rating of 12.5 MW for base-load operation at a net station heat rate of 9,400 BTU per kilowatthour. The cost of fuel-oil for a plant located at Masaya was assumed to be the same as the cost of Bunker C

delivered to the Managua thermal plant at mid-1975 price levels. It was further assumed that the same grade of fuel would be used as that intended for the Puerto Somoza thermal plant, with a heating value of 140,000 BTU per gallon. Thus, the assumed differential between the costs of fuel delivered to the Puerto Somoza and Masaya plants was the single factor causing an operational cost advantage in favor of the Puerto Somoza Unit 3.

As the production costs for the two thermal plant alternatives were very similar, the selection of the most economic contingency plan depended on a comparison of levels of investment cost and the amount and timing of disbursements. The cost estimate for the Masaya plant was based on a quotation received from a manufacturer, capable of supplying the complete installation. The total installed cost was estimated to be the equivalent of $380 per kilowatt, at 1975 cost levels. A separate estimate was made for the cost of the plant substation equipment required to connect the four unit installation to the 138 kV bus at Masaya. Plant O & M costs were estimated based on the manufacturer's recommendation.

C. COMPARISON OF ALTERNATIVE CONTINGENCY PLANS

An economic comparison was made of the two thermal plants, assuming that the selected contingency plan would require plant commissioning by end-of-year 1980; for start of commercial operation on January 1, 1981. As both plans are intended to serve as a possible substitute for a geothermal unit addition, the analysis was conducted over the 25-year service life of a geothermal plant.

The selection of the most economical contingency plan hinged on the relative capital investment required for the two alternatives and their annual disbursement. The following summary tabulation indicates the relative magnitudes involved.

ANNUAL CAPITAL DISBURSEMENTS FOR ALTERNATIVE THERMAL PLANTS

PLAN	YEAR 1 (1977)	YEAR 2 (1978)	YEAR 3 (1979)	YEAR 4 (1980)
C1. Puerto Somoza Unit 3				
Thermal Plant	$1,200,000	$7,500,000	$4,390,000	$1,045,000
Substation			260,000	605,000
Total	$1,200,000	$7,500,000	$4,650,000	$1,650,000
C.2 Masaya Diesel Plant				
Thermal Plant		$1,900,000	$7,600,000	$9,500,000
Substation			190,000	445,000
		$1,900,000	$7,790,000	$9,945,000

The annual fuel cost and O & M expenses for the two plants were as follows:

	Annual Fuel Cost	Annual O & M Expenses*/
Plan C1. - Puerto Somoza Unit 3	$6,445,000	$398,000
Plan C2. - Masaya Diesel Plant	$6,520,000	$419,000

*/Includes Substation O & M

The economic comparison resulted in the selection of the Puerto Somoza Unit 3 as a possible alternative to geothermal power on a contingency basis. However, the conclusion requires a degree of caution in view of the fact that the cost estimate for the diesel plant was based on one manufacturer's quotation rather than competitive bid proposals. After the comparative analysis was completed, information was received from ICE relative to the bid analysis of an identical plant at Puerto Limon, Costa Rica. It appears that even with due allowance for site development and installation costs, the quotation received for the Masaya Plant was substantially above competitive pricing levels. One factor that could mitigate against this conclusion would be the need for inclusion of fuel treatment equipment costs in the Masaya Plant cost estimate, should this be required for Bunker C fuel oil, as no allowance was made for this in the manufacturer's cost quotation. It emphasizes the need to base future economic comparisons on competitive proposals, prepared in response to engineering specifications for plant and equipment.

S.3.3 TRANSMISSION PLANS FOR INDEPENDENT POWER SYSTEM EXPANSION

One objective of the transmission planning for independent system expansion was the completion of a preliminary study for the transmission facilities associated with the hydroelectric developments on the Rio Grande de Matagalpa. The purpose of the study was to select the appropriate transmission voltage and determine the approximate location and scheduling of facilities. The results of the study are contained in Appendix F and may be summarized in the recommendation that 230 kV transmission systems be utilized for either the two or three dam developments on the Rio Grande de Matagalpa. Comprehensive system expansion plans formulated for the alternative long-range developments include the transmission line and substation facilities associated with the two and three dam schemes. These are discussed in Section 7.1 of Chapter VII and are summarized as follows:

A. TWO DAM DEVELOPMENT TRANSMISSION SYSTEM FOR PLAN A1

The transmission system linking the Copalar high dam and Paso Real developments with the system load centers of Managua and Masaya is comprised of a 230 kV double-circuit line to transmit power direct from Copalar to Masaya, together with a 230 kV single-circuit line from Copalar to Masaya via Paso Real and a loop connection to the Los Brasiles Substation near Managua. This transmission loop is carried on a section of 230 kV double-circuit line between Masaya and Los Brasiles, with the final termination at the Masaya 230 kV bus. A schematic representation of the 230 kV transmission line arrangement is shown on Figure VII.1 of Chapter VII. The total circuit length of the 230 kV transmission system associated with the two dam development is approximately 630 kilometers.

The substations associated with Copalar and Paso Real consist of ring bus configurations, comprising six and three elements, respectively. At Copalar three 135 MVA transformer banks will step-up the 330 MW plant output from 13.8 kV generator voltage to 230 kV transmission voltage, for switching at the plant substation. A single 65 MVA transformer bank at Paso Real will transform the entire 50 MW output for connection to the high voltage transmission system. At the receiving end, the Masaya substation will require 230 kV switching facilities and provision for step-down transformation to 138 kV for subsequent transmission at the underlying voltage level. The 230 kV substation must accommodate line terminations for two Copalar circuits, the single-circuit from Los Brasiles, an ultimate installation of four 230/138 kV transformers and a bus-tie position. The Los Brasiles Substation will be expanded to allow the termination of the incoming line from Paso Real and the outgoing circuit to Masaya. No additional transformer capacity will be required at Los Brasiles.

B. THREE DAM DEVELOPMENT TRANSMISSION SYSTEM FOR PLAN B1

A similar 230 kV transmission system to that planned for the two dam development was included in the comprehensive plan for the three dam development of the Copalar low dam, El Carmen and Paso Real. The single exception to the previous transmission system configuration consists of the termination to the El Carmen plant substation of a section of 230 kV double-circuit line, which forms a loop inserted into one circuit of the double-circuit line from Copalar to Masaya. The transmission line arrangement for the three dam development is shown on Figure VII.2 of Chapter VII, the total circuit length being approximately 670 kilometers.

Switching facilities at the sending-end substations of the Copalar and Paso Real plants are similar to those for the two dam development. A six element ring bus configuration is planned for the Copalar Substation to accommodate two 135 MVA transformer banks, a single 65 MVA transformer for Unit 3 and three 230 kV line positions. At El Carmen a three element ring bus will be used to accommodate an 85 MVA, 13.8/230 kV step-up transformer position and two 230 kV line positions. The substation facilities at Paso Real, Masaya and Los Brasiles substations will be identical to those required for the two dam development.

C. SELECTION OF TRANSMISSION SYSTEM AND OPERATING VOLTAGE LEVEL

The basic transmission system design configuration and operating voltage level for the Copalar Project was determined following a detailed transmission voltage study, the results of which are contained in Appendix F. The selection was made between 230 kV and 138 kV for operating voltage, after successive economic comparisons were made between combinations of single and double-circuit line configurations, with evaluation of line losses.

To evaluate the alternative transmission systems according to a common measure of performance standards, the equipment and facility requirements for each voltage level were established based on the following criteria:

- Maximum Power Transfer
- Voltage Regulation
- Transmission Stability
- Thermal Limits
- System Reliability

Facility requirements were defined for both 138 kV and 230 kV voltage levels, these being contained within four alternative plans for the Copalar Project transmission system.

Plan	Description of Alternative Transmission Systems
F1	Five Single-Circuit 138 kV Lines
F2	Three Single-Circuit 230 kV Lines
F3	One Single-Circuit and Two Double-Circuit 138 kV Lines
F4	One Single-Circuit and One Double-Circuit 230 kV Lines

Plans F1 and F2 were compared to determine the most economic single-circuit transmission system, then Plans F3 and F4 were analysed to determine the best combination of circuit configurations and operating voltage. Finally Plans F2 and F4 were compared for definitive plan selection.

Investment costs and O & M expenses were estimated for the transmission line and substation facilities comprising each of the alternative plans, together with an evaluation of losses corresponding to each of the transmission systems, for economic comparison. Successive plan combinations were compared by present worth analysis of discounted cash flow, at 1975 cost levels and also with escalation applied for sensitivity analysis. The results of the economic analyses are contained in the Annexes to Appendix F. and are shown graphically on Figures F.6, F.7 and F.8. The sensitivity analyses at escalated cost leves are summarized in Tables F.8, F.9 and F.10 of Appendix F, for five sensitivity tests with successive escalation profiles applied to investment and O & M.

At 1975 cost levels, the following differentials were indicative of the relative advantage of alternative plans in terms of the present worth of future expenditures.

Plan	Vs.	Plan	Net Differential	In Favor of Plan
F1		F2	$2,981,000	F2
F3		F4	$2,380,000	F4
F2		F4	$1,487,000	F4

So, by successive analytical steps, the selection of Plan F4 was made for the Copalar Project, to enable a firm recommendation of 230 kV as the operating voltage. The transmission system will comprise one double-circuit line and a single-circuit line from Copalar to the delivery point at the Masaya Substation. This system provides transmission reliability at the most economical cost of facilities and was used as the basis for all subsequent planning of the transmission system for the Copalar Project, in context of a general system expansion plan.

S.4 GENERAL PLAN FOR INTERCONNECTED POWER SYSTEM EXPANSION

The basic long-range plans, discussed in the previous section, pertain to the introduction of alternative hydroelectric power developments on the Rio Grande de Matagalpa into comprehensive plans for the independent expansion of the National Interconnected System. As the name implies, the ENALUF power system is interconnected within Nicaragua to supply a service area covering the Pacific, North and Central Zones, as shown on the location map which forms the frontispiece to this report. It is decided that the ENALUF system be interconnected with the ENEE system of Honduras, the present schedule for construction of the transmission facilities is intended to allow the energization of the transmission inter-tie between Pavana and Leon Substations during 1976. At present, the proposed interconnection between the ENALUF system and the ICE system of Costa Rica is under study, with a possible commissioning date set for July, 1978. The effect of the interconnections on the basic plans for generation expansion of the ENALUF system are discussed in Chapter VI, with detailed economic analysis relating to the selection of operating voltage level and determination of viable tie-line rates being given in Appendices H and I.

S.4.1 TRANSMISSION PLANS FOR INTERCONNECTED POWER SYSTEM EXPANSION

The transmission plans presented in Section VII.2 of Chapter VII are adequate to meet ENALUF system requirements for general transmission expansion over the period 1978 through 1988. However, these plans also take into consideration the possible impact of transmission interconnections between national power systems

of adjacent countries on the Isthmus of Central America. Energy from the two major indigenous resources of Nicaragua, geothermal and hydroelectric sources, will be generated for transformation to a 230 kV transmission grid that will extend across national frontiers, to link the main supply systems of Honduras, Nicaragua and Costa Rica.

The second objective of transmission planning, accomplished during the course of the study, was the coordination of the scheduled transmission facilities required for the selected hydroelectric development on the Rio Grande de Matagalpa within an overall plan for expansion of the National Interconnected System. The resultant recommended line arrangement was similar to the basic plans discussed in Section S.3, comprising a 185 kilometer double-circuit 230 kV line from the Copalar generating plant to an existing load-center substation located at Masaya, together with a 213 kilometer single-circuit 230 kV line from Copalar to the planned Los Brasiles Substation, which will be located northwest of Managua. A loop connection will be made between the Los Brasiles and Masaya terminal substations via the second circuit of a 37 kilometer section of double-circuit 230 kV line. The first circuit of this line will form part of the interconnection between the ENALUF and ICE systems, with the continuation from Masaya to the Frontier at Penas Blancas carried on a 119 kilometer section of single-circuit 230 kV line. The planned interconnection with the ENEE system of Honduras will consist of a single-circuit 230 kV line connecting the Leon Substation with the Pavana Substation in Honduras. Initially the ENALUF-ENEE transmission inter-tie will be operated at 138 kV; however, the operating voltage will be upgraded to 230 kV for firm power transfer from the El Cajon hydroelectric plant in Honduras beginning in 1982.

Six major transmission projects are included in plans for the development period 1978-1988:

- Interconnection in 1978 with the ICE system of Costa Rica.
- Rural electrification of new load zones beginning in 1978.
- Extension of 230 kV grid, for transmission of Momotombo geothermal power in 1979 and firm capacity transfers from Honduras after 1981.
- Completion of the 138 kV transmission ring, around the Managua and Masaya load centers in 1979, by the Sur-Masaya 138 kV line.
- Upgrading of the interconnection with Honduras to 230 kV operation in 1982.
- Transmission system associated with the Copalar hydroelectric development.

The above projects are discussed in Section 7.2.3 of Chapter VII, with the expansion plans for the National Interconnected System for the period 1978-1988 shown on Figure VIII.3.

S.4.2 INTERCONNECTION WITH ICE (COSTA RICA) SYSTEM

The definition of the potential for off-peak energy transfer from the ICE system of Costa Rica to the ENALUF system of Nicaragua is discussed in Section 6.1 of Chapter VI, with tabulations of energy available and transfer limitations due to system constraints, based on projected monthly energy surpluses provided by the ICE Planning Department.

Three options for operating voltage and terminal location form the basis for analytical and economic studies to select a definitive plan for system interconnection. The results of these studies are given in Appendix H and may be summarized as follows:

- The economic operating voltage level for the inter-tie must be 230 kV.
- The ENALUF system terminal is to be located at Los Brasiles Substation.
- The interconnection line route is Los Brasiles to the Frontier, via Masaya.

The detailed economic analysis pertaining to the determination of breakeven tie-line rates for off-peak energy transfer is contained in Appendix H. The rates are defined as a matrix of values corresponding to 1975 cost levels and a range of escalation profiles over a series of discount rates corresponding to cost of capital. An example is given of the effect of the most recent OPEC oil-price increase on the breakeven rate for energy purchases at the Nicaragua/Costa Rica frontier.

It is recommended that the Consultants for the ENALUF-ICE Interconnection Study, continue the analysis of optimal energy transfer between the two systems, taking into consideration the future impact of firm power transfers as well as off-peak energy. The generation expansion program of ICE should be reviewed with a view to utilizing available firm power capacity and energy from the El Cajon plant in Honduras. System reserves should be carefully analysed to minimize individual system margins following a policy of shared risk for interconnected system operation. There are potential mutual benefits to interconnection of the ENALUF and ICE systems, the task ahead is to optimize for their realization in the interest of the participants.

S.4.3 INTERCONNECTION WITH ENEE (HONDURAS) SYSTEM

The ramifications of the interconnection of the ENALUF system with the ENEE system of Honduras are discussed in Sections 6.2 and 6.3 of Chapter VI. The present schedule for the introduction of the El Cajon hydroelectric plant to the ENEE system, will enable firm power allocations to be contracted by ENALUF for the period 1982 through the end of the development decade in 1988. The most critical years are 1982 to 1986, inclusive, as the allocations made for these years are keyed to the scheduled introduction of the Copalar hydroelectric plant on the ENALUF system. Thereafter, the energy balance depends on the complementary aspects of imported hydroelectric energy and the optimum utilization of indigenous sources of energy, to enable minimal usage of imported fuel-oil for generation purposes.

In addition the reliability of supply on the ENALUF system is dependent on the availability of firm power from the ENEE system beginning in 1982. On-peak capacity is fortunately available in excess of the actual allocations required to maintain preferred risk levels on the ENALUF system. The tabulation on the following page provides a comparison of available capacity and energy with the required allocations defined in this study.

This tabulation serves to emphasize the possibility of major firm power transfers from Honduras to Nicaragua and potentially to Costa Rica and even Panama. The sale of allocations of El Cajon power to Guatemala is a possibility, but the great need is for a major re-examination of the generation expansion programs of all national systems in Central America that could potentially benefit from a sharing of national resources.

ENALUF - ENEE (HONDURAS) INTERCONNECTION

COMPARISON OF POWER AVAILABLE WITH REQUIRED POWER ALLOCATIONS

	Capacity - MW/%			Energy - GWH/%		
Year	Available	Required	Surplus	Available	Required	Surplus
1982	194/100	45/23	149/77	982/100	361/37	621/63
1983	172/100	65/38	107/62	862/100	569/66	293/34
1984	148/100	85/57	63/43	732/100	732/100	-
1985	120/100	50/42	70/58	588/100	401/68	187/32
1986	91/100	45/49	46/51	430/100	376/87	54/13
1987	58/100	10/17	48/83	254/100	11/4	243/96
1988	21/100	10/48	11/52	62/100	47/76	15/24
1989	99/100	99/100	-	277/100	277/100	-

The mutual benefits from the sequential interconnection of power systems along the Isthmus are too great to neglect at this time of energy crisis. The long-term aim should be an integration of national systems from Mexico to Panama, within the framework of a supra-national agency for international development in the Americas. In this regard guidance can be provided by CEPAL. An impetus can be gained at this juncture, spurred on by the ever-pressing need to continue progressive regional efforts for the economic integration of Central America.

A detailed economic analysis of interconnected system expansion as compared with independent system expansion is provided in Appendix I, which includes the determination of viable tie-line rates for purchases by ENALUF from both ENEE of Honduras and ICE of Costa Rica, over the time-frame 1982 through 1988. The potential benefits accruing to the participating utilities are such as to render imperative the need for early commencement of serious negotiations for the interchange of power.

S.4.4 SINGLE DAM DEVELOPMENT FOR INTERCONNECTED SYSTEM EXPANSION

The utilization of on-peak power allocations from the ENEE system of Honduras and off-peak energy transfers from the ICE system of Costa Rica will enable the thermal dispatch on the ENALUF system to be minimal from the end of 1981 to the last year of the decade of development in 1988. The availability of a major power allocation from Honduras in 1989 will postpone the need for introduction of the Paso Real hydroelectric plant of the two dam development to the year 1990 at the earliest. Hence, the recommended plan for interconnected system expansion will only require the placement of a single dam at the Copalar site,as opposed to the two dam development for independent expansion of the ENALUF system.

The resource development and utilization program, intrinsic to the generation additions and power purchases of interconnected system expansion Plan E1, is given in Table S.4 and Figure S.4 shows the components of energy purchase and system generation.

Table S.4 Sheet 1

EMPRESA NACIONAL DE LUZ Y FUERZA
NATIONAL INTERCONNECTED SYSTEM
N I C A R A G U A
GENERATION EXPANSION PLAN E1
1978-1988

COPALAR HIGH DAM DEVELOPMENT ON RIO GRANDE DE MATAGALPA
POWER PURCHASES FROM HONDURAS AND COSTA RICA
F O R
INTERCONNECTED SYSTEM EXPANSION

YEAR	GENERATING PLANT ADDITIONS SOURCE	UNIT	TYPE	MW	GWH	TOTAL EFFECTIVE OPERATING CAPACITY OF SYSTEM RESOURCES MW	TOTAL FIRM ANNUAL ENERGY FROM RESOURCES GWH	SYSTEM PEAK DEMAND MW	SYSTEM GROSS ENERGY GENERATION REQUIRED GWH	NOMINAL SYSTEM RESERVE MW	%	GWH	%	INSTALLED RESERVE MARGIN AFTER LOSS OF LARGEST RISK MW	%	LOSS OF LOAD PROBABILITY (RISK LEVEL INDEX) DAYS/YEAR
Base	Existing Plants plus Thermal Units Installed at Puerto Somoza Plant					283	1,640									
1978	Energy Purchase from ICE				147	283	1,787	220	1,253	63	29	534	43	13	6	1.18
1979	Momotombo	1	G	45	350											
	Energy Purchase from ICE		P	-	112											
	Total Source Additions			45	462	328	2,102	241	1,374	87	36	728	53	37	15	0.94
1980	Momotombo	2	G	45	350											
	Energy Purchase from ICE		P	-	90											
	Total Source Additions			45	440	373	2,430	266	1,508	107	40	922	61	57	21	0.62
1981	Momotombo	3	G	45	350											
	Energy Purchase from ICE		P	-	57											
	Total Source Additions			45	407	418	2,747	295	1,668	123	42	1,079	65	73	25	0.87
1982	Power Purchase from ENEE		P	45	361											
	Energy Purchase from ICE		P	-	31											
	Total Source Additions			45	392	463	3,082	326	1,837	137	42	1,245	68	87	27	0.07
1983	Power Purchase from ENEE		P	65	569											
	Energy Purchase from ICE		P	-	14											
	Total Source Additions			65	583	483	3,273	361	2,027	122	34	1,246	61	57	16	0.30
1984	Power Purchase from ENEE		P	85	732											
	Energy Purchase from ICE		P	-	7											
	Total Power Purchases			85	739											
	Copalar	1	H	55	-											
	Copalar	2	H	55	-											
	Total Unit Additions			110												
	Total Source Additions			195	739	613	3,429	394	2,210	219	56	1,219	55	134	34	1.01

END OF FIRST RESERVOIR FILLING SEASON - LIMITED OPERATION ONLY IN 1984

TABLE S.4 Sheet 2

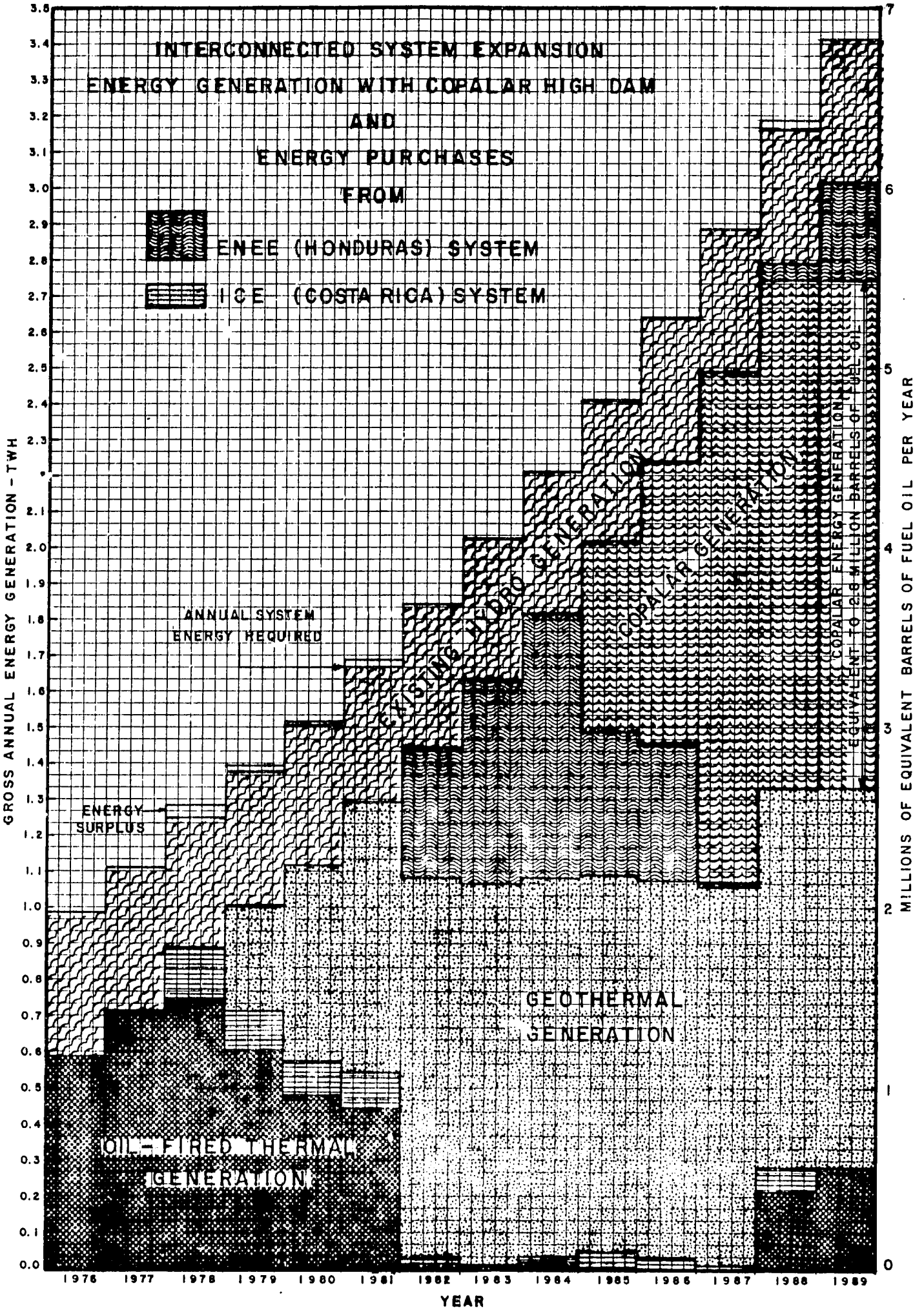
EMPRESA NACIONAL DE LUZ Y FUERZA
NATIONAL INTERCONNECTED SYSTEM
N I C A R A G U A
GENERATION EXPANSION PLAN E1
1978-1988

COPALAR HIGH DAM DEVELOPMENT ON RIO GRANDE DE MATAGALPA
POWER PURCHASES FROM HONDURAS AND COSTA RICA
F O R
INTERCONNECTED SYTEM EXPANSION

YEAR	GENERATING PLANT ADDITIONS SOURCE	UNIT	TYPE	MW	GWH	TOTAL EFFECTIVE OPERATING CAPACITY OF SYSTEM RESOURCE MW	TOTAL FIRM ANNUAL ENERGY FROM RESOURCES GWH	SYSTEM PEAK DEMAND MW	SYSTEM GROSS ENERGY GENERATION REQUIRED GWH	NOMINAL SYSTEM RESERVE MW	%	GWH	%	INSTALLED RESERVE MARGIN AFTER LOSS OR LARGEST RISK MW	%	LOSS OF LOAD PROBABILITY (RISK LEVEL INDE DAYS/YEAR
1985	Power Purchase from ENEE		P	50	401											
	Energy Purchase form ICE		P	-	40											
	Total Power Purchases			50	441											
	Copalar	3	H	55		OPERATION DURING 2ND YEAR OF RESERVOIR FILLING - 37% OF NORMAL ANNUAL ENERGY										
	Copalar	4	H	55												
	Total Unit Additions			110	526											
	Total Source Additions			160	987	688	3,657	431	2,411	257	60	1,246	52	202	47	0.09
1986	Power Purchase from ENEE		P	45	376											
	Energy Purchase from ICE		P	-	25											
	Total Power Purchases			45	401											
	Copalar	5	H	55		OPERATION DURING 3RD YEAR OF RESERVOIR FILLING - 56% OF NORMAL ANNUAL ENERGY										
	Copalar	6	H	55												
	Total Unit Additions			110	262											
	Total Source Additions			155	663	793	3,879	472	2,635	321	68	1,244	47	266	56	0.01
1987	Power Purchase from ENEE		P	10	11											
	Energy Purchase from ICE		P	-	9	COPALAR RESERVOIR FULL-FIRST YEAR OF NORMAL ENERGY GENERATION										
	Total Power Purchases			10	20											
	No Unit Additions			-	630											
	Total Source Additions			10	650	758	4,128	518	2,884	240	46	1,244	43	185	36	0.01
1988	Power Purchase from ENEE		P	10	47											
	Energy Purchase from ICE		P	-	66											
	Total Power Purchases			10	113											
	No Unit Additions			-	-											
	Total Source Additions			10	113	758	4,221	568	3,160	190	33	1,061	34	135	24	0.61
1989	Power Purchase from ENEE		P	100	277											
	No Energy Purchase from ICE		P		-											
	Total Power Purchases			100	277	848	4,385	615	3,413	233	38	972	28	133	22	0.62

Note: Type Code: H - Hydro
G - Geothermal
P - Purchase

FIG. S.4


INTERCONNECTED SYSTEM EXPANSION
ENERGY GENERATION WITH COPALAR HIGH DAM
AND
ENERGY PURCHASES
FROM
ENEE (HONDURAS) SYSTEM
ICE (COSTA RICA) SYSTEM
ANNUAL SYSTEM ENERGY REQUIRED
ENERGY SURPLUS
OIL-FIRED THERMAL GENERATION
GEOTHERMAL GENERATION
COPALAR ENERGY GENERATION
COPALAR ENERGY GENERATION EQUIVALENT TO 2.8 MILLION BARRELS OF FUEL OIL
GROSS ANNUAL ENERGY GENERATION - TWH
MILLIONS OF EQUIVALENT BARRELS OF FUEL OIL PER YEAR
YEAR
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989

Sheet 1 provides system data for the period 1978 to 1984, from the base-year of the study to the year during which the first two units at the Copalar High Dam are commissioned ready for commercial service. Sheet 2 continues the system expansion from 1985 to 1989, during which period the Copalar reservoir fills to capacity and begins normal operation.

The salient feature of the tabulations on Sheets 1 and 2 of Table S.4 is the relatively large capacity and energy reserves, caused by the effective retirement of thermal generation from operation on a progressive basis, following the introduction of the first geothermal generating plant at the Momotombo site. The investment in the existing thermal plant and in particular, the new Puerto Somoza Plant now under construction, must be covered by revenue from the sale of energy generated by oil-fired units. The problem thus created has to be solved by arranging for the alternative use of the Puerto Somoza Plant as an 'Extra-Utility System' supply source.

S.5 ALTERNATIVE UTILIZATION OF PUERTO SOMOZA THERMAL PLANT

In this time of energy crisis and the renewed search for viable alternatives to the continued use of fuel-oil for thermal generation, it is somewhat paradoxical that after an energy solution has been found for Nicaragua during the present power study, the viable solution has created the problem of how best to utilize the Puerto Somoza oil-fired thermal plant that has been rendered economically inoperative by the policy of OPEC. In particular, the problem is all too apparent that, having been committed prior to the October War of 1973 and the imposition of quadruple oil prices, the new units of the Puerto Somoza Thermal Plant are apparently obsolete before they have even been placed in commission. The planners who visualized the growth of the thermal plant at Point Tiscucu to a six-unit plant of 500 MW ultimate capacity, could hardly imagine the impact of the present posted prices for fuel-oil and possible future escalation on the realization of their projected plans. However, the oil pricing structure is a reality and future escalation has an immediacy that is as near as the OPEC Council decision to increase posted oil prices by 10 percent, effective October 1, 1975.

In the Nicaragua Power Study, a plan has been conceived that effectively dispenses with the need to generate power at the Puerto Somoza Plant after 1981, by careful utilization of the indigenous hydroelectric and geothermal resources of Nicaragua, supplemented by importations of limited allocations of power over transmission system interconnections with Honduras and Costa Rica. Figure S.4 illustrates the resulting energy generation 'mix' when hydroelectric and geothermal energy is substituted for oil-fired thermal generation. It is clear that after a period of five years from the in-service date of the twin 50 MW units at Puerto Somoza, the thermal dispatch over the period 1982-1987 is effectively nullified, with a promise of entire elimination if geothermal development proves to be more successful than the conservative estimates used for the present study. The problem that presents itself is then, to what alternative economic use can the two 50 MW Puerto Somoza units, now under construction, be turned from 1982 on.

Complex though the solution may seem, the problem is relatively easily formulated: How can two thermal units be utilized economically for approximately 70 to 80 percent of their useful service life, with oil prices prevailing from 1982 through 2007, when their need as sources of supply for the National Interconnected System, or energy sales to other systems, is pre-empted by the development of economic indigenous resources.

The potential solution has to be sought in the harnessing of thermal energy to supply the public needs of Nicaragua through the medium of private industry, with sufficient economic incentive to offset the adverse oil pricing structure. An accommodation has to be reached with private enterpreneurs and industrialists, to enable them to introduce the expertise which will serve to enhance the future growth of the Nicaraguan economy, even with the burden of fuel costs priced at OPEC levels for crude delivered to the ESSO off-shore terminal at Tiscuco from the Maracaibo field.

The technology that will produce the input to the primary and secondary sectors of the economy is available, all that is required is energy delivered at economic rates. In selecting the process or industrial complex that will make the greatest impact on the economic growth of the nation, cognizance has to be taken of the inter-related needs of the agro-industrial economy of Nicaragua. What commodity represents the achievement of a measure of independence from the petrochemical industry. One of the unfortunate aspects of the quantum leap of oil prices in 1973-74, was the double burden placed on developing nations, dependent so heavily on inputs of energy and fertilizer to further the agro-industrial growth processes.

The problem becomes more clearly defined when the necessity arises to use high priced oil as input to produce energy at related price levels, for sale to industry or process plants that will help alleviate shortages of the single ingredient necessary to accelerate the growth of the primary sector - fertilizer for agriculture and the production of the nation's food supply.

The feasibility of fertilizer process plants, particularly with electrolytic processes requiring large energy blocks as inputs for sustained time periods, relies on an economic purchase rate for the primary energy supply to enable competitive pricing of output fertilizer products in the national or regional market. The provision of energy at an economic rate is attained by the careful utilization of indigenous resources, to supplement the high priced oil inputs to the single power plant able to supply continuous energy requirements of a process that requires high plant factor operation to meet an equally high load factor utilization.

Hydroelectric resources are abundant in Nicaragua and adjacent countries of Central America and one of the most effective ways of diluting the high price of energy generated with oil as fuel is to harness the natural resources of hydroelectric energy, in tandem with the geothermal resources of the earth under the soil of Nicaragua. It would be a natural closing of the energy cycle, if hydroelectric energy from the Copalar development on the Rio Grande de Matagalpa were used in conjunction with geothermal energy from Momotombo, to supplement thermal energy from the Puerto Somoza plant, for supply to a fertilizer process plant which would return the natural elements to the soil of Nicaragua for the bountiful harvest of the future. Technology can make this possible with the application of human ingenuity, all that is presently required is an executive decision for immediate implementation.

CAPITULO I

HIDROLOGIA
Y
METEOROLOGIA

CHAPTER I

HYDROLOGY
AND
METEOROLOGY

CHAPTER I

HYDROLOGY AND METEOROLOGY

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CHAPTER I
HYDROLOGY AND METEOROLOGY

1.1 INTRODUCTION

This chapter contains the results of the hydrology and meteorology investigations performed during Phase II. This work is a continuation, refinement and up-dating of the more preliminary investigations perfomed during Phase I. The results of the Phase I Study are contained in Chapter III, Hydrology and Meteorology, of the report covering that phase. Some portions of the earlier report are entirely repeated herein for convenience. Other portions appear to be very similar, but actually vary considerably in numerical values and other data as a result of the additional basic data available and work performed during Phase II.

1.1.1 PURPOSE

Phase I studies of the designated reaches of the Rio Coco, Rio Viejo and Rio Grande de Matagalpa resulted in the selection of projects on the Rio Grande de Matagalpa and at Laguna de Apoyo as most feasible for immediate development. Phase II studies discussed in this chapter were undertaken, principally for selected projects on the Rio Grande de Matagalpa, to:

1. Incorporate revised and additional monthly mean discharges in calculations of average discharge.

2. Incorporate additional data from the Hurricane Fifi flood of September 1974 in the construction flood studies.

3. Improve estimates of spillway design floods for the selected construction sequence of the projects.

4. Assess the significance of any changes in estimates of reservoir sedimentation resulting from revised monthly mean discharge.

1.1.2 STUDY AREAS

The designated study areas for consideration and exploration of water power potential and exploitation in Phase I are shown on Figure I.1 and in greater detail on Figure I.2. The Rio Coco study reach extends for a distance of 62 kilometers between Cano Namasli and Quebrada El Corozal and has a total fall in river bed level of about 120 meters. The study reach for the Rio Grande de Matagalpa extends for a distance of 220 kilometers between Quebrada El Jicaro and Rio Okawas and has a total fall of about 325 meters.

The study of Rio Viejo included the Nicaragua Project and the Rafael Mora Project only which have been studied previously by another consultant. Operation of two existing hydroelectric installations, Centroamerica and Somoza Garcia on the Rio Viejo, were considered in the study of the specified projects and required consideration of more than 100 kilometers of the Rio Viejo between Centroamerica in the headwater area and Rafael Mora

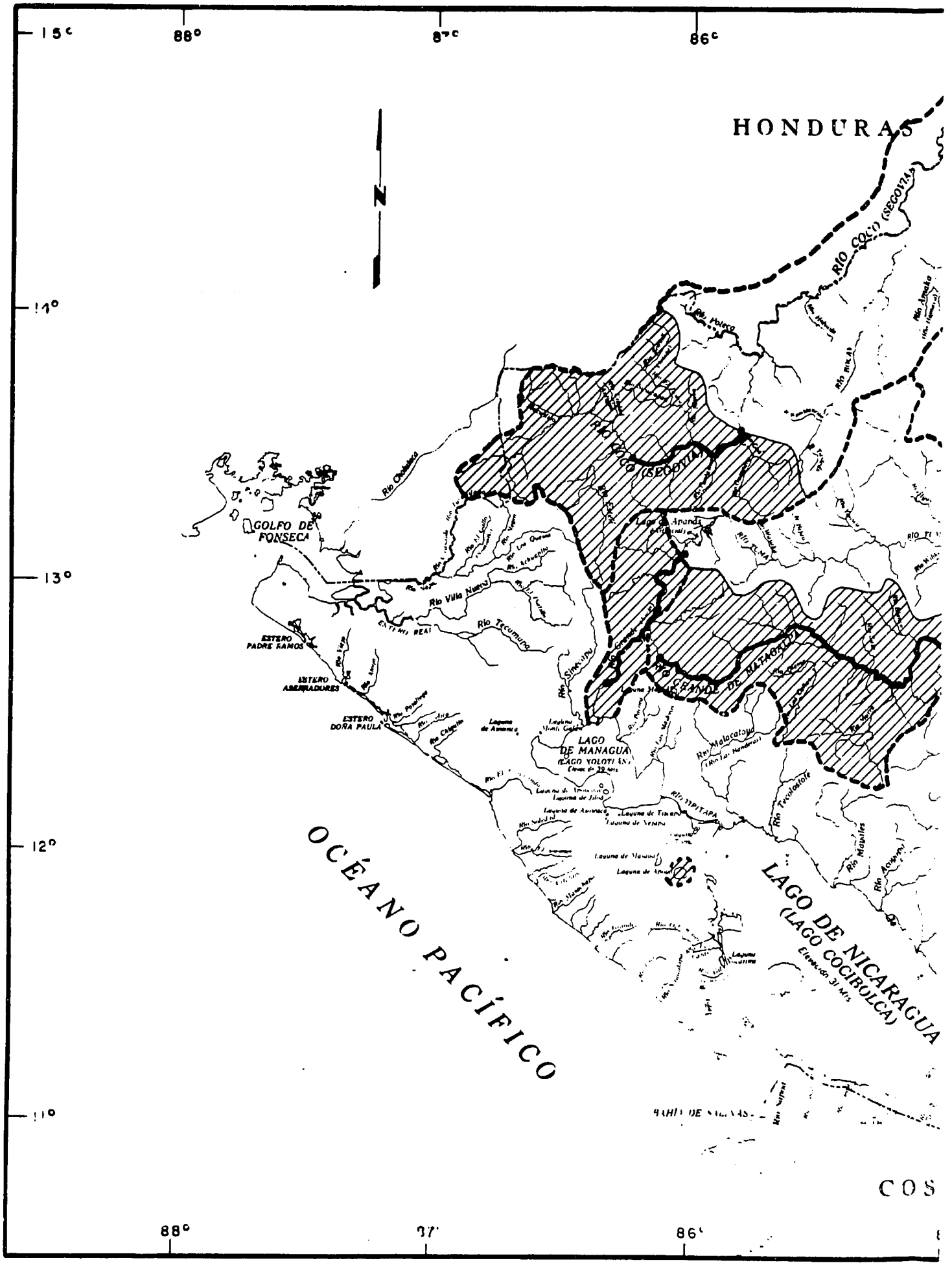
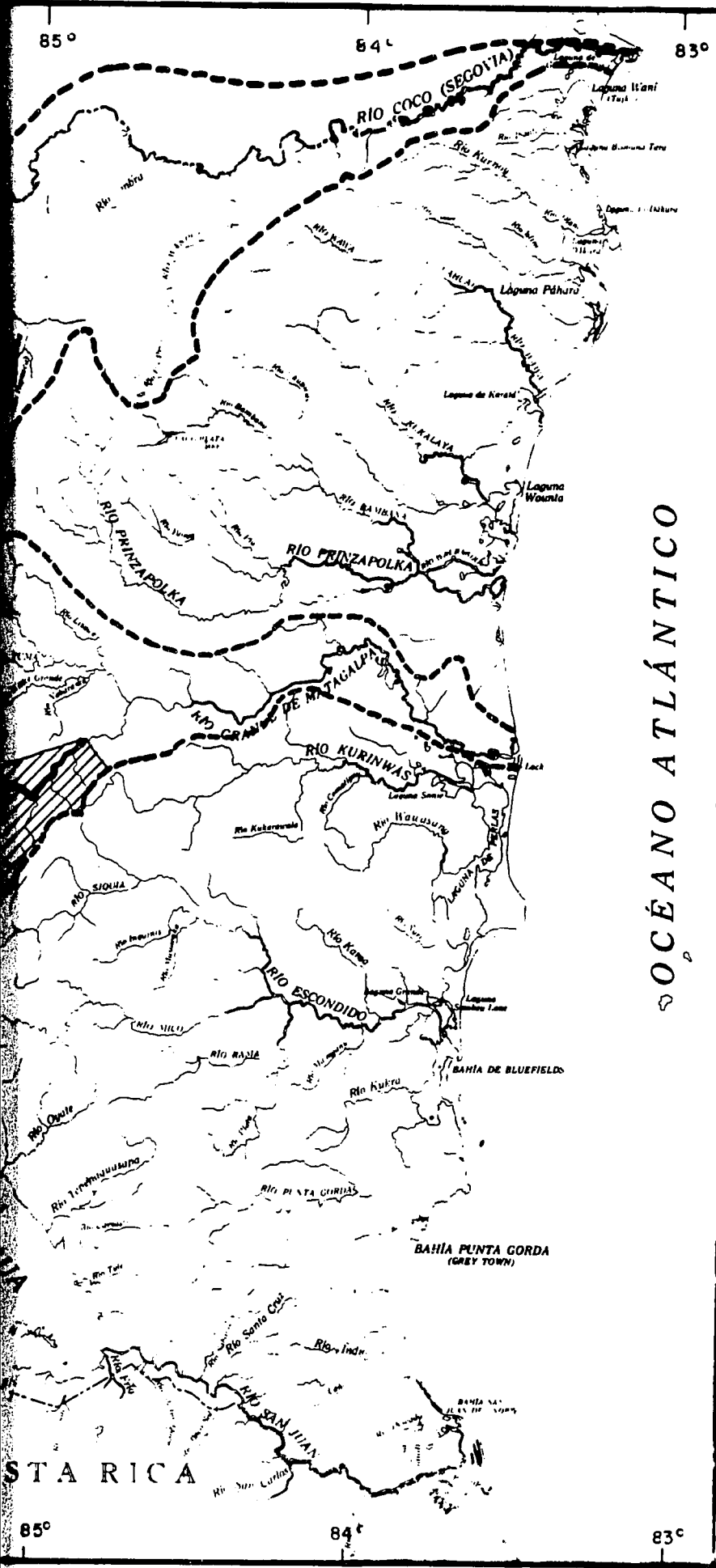

HONDURAS
RIO COCO (SEGOVIA)
RIO RIO (SEGOVIA)
GOLFO DE FONSECA
Rio Villa Nueva
Rio Tecomuca
ESTERO REAL
ESTERO PADRE RAMOS
ESTERO ABRAZADORES
ESTERO DOÑA PAULA
LAGO DE MANAGUA
(LAGO XOLOTLAN)
Rio Malacatoya
Rio Tipitapa
Rio Tecolostote
Rio Mayales
OCÉANO PACÍFICO
LAGO DE NICARAGUA
(LAGO COCIBOLCA)
Elevación 31 mts
BAHIA DE SALINAS
COS
15°
14°
13°
12°
11°
88°
87°
86°

FIG. I. 1



LEYENDA
Legend

LIMITE DE CUENCA EN ESTUDIO
Study Drainage Area Boundary

TRAMO DEL RIO EN ESTUDIO
River Study Reach

FRONTERA INTERNACIONAL
International Boundary
EXCEPTO CUANDO ESTA FORMADA POR LOS RIOS
Except When Formed by Rivers

0 20 40 60
MILLAS TERRESTRES
Miles

0 20 40 60 80 100
KILOMETROS
Kilometers

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA DN. NICARAGUA

PLAN GENERAL DE DESARROLLO - NATIONAL POWER STUDY 1976-1980
ESTUDIO DE PREFACTIBILIDAD FASE II

MAPA DE LOCALIZACION - AREAS DE ESTUDIO

LOCATION MAP - STUDY AREAS

INTERNATIONAL ENGINEERING COMPANY, INC.

DRAWN / DIBUJO M.R.G.	CHKD. / REVISO	APPROVED / APROBADO

SAN FRANCISCO, CAL.

DATE / FECHA AGOSTO 29, 1975

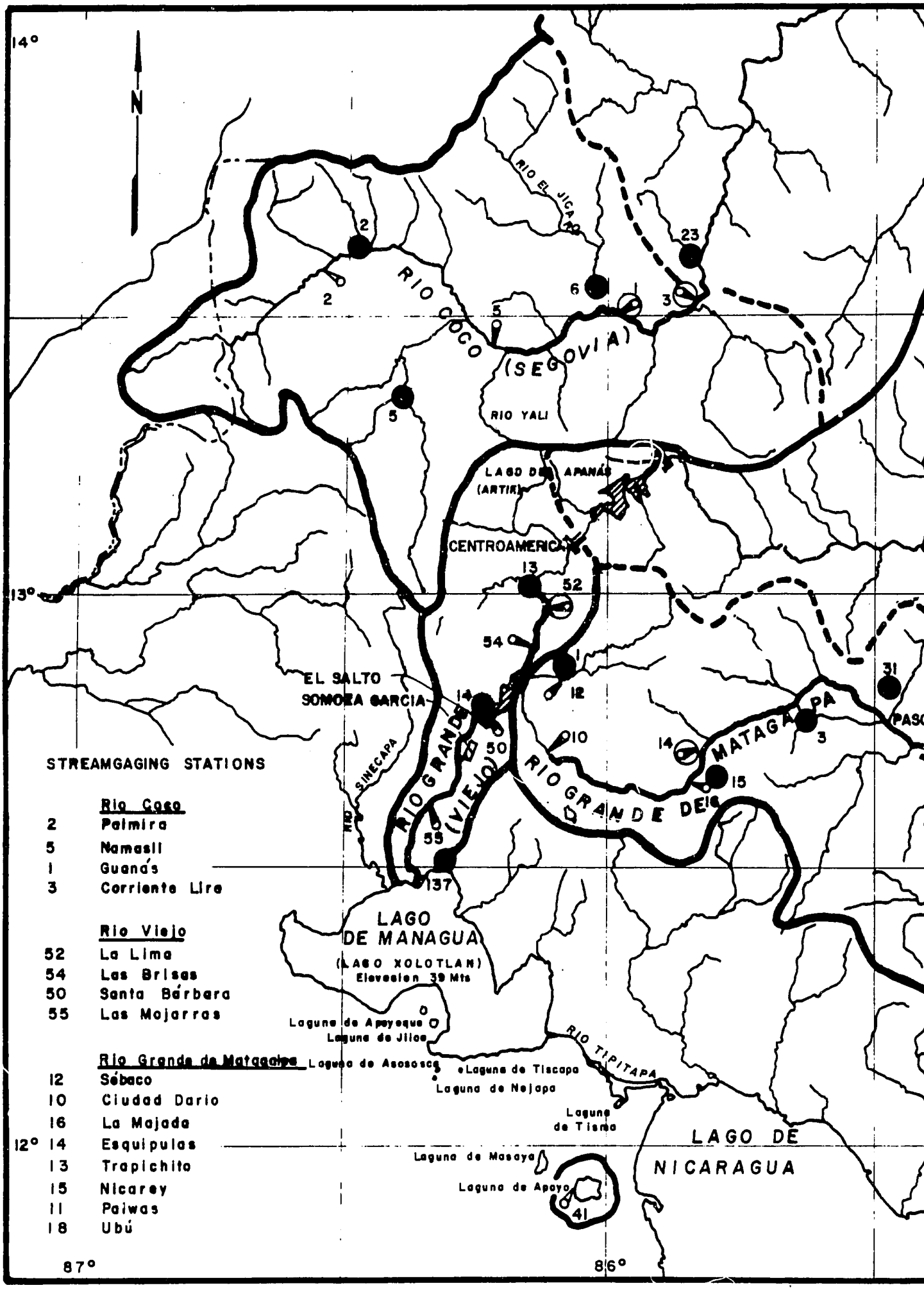
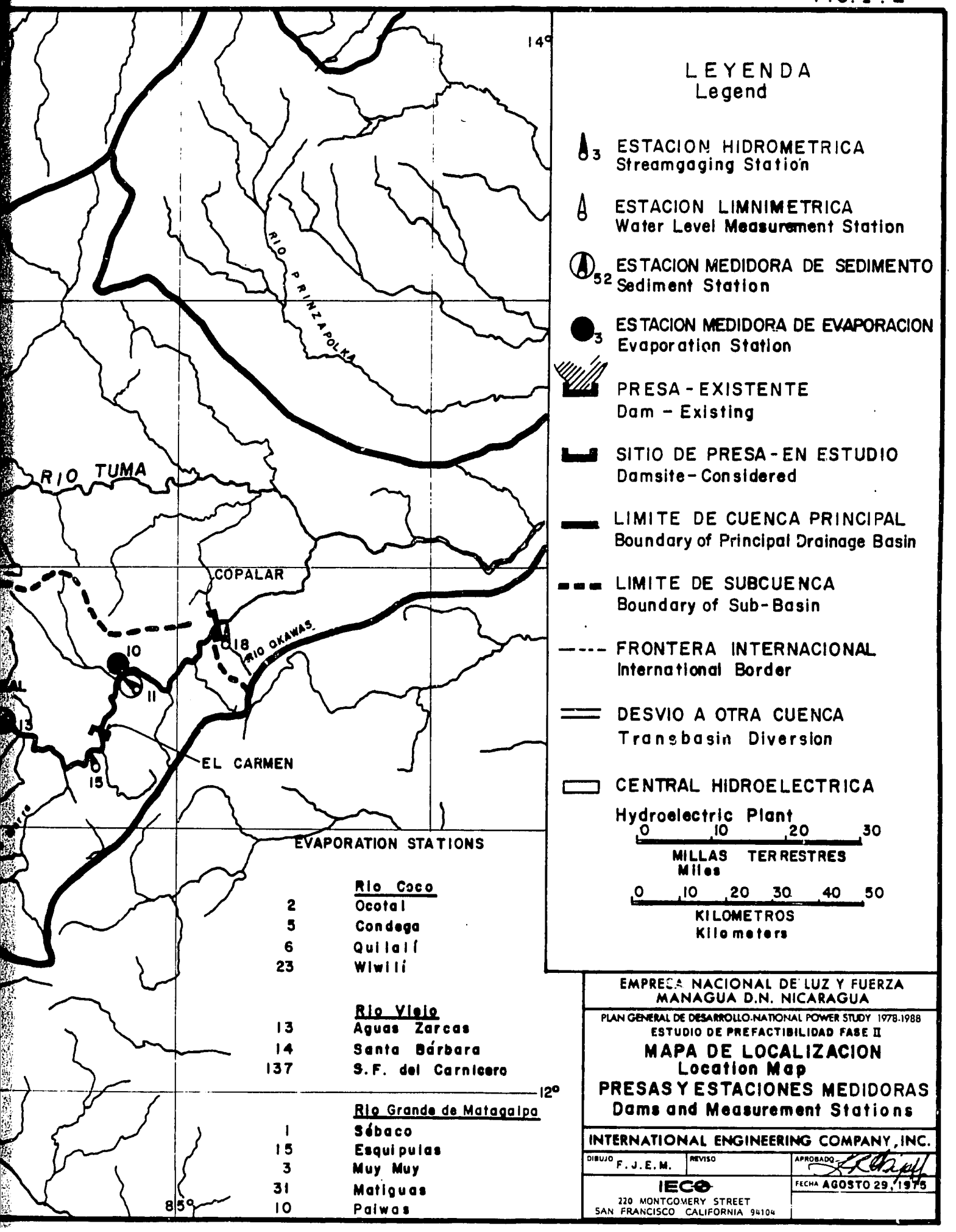

14°
13°
12°
87°
86°
N
RIO EL JICARO
RIO COCO (SEGOVIA)
RIO YALI
LAGO DE APANÁS (ARTIZ)
CENTROAMERICA
EL SALTO SOMOZA GARCIA
SINECAPA
RIO GRANDE (VIEJO)
RIO GRANDE DE MATAGALPA
RIO TIPITAPA
LAGO DE MANAGUA
(LAGO XOLOTLAN)
Elevacion 39 Mts
Laguna de Apoyeque
Laguna de Jiloa
Laguna de Asosasca
Laguna de Tiscapa
Laguna de Nejapa
Laguna de Tisma
Laguna de Masaya
Laguna de Apoyo
LAGO DE NICARAGUA
STREAMGAGING STATIONS
Rio Coco
2 Palmira
5 Namasli
1 Guanás
3 Corriente Lire
Rio Viejo
52 La Lima
54 Las Brisas
50 Santa Bárbara
55 Las Mojarras
Rio Grande de Matagalpa
12 Sébaco
10 Ciudad Dario
16 La Majada
14 Esquipulas
13 Trapichito
15 Nicarey
11 Paiwas
18 Ubú

FIG. I . 2


14°
RIO PRINZAPOLKA
RIO TUMA
COPALAR
RIO OKAWAS
10
11
18
13
15
EL CARMEN
EVAPORATION STATIONS
Rio Coco
2 Ocotal
5 Condega
6 Quilalí
23 Wiwili
Rio Viejo
13 Aguas Zarcas
14 Santa Bárbara
137 S.F. del Carnicero
12°
Rio Grande de Matagalpa
1 Sébaco
15 Esquipulas
3 Muy Muy
31 Matiguas
10 Paiwas
85°
LEYENDA
Legend
3 ESTACION HIDROMETRICA
Streamgaging Station
ESTACION LIMNIMETRICA
Water Level Measurement Station
52 ESTACION MEDIDORA DE SEDIMENTO
Sediment Station
3 ESTACION MEDIDORA DE EVAPORACION
Evaporation Station
PRESA - EXISTENTE
Dam - Existing
SITIO DE PRESA - EN ESTUDIO
Damsite - Considered
LIMITE DE CUENCA PRINCIPAL
Boundary of Principal Drainage Basin
LIMITE DE SUBCUENCA
Boundary of Sub-Basin
FRONTERA INTERNACIONAL
International Border
DESVIO A OTRA CUENCA
Transbasin Diversion
CENTRAL HIDROELECTRICA
Hydroelectric Plant
0 10 20 30
MILLAS TERRESTRES
Miles
0 10 20 30 40 50
KILOMETROS
Kilometers
EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
MAPA DE LOCALIZACION
Location Map
PRESAS Y ESTACIONES MEDIDORAS
Dams and Measurement Stations
INTERNATIONAL ENGINEERING COMPANY, INC.
DIBUJO F. J. E. M.
REVISO
APROBADO
IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104
FECHA AGOSTO 29, 1975

near Lago de Managua.

The study requirement also included a pumped-storage project at Laguna de Apoyo, also previously studied by another consultant. The study included the volcanic lake itself and the contributing drainage area.

The Phase II Study areas are limited to Laguna de Apoyo for the pumped-storage project and the lower reaches of the Rio Grande de Matagalpa where the selected projects, Paso Real, El Carmen and Copalar are located. The locations of these projects are shown on Figure 1.2.

1.1.3 DESCRIPTION OF RIVER BASIN AND LAGUNA DE APOYO

A. RIO GRANDE DE MATAGALPA

The headwaters of the Rio Grande de Matagalpa, the second longest river in Nicaragua, originate northeast of the town of Sebaco at elevation 1,500 meters. At Sebaco, the southwest course of the river in the Sebaco Valley plain turns south to Ciudad Dario. Below Ciudad Dario, the river is at elevation 400 meters and sweeps in a broad arc to the northwest past Esquipulas to Paso Real where the river is at elevation 205 meters. Downstream of this location, the river is more confined by hills in its southeast trending direction to Nicarey and rapids are more frequent. At Nicarey the river turns northeast and at Copalar, the end of the study reach, the river is at elevation 70 meters. The total drainage area at Copalar is 7,125 square kilometers.

The Cordillera Dariense reaches point elevations above about 1,700 meters and forms the northern topographic boundary of the basin. A southwest trending spur of this range extends to below Ciudad Dario and is penetrated by the Rio Grande de Matagalpa in the vicinity of La Majada. Beyond Esquipulas, the Cumaica Highlands, with point elevations of as much as 1,200 meters, force the course of the river to the northeast to reach the Maizama Plains. The southern topographical boundary then becomes the Montanas de Huapi with elevations at some points reaching more than 800 meters south of Nicarey.

Topography of the study reach at and beyond Esquipulas is hilly and the difference between crests of mountains and adjacent valley bottoms is generally between 150 meters and 600 meters. Most slopes are between 30 and 70 percent with a few slopes between 30 and 40 percent.

Underlying rock types are tertiary volcanics throughout the area tributary to the study reach. The alluvial soils of the Sebaco Valley plain extend on either side of the river from Sebaco almost to Esquipulas. Soils of the drainage area from the headwaters to Paso Real are shallow stony soils and recent volcanic ash, tuff and other volcanic materials. From Paso Real to Copalar, the predominant soil types are friable loam to clay loam.

Precipitation over the drainage area of the study reach increases as the river winds its way eastward from the Sebaco Valley. Annual precipitation increases from about 1,000 millimeters at Ciudad Dario to about 1,600

millimeters at Paso Real and then to about 2,500 millimeters in the vicinity of Paiwas and Copalar. The entire drainage area west of Paso Real is tropical savannah Aw, according to the Koppen classification and that to the east is tropical rain forest Amw climate.

Coffee is grown in areas near Esquipulas, Muy Muy and Trapichito. The vegetation changes in an eastward direction from crops intermingled with patches of deciduous forest and grasslands in the Sebaco Valley, to deciduous forest and shrub, then to savannah partly in pasture and to crops intermingled with patches of broadleaf evergreen forests or thickets in the central area around Nicarey. Finally, tall broadleaf evergreen forests being to predominate in the vicinity of Paiwas and continue downstream of Copalar.

B. LAGUNA DE APOYO

This is the largest of the volcanic lakes in Nicaragua and occupies the bottom of a crater formed by a tremendous explosion of pumaceous materials in prehistoric times. Vertical walls of basalt and dacite on the west side reach a height of more than 500 meters above the water surface of the lake, which is almost circular and about five kilometers in diameter. The depth of the lake is reported to be more than 200 meters.

Rock types in the region are quaternary volcanic. The soils are well drained, friable loam soils developed from volcanic ash and other similar materials and are stony in some places. The surface layer of these soils overlies deep deposits of grayish ash, tuff and lava.

Vegetation on the slopes rising from the lake surface is savannah type as characterized by areas partly in pasture with scattered shrubs and patches of forest.

Annual precipitation averages about 1,500 millimeters and free water surface evaporation in the region ranges from about 1,770 millimeters at elevation 82 meters to about 1,360 millimeters at elevation 450 meters. Climate, according to the Koppen classification, is tropical savannah Aw.

1.1.4 BASIC INFORMATION

Basic data on streamflow, precipitation, evaporation, sediment transport and air temperature collected by the Basic Studies Section of ENALUF were used in these studies. The Water Resources of Nicaragua, Volume III of Tax Improvement and Natural Resources Inventory Projects, Nicaragua, and Nicaragua, National Inventory of Physical Resources, 1966 served as background reference material. Topographic maps, at a scale of 1:50,000 provided almost complete coverage of the study areas.

1.2 METEOROLOGICAL DATA

1.2.1 PRECIPITATION

Isohyetals of average annual precipitation over Nicaragua as prepared by ENALUF for the 5-year period 1969-1973 are shown on Figure I.3. Rainfall

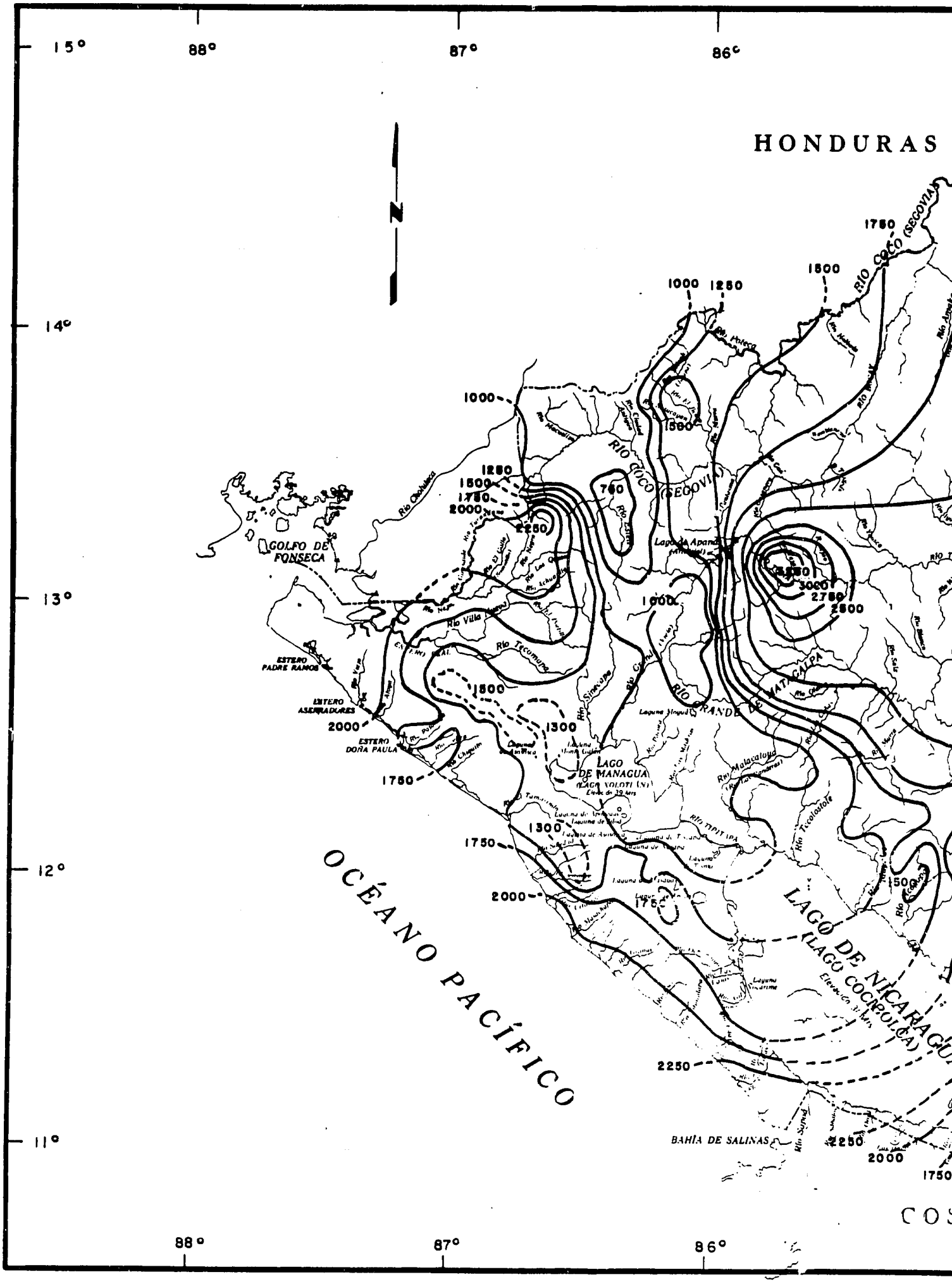
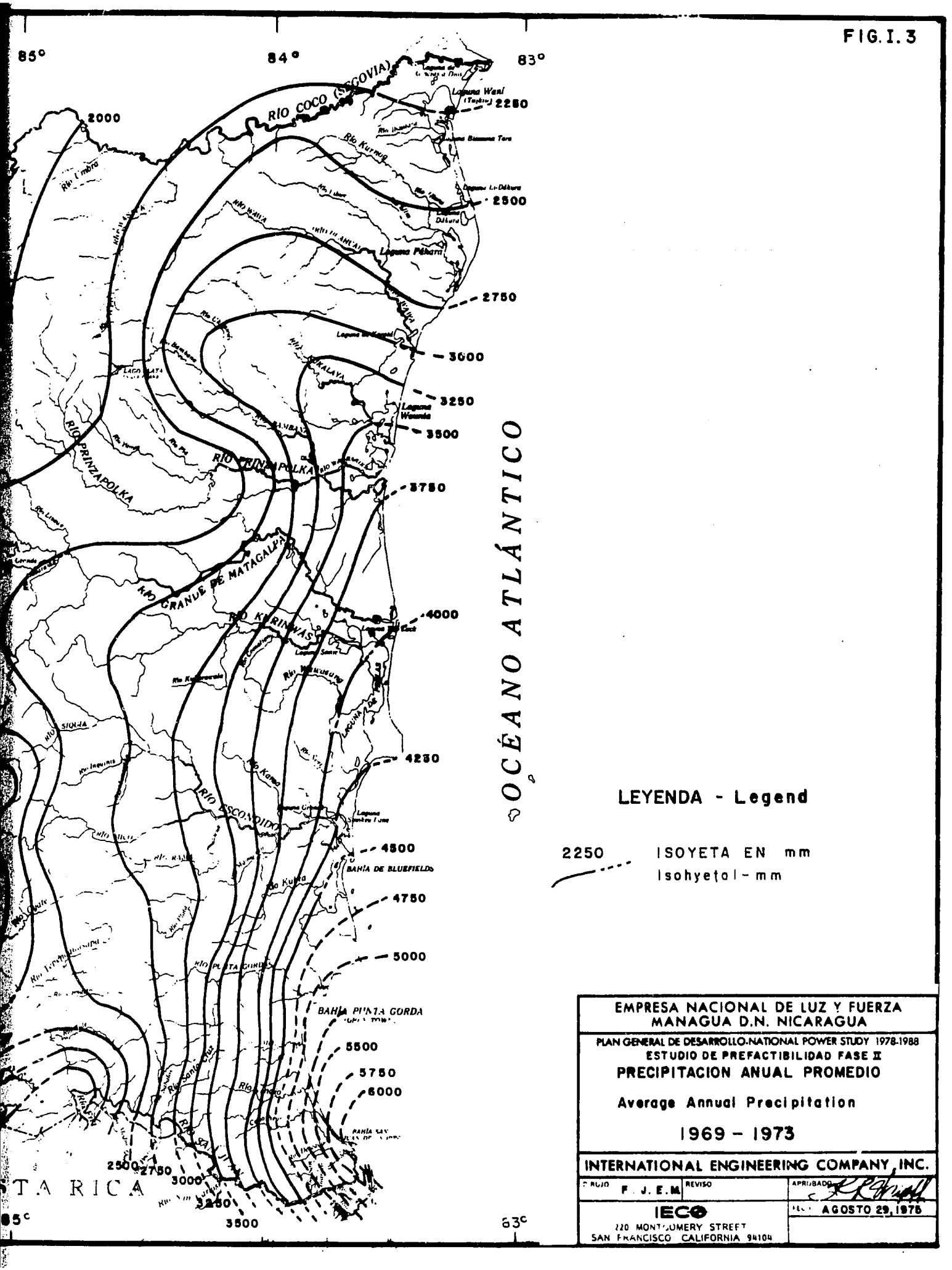

HONDURAS
COS
15°
14°
13°
12°
11°
88°
87°
86°
N
GOLFO DE FONSECA
ESTERO PADRE RAMOS
ESTERO ASERRADORES
ESTERO DOÑA PAULA
OCÉANO PACÍFICO
LAGO DE MANAGUA
(LAGO XOLOTLÁN)
LAGO DE NICARAGUA
(LAGO COCIBOLCA)
RIO COCO (SEGOVIA)
RIO GRANDE DE MATAGALPA
Rio Villa
Rio Tecomuna
Rio Tipitipa
Rio Malacatoya
Rio Tecolostote
Rio Ochomogo
BAHÍA DE SALINAS
1750
1500
1000
1250
1300
2000
2250
2500
2750
3000
1600
750

FIG. I. 3


85°
84°
83°
RIO COCO (SEGOVIA)
RIO PRINZAPOLKA
RIO GRANDE DE MATAGALPA
RIO KURINWAS
RIO ESCONDIDO
RIO PLATANO
OCÉANO ATLÁNTICO
BAHIA DE BLUEFIELDS
BAHIA PUNTA GORDA
2000
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
4750
5000
5500
5750
6000
LEYENDA - Legend
2250 ISOYETA EN mm
Isohyetal - mm
EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
PRECIPITACION ANUAL PROMEDIO
Average Annual Precipitation
1969 - 1973
INTERNATIONAL ENGINEERING COMPANY, INC.
F. J. E. M.
REVISO
APROBADO
IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104
AGOSTO 29, 1975

generally decreases from east to west reaching a minimum centering on the upper parts of the Rio Coco and the Rio Viejo basins, then increases again toward the coast of the Pacific Ocean. Time distribution of rainfall in the project areas defines a wet season from May to October and a dry season from November to April.

Nearly all rainfall comes from convective showers. On some days, they are quite general and cover nearly all of the country with at least some rain. On other days, only a few widely spaced showers occur. In May, June and September there are usually some days when rain occurs everywhere. Large areas of converging air moving slowly from east to west on these days can be identified on a weather map. During July and August there are few, if any, general storm days and the local effect of valleys and mountains becomes more important.

Hurricanes produce heavy rain in Nicaragua. A detailed study of the effect of Hurricane Gladys, October 1968, and Hurricane Camille, August 1969, is given in the Water Resources of Nicaragua. Hurricane Fifi, September 1974, produced record streamflow peaks in the Rio Coco basin, the lower part of the Rio Viejo and the upper and middle parts of the Rio Grande de Matagalpa.

Records of precipitation in or near the Rio Grande de Matagalpa basin began about 1952. A major increase in the number of rain gages in these areas and in the entire country began about 1968. The longest continous records of rainfall maintained in Nicaragua are those at Bluefields (since 1934) on the Atlantic Coast and at Ingenio San Antonio Plantel (since 1903) near Estero Dona Paula on the Pacific Coast.

Rainfall stations in or near the Rio Grande de Matagalpa basin with the longest length of record are listed in Table I.1. The table also shows some stations with shorter records which can be used for reservoir net evaporation computations.

1.2.2 TEMPERATURE

Air temperature is typical of tropical areas. The daily variation of air temperature from minimum to maximum constitutes a larger fluctuation than the changes in the average monthly minimum or maximum temperature between the coldest and the warmest month of the year.

Air temperature data from Muy Muy, Matiguas, and Paiwas given in Table I.1 are approximately typical of the temperature conditions at or near principal reservoir sites under investigation. The locations of these stations are shown on Figure I.2

1.2.3 WIND

Upslope and downslope air motion occurs throughout Nicaragua near mountainous terrain. The wind direction depends on the orientation of the location with respect to nearby mountains. Near calm conditions are most frequently observed in central valleys. The strongest winds are associated with heavy thunderstorms. They can be from any direction and sometimes cause damage to buildings or crops. Peak gusts sometimes reach 100 kilometers

TABLE I.1

SELECTED METEOROLOGICAL DATA IN PROJECT STUDY AREA

STATION	LAT	LONG	ELEVATION m	RECORD BEGAN	MEAN ANNUAL PRECIPITATION mm	TEMPERATURE °C Maximum	TEMPERATURE °C Minimum
Caratera	13° 09'	85° 45'	960	May 1952	2676		
Corinto Finca	13 10	85 53	1070	May 1952	1888		
Hac. San Francisco	12 57	85 52	800	May 1952	2008		
Jinotega	13 05	86 00	1009	May 1952	1222		
La Reina	12 55	85 49	700	May 1952	1870		
Los Robles	13 10	85 57	990	Mar 1953	1471		
Mancotal	13 14	85 54	1000	Oct 1963	1847		
Matagalpa	12 55	85 55	680	July 1953	1497		
*Matiguas	12 50	85 27	300	Apr 1971	1369	36	14
*Muy Muy	12 46	85 38	320	June 1970	1538	37	15
*Paiwas	12 47	85 07	118	Apr 1963	2481	39	12
*Palestina	12 40	85 11	230	June 1970	2525		
Sebaco	12 51	86 06	470	May 1952	913		
*Trapichito	12 42	85 22	280	Oct. 1969	1531		

CLASS A PAN EVAPORATION AT SELECTED SITES - MILLIMETERS

	RECORD BEGAN	M	J	J	A	S	O	N	D	J	F	M	A	ANNUAL
Sebaco	Jun 1953	265	185	202	212	172	168	163	192	223	240	303	307	2632
Esquipulas	Jan 1971	152	126	113	200	121	116	106	120	113	142	218	235	1762
* Muy Muy	Jun 1971	189	128	118	125	118	132	112	114	125	150	214	222	1747
* Matiguas	Apr 1971	203	141	131	144	135	138	129	130	121	165	215	211	1863
*Paiwas	May 1963	153	114	91	100	113	129	111	96	97	11[illegible]	157	166	1441

* Selected for reservoir net evaporation calculation
Source: See Section 1.6

per hour for brief periods.

The strongest winds not related to thunderstorms occur primarily in the dry season months. The direction of air flow during this period is almost always from the east or northeast. Strong wind periods in the months of December through April often last for more than one day and steady wind velocities of 45 to 55 kilometers per hour are experienced on hilltops and in mountains pass areas.

Although hurricanes in the western Atlantic and eastern Pacific oceans can influence the direction of airflow over western Nicaragua, the very strong winds near the center of these hurricanes apparently dot not move across the nation.

1.2.4 EVAPORATION

Recorded measurements of evaporation from Class A pans, considered to be an index of potential evaporation from large water surfaces, are available at Muy Muy, Matiguas and Paiwas in the project study area of the Rio Grande de Matagalpa basin. Average monthly and annual pan evaporation at these sites are given in Table I.1 and the location of the stations is shown on Figure I.2.

1.3 HYDROLOGICAL DATA

1.3.1 LAGUNA DE APOYO

The average monthly water surface elevation of Laguna de Apoyo, based on daily observations started in August 1968, are shown in Table I.2. For the sixty seven months of available record the difference between the highest and the lowest observed water surface level was 1.47 meters.

The results of the chemical analyses of five water samples taken from Laguna de Apoyo are shown in Table I.3.

1.3.2 RIO GRANDE DE MATAGALPA

A. STREAMFLOW

Gaging stations in the project area of the Rio Grande de Matagalpa basin together with upstream stations, selected project damsites, associated drainage areas, and maximum discharge data are shown in Table I.4. The accompanying bar chart shows the monthly discharge record available at each gaging station before estimates were made to complete the missing records.

Records of water level at all gaging stations are obtained from water-stage recorders usually supplemented by twice-daily staff-gage readings. Periods of missing record at gaging stations generally resulted from water-stage recorder malfunction and simultaneous lack of staff-gage observations.

TABLA I.2
LAGUNA DE APOYO
NIVELES DE AGUA - M.S.N.M.

TABLE I.2
LAGUNA DE APOYO
WATER SURFACE LEVELS - M

AÑO-HIDROLOGICO Water Year	MAYO May	JUN June	JUL July	AGO Aug	SEP Sep	OCT Oct	NOV Nov	DIC Dec	ENE Jan	FEB Feb	MAR Mar	ABR Apr
1968-69				76.7	77.0	77.2	77.3	77.6	77.6	77.0	77.0	76.7
1969-70	76.8	77.1	77.1	77.1	77.2	77.5	77.6	77.5	77.4	77.2	77.1	77.1
1970-71	77.0	77.0	77.0	77.2	77.6	77.0	77.2	77.0	76.9	76.8	77.3	77.3
1971-72	77.3	77.4	77.5	-	-	-	-	-	-	77.9	77.7	77.5
1972-73	77.4	77.5	77.4	77.4	77.4	77.4	77.4	77.3	77.1	76.9	76.7	76.7
1973-74	-	76.5	76.7	76.8	77.2	77.4	77.7	77.6	77.5	77.3	-	76.9
1974-75	76.8	76.9	77.0	77.0	77.1	77.3						
PROMEDIO Mean	77.1	77.1	77.1	77.0	77.2	77.3	77.4	77.4	77.3	77.3	77.2	77.0

MAXIMO DIARIO 77.95
Maximum daily

MINIMO DIARIO 76.48
Minimum daily

Fuente: Vease Sección 1.6
Source: See Section 1.6

TABLA I.3
LAGUNA DE APOYO
ANALISIS QUIMICOS DEL AGUA

TABLE I.3
LAGUNA DE APOYO
CHEMICAL ANALYSES OF WATER

ITEM	FECHA DE MUESTRA Date of Sample			
	29-6-68	4-12-69	*6-11-74	4-1-75
	PARTES POR MILLON Parts per Million			
SOLIDOS DISUELTOS Dissolved Solids	2598	2599	3304	
BORO Boron	1.8	4.3	-	
SILICIO Silica ($Si\ O_2$)	10	70	96	
DUREZA TOTAL Total Hardness	226	270	280	
CALCIO Calcium (Ca)	52	62	85	
MAGNESIO Magnesium (Mn)	23	28	16.5	
SODIO Sodium (Na)	865	715	993	
POTASSIO Potassium (K)	13	115	116	
CARBONATO Carbonate (CO_3)	62	15	4.5	
BICARBONATO Bicarbonate (HCO_3)	271	140	140	
SULFATO Sulfate (SO_4)	36	12	146	102
CLORURO Chloride (Cl)	1279	1292	1601	
FOSFATOS Phosphate (PO_4)	0.07	0	0.07	
NITRATO Nitrate (NO_3)	14	0.2	0.60	
FLUORURO Fluoride (F)	0.57	0.6	1.6	
CONDUCT. A 25° C - MICROMHOS Conduct. at 25° C - Micromhos	5000	3900		
RELAC. ABSOR. SODIO % (Na+K) Sodium Absorption Ratio %	25.1	19	26	

*PROMEDIO DE 2 MUESTRAS-Mean of 2 Samples

Fuente: Vease Sección 1.6
Source: See Section 1.6

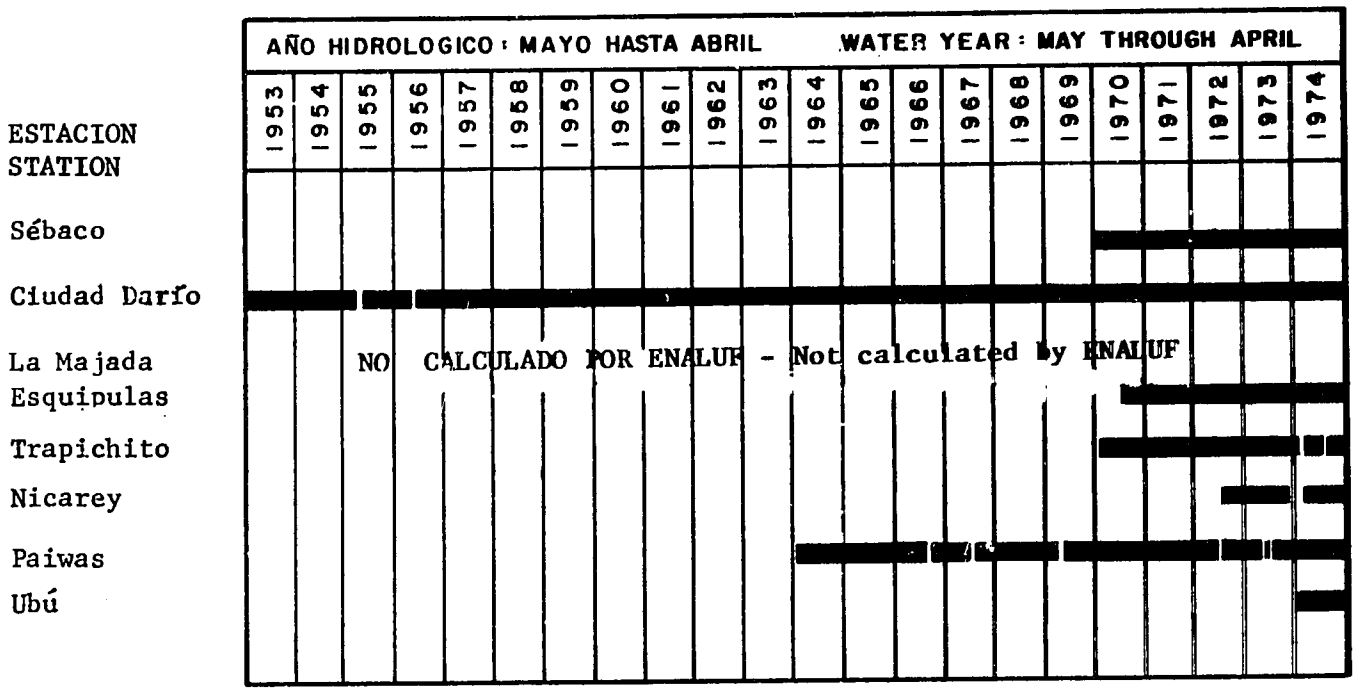
TABLA I.4
TABLE I.4
RIO GRANDE DE MATAGALPA

ESTACIONES HIDROMETRICAS, SITIOS DE PRESAS ASOCIADOS Y GRAFICO DE REGISTROS DE CAUDALES DISPONIBLES
STREAMGAGING STATIONS, ASSOCIATED DAMSITES AND GRAPH OF AVAILABLE DISCHARGE RECORDS

ESTACION STATION	PROYECTO PROJECT	AREA DE DRENAJE DRAINAGE AREA km^2	CAUDAL MAXIMO MAXIMUM DISCHARGE MEASURED MEDIDO m^3/s	 EXPERIENCED OCURRIDO m^3/s
Sébaco		426	24	233
Ciudad Darío		728	122	455
La Majada		1530	53	-
Esquipulas		1704	40	1090
	Paso Real	3897		
Trapichito		3922	933	1650
Nicarey		5697	521	2690
	El Carmen	5944		
Paiwas		6500	1117	*3690
Ubú	Copalar	7125	1110	4530

* Durante el período de registro, pudo haberse excedido en 1952
* During period of record; may have been exceeded in 1952

REGISTROS DE CAUDALES DISPONIBLES
AVAILABLE DISCHARGE RECORDS



Lack of definition of the upper end of the stage-discharge relation is a common feature of most of the discharge records, due in part to the relatively short periods some stations have been in operation and a decline in the frequency of discharge measurements. Generally, logarithmic extension of rating curves is employed and seems to produce consistant results at most gaging sites. Table I.4 shows the highest discharge measured by cable measurement and the calculated peak flow at the highest water level recorded at the stations.

A highway bridge across the Rio Grande de Matagalpa at Ciudad Dario has afforded facilities for high water discharge measurements. A cableway was installed at the Paiwas gaging station in about 1969 and all recently installed gages incorporate a similar facility. High-water measurements made since 1969 at Paiwas are the basis for computed high-water discharge at this station prior to 1969. Cableway measurements utilized sounding weights up to about 25 kilograms. For sections with large depths and relatively high velocities, errors may have been incurred in estimates made for depths under these conditions.

A rating curve revision made by ENALUF for the Rio Grande de Matagalpa at Sebaco may affect discharges above 25 cubic meters per second prior to the 1973-74 water year. The discharge records for water years 1972, 1973 and 1974 have been revised since the conclusions of Phase I studies for the stations at Ciudad Dario and Paiwas.

The United Nations Development Program is furnishing advisory services to ENALUF through the Hydrometeorological Project for Central America of the World Meteorological Organization. Assistance in revision of records and procurement of gaging equipment is included in these services.

B. SEDIMENT SAMPLING

Recorded measurements of suspended sediment are available for the following locations on the Rio Grande de Matagalpa in the project study area:

Station Number	Location	Date Begun
14	Esquipulas	Mar 1970
13	Trapichito	Mar 1970
11	Paiwas	June 1970

The measurements were made by ENALUF and sediment samples were obtained by two methods:

1. Using a USD-49 depth-integrating sampler by suspension from a cable spanning the stream and

2. Using pint-sized milk bottles to obtain much more frequent samples from the edge of the stream by a local observer.

Standard methods were employed with the USD-49 sampler and results are considered reliable. The edge-of-stream sampling technique did not attempt depth integration and therefore is less reliable. Standard laboratory analysis of samples was limited to sediment concentration only and no grain size analysis was made on a regular basis. Although sediment sampling did not cover a wide range of flows at most sites, the number of samples obtained and the length of record are considered sufficient to make an adequate estimate of sediment load for damsite evaluation.

1.4 HYDROLOGICAL STUDIES

1.4.1 GENERAL

The streamflow records available in the project area of interest are of relatively short duration. Much longer records of natural streamflow are desirable to obtain a reliable estimate of average discharge and the extension of streamflow records by correlation with usually longer-term precipitation records is a normal procedure.

The only long-term precipitation station on the Rio Grande de Matagalpa in the project area is at Paiwas. It began operation in April 1963, whereas the streamgage at this location commenced operation two months later. The only other long-term precipitation records are those in the extreme headwaters of the basin listed in Table I.1. These stations began operation about the same time as the streamgaging record on Rio Grande de Matagalpa at Ciudad Dario.

Streamflow at Ciudad Dario differs considerably in magnitude from that in the project area. The wet and dry seasons are the same at the two locations, but average discharge at Ciudad Dario is only slightly greater than two cubic meters per second reflecting many months of zero flow; whereas average discharge at Paiwas is more than 130 cubic meters per second. At Esquipulas the long-term mean discharge estimated by correlation with Ciudad Dario streamflow is only about five cubic meters per second. Therefore, the 11-year record at Paiwas was accepted as that available for mean discharge studies during this investigation.

1.4.2 STREAMFLOW EXTENSION

A small percentage of missing monthly streamflows at Trapichito, Nicarey and Paiwas was reconstituted by reasonable estimates based on available days of record or discharge data derived from twice-daily staff-gage readings, or both. Separate correlations were then made between Paiwas and Trapichito, Paiwas and Nicarey, and Paiwas and Ubu to obtain estimates of monthly, annual, and 11-year average discharge at Trapichito, Nicarey, and Ubu. Revised monthly discharge data for Paiwas were utilized in the correlation and the extension of historical streamflow records was made by using the U. S. Army, Corps of Engineers computer program HEC-4 Monthly Streamflow Simulation. Table I.5 through Table I.9 show historical and extended discharge at streamgaging stations utilized for studies at the selected damsites.

TABLA I.5
RIO GRANDE DE MATAGALPA EN TRAPICHITO
CAUDAL PROMEDIO MENSUAL - m^3/s

TABLE I.5
RIO GRANDE DE MATAGALPA AT TRAPICHITO
AVERAGE MONTHLY DISCHARGE - m^3/s

EST STA	ANO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
13	1964	13	26	53	37	68	85	38	12	6	4	1	1	28.7
13	1965	3	18	55	32	35	149	40	48	16	9	3	2	34.2
13	1966	6	76	69	38	97	85	33	16	11	7	4	3	37.1
13	1967	10	96	72	86	65	199	38	15	9	7	4	3	50.3
13	1968	5	22	106	187	103	89	26	18	22	5	3	2	49.0
13	1969	6	70	91	222	156	287	40	14	14	7	3	2	76.0
13	1970	3	94	71	146	129	228	77	20	10	8	5	6	66.4
13	1971	12	38	119	101	225	106	24	25	19	8	5	3	57.1
13	1972	4	48	80	60	157	183	29	18	26	8	4	2	51.6
13	1973	8	11	62	95	55	44	38	26	10	4	2	1	29.7
13	1974	4	36	70	42	131	204	58	18	20	12	5	3	50.2
PROMEDIO AVERAGE		6.7	48.6	77.1	95.1	111.0	150.8	40.1	20.9	14.8	7.2	3.5	2.5	48.2

Estimado por correlación con los caudales en Paiwas
Estimated by correlation with discharges at Paiwas

RIO GRANDE DE MATAGALPA EN NICAREY
CAUDAL PROMEDIO MENSUAL - m3/s

RIO GRANDE DE MATAGALPA AT NICAREY
AVERAGE MONTHLY DISCHARGE - m^3/s

EST STA	ANO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
15	1964	11	47	141	94	114	139	81	29	15	8	4	3	57.2
15	1965	7	52	157	113	85	250	80	67	28	18	10	3	72.5
15	1966	17	114	196	132	121	177	81	36	28	15	8	5	77.5
15	1967	32	154	129	209	133	322	96	23	15	15	8	8	95.3
15	1968	8	46	278	246	237	112	44	40	62	17	9	4	91.9
15	1969	16	120	229	336	313	393	99	32	27	12	7	3	132.3
15	1970	8	128	131	204	185	289	145	33	19	15	8	7	97.7
15	1971	12	70	214	158	442	159	42	53	54	23	12	7	103.8
15	1972	9	100	210	140	280	350*	52	46	72	21	10	4	107.8
15	1973	25	27	160	205	169	84	104	64	26	12	6	3	73.7
15	1974	5	80	151	119	211	317	122	43	42	23	11	7	94.2
PROMEDIO AVERAGE		13.6	85.3	181.5	177.8	208.2	235.6	86.0	42.4	35.3	16.3	8.5	4.9	91.3

[ ] Estimado por correlación con los caudales en Paiwas
Estimated by correlation with discharge at Paiwas

* Estimado por correlación con los caudales en Trapichito
Estimated by correlation with discharge at Trapichito

TABLA I.7
RIO GRANDE DE MATAGALPA EN EL SITIO DE PRESA EL CARMEN
CAUDAL PROMEDIO MENSUAL - m^3/s

TABLE I.7
RIO GRANDE DE MATAGALPA AT EL CARMEN DAMSITE
AVERAGE MONTHLY DISCHARGE - m^3/s

EST. STA.	ANO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
9	1964	13	59	164	105	129	155	92	33	18	10	5	5	65.7
9	1965	7	64	185	129	92	271	89	78	33	21	12	5	82.2
9	1966	21	134	232	151	142	198	91	44	33	18	11	6	90.1
9	1967	39	178	149	248	158	361	108	24	18	17	10	10	110.0
9	1968	10	56	315	288	265	132	51	49	75	20	11	6	106.5
9	1969	18	138	267	396	336	453	111	39	32	14	8	4	151.3
9	1970	9	145	152	241	215	320	169	41	23	17	10	9	112.6
9	1971	16	84	249	184	455	176	49	65	64	27	14	9	116.0
9	1972	10	117	242	164	310	388	60	54	87	24	12	6	122.8
9	1973	29	34	188	240	194	98	118	75	31	14	8	4	86.1
9	1974	6	93	175	136	241	340	137	50	50	26	13	9	106.3
PROMEDIO AVERAGE		16.2	100.2	210.7	207.5	230.6	262.9	97.7	50.2	42.2	18.9	10.4	6.6	104.5

Nota: Los caudales se han calculado como las diferencias entre los caudales de Paiwas y Nicarey ajustadas por la relacion entre las areas de drenaje incrementadas y sumadas a los caudales de Nicarey.
Note: Discharges computed as difference between the discharges at Paiwas and Nicarey adjusted by ratio of incremental drainage areas and added to discharges at Nicarey.

TABLA I.8
RIO GRANDE DE MATAGALPA EN PAIWAS
CAUDAL PROMEDIO MENSUAL - m^3/s

TABLE I.8
RIO GRANDE DE MATAGALPA AT PAIWAS
AVERAGE MONTHLY DISCHARGE - m^3/s

EST STA	ANO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT.	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
11	1964	31+	83	213	129	164	192	116	43	24	15	8	8	85.5
11	1965	7	91	248	165	109	320	112	105	45	28	14	8	104.3
11	1966	30	180	312	195	189	243	113	63	45	24+	17	10	118.4
11	1967	54	231	195	335	214	464+	152+	26	23	22	15	15	145.5
11	1968	14	77	399	385	328	176	67	67	104	25	14	9	138.8
11	1969	22	179	352	531	386	570+	136	54	44	19	11	7	192.6
11	1970	11	182	197	324	283	391	225	59	31	22	16	14	146.3
11	1971	25	117	327	244	485	214	66	92	89	35	19	13	143.8
11	1972	14	156	316	217	378	475*	77	72	120	31	15	9	156.7
11	1973	39	50	251	317	251	131	150#	101	42#	19	11	7	114.1
11	1974	9	123	228	174	276	394	172	66	69	32	18	14	131.3
PROMEDIO AVERAGE		23.3	133.5	276.2	274.2	278.5	324.5	126.0	68.0	57.8	24.7	14.4	10.4	134.3

\+ Estimados como promedio por correlación con los caudales en Trapichito, sitio de El Carmen y Ubu.
Estimated as average of correlations with discharge at Trapichito, El Carmen site and Ubu

* Estimado por correlacion con los caudales en Trapichito
Estimated by correlation with discharge at Trapichito

\# Estimado por correlacion con los caudales en Nicarey
Estimated by correlation with discharge at Nicarey

TABLA I.9
RIO GRANDE DE MATAGALPA EN UBU
CAUDAL PROMEDIO MENSUAL - m3/s

TABLE I.9
RIO GRANDE DE MATAGALPA AT UBU
AVERAGE MONTHLY DISCHARGE - m3/s

EST STA	ANO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
18	1964	52	91	258	148	191	231	139	44	29	17	10	10	101.7
18	1965	10	115	294	191	130	393	134	123	53	32	16	9	125.0
18	1966	32	219	362	228	218	293	136	67	53	27	20	12	138.9
18	1967	57	255	235	402	245	554	165	26	28	25	18	17	168.9
18	1968	21	89	462	468	386	207	79	76	121	30	16	11	163.8
18	1969	26	208	408	661	466	666	163	57	52	22	13	8	229.2
18	1970	13	227	238	388	328	472	267	61	37	25	18	16	170.2
18	1971	30	130	384	287	590	260	77	105	103	40	22	15	170.2
18	1972	17	182	370	255	450	570	91	85	140	37	17	11	185.4
18	1973	46	58	300	380	295	155	180	120	50	22	13	8	135.6
18	1974	11	154	271	202	325	486	206	69	80	37	21	16	156.5
PROMEDIO AVERAGE		28.6	157.1	325.6	328.2	329.5	389.7	148.8	75.7	67.8	28.5	16.7	12.1	159.0

Estimado por correlación con los caudales en Paiwas
Estimated by correlation with discharge at Paiwas

1.4.3 STREAMFLOW AT DAMSITES

The average discharge values at the Paso Real damsite are the same as those at the nearby Trapichito gaging station. The incremental flows from the drainage area of about 25 square kilometers between the damsite and the gaging station are considered negligible on a percentage basis. The average discharge values at the Copalar damsite are the same as those at the Ubu gaging station, about one kilometers downstream. The monthly discharge values at the El Carmen damsite were derived on the basis of incremental area contribution of flows between the Nicarey and Paiwas gaging stations. The derived set of flows for the El Carmen damsite was assigned the number "9" as an arbitrary station identification for related studies.

1.4.4 STREAMFLOW GENERATION

The relatively short periods of historical flows recorded on the Rio Grande de Matagalpa in the project area may or may not contain significant critical low-flow periods. Therefore, stochastic methods were used to develop monthly flows for a longer period to obtain an estimate of critical conditions. In stochastic analysis, the observed statistical properties of the recorded streamflow are coupled with a Monte Carlo procedure to generate a large number of the flow sequences, each N-years long. "N" is frequently the project life selected for economic studies and may be approximately 50 years. This is an effective method of determining the probability of low-flow sequences more critical than in the historical record, if the record is 30 years or more in length. The probable degree of flow variability may not always have been sampled for shorter historical records.

Stochastic generation of monthly flows produces flow sequences that have the same monthly means and standard deviations and the same correlations between adjacent months as the recorded data. By generating a sufficient number of sequences, the random component in the process causes successive flow values for months and years in each sequence to differ by chance from the historical record.

Twenty sequences of 50 years each were generated by the Monthly Streamflow Simulation program, previously mentioned, using the extended records of discharge for Trapichito, El Carmen, and Ubu. A search was made for the 50-year sequence, common to the three generated records, which contained the minimum volume for a 54-month period occurring at the same point in each sequence. The 50-year sequence, selected in this manner for each site, was judged to be a suitable criterion of a 50-year period containing a critical low-flow period and was chosen for use in reservoir operation studies.

Based on the sample sequences generated, there is a 95 percent chance that the minimum 54-month period discharge will be exceeded in a 50-year period of reservoir operation. The critical 50-year sequences for the Paso Real, El Carmen and Copalar damsites are shown in Table I.10, Table I.11 and Table I.12, respectively.

The selection of a 54-month duration as a critical period index was based on examination of residual mass diagrams of annual precipitation at Bluefields and Ingenio San Antonio Plantel. These diagrams indicated that the duration

RIO GRANDE DE MATAGALPA
SITIO DE LA PRESA PASO REAL
SECUENCIA CRITICA DE 50 AÑOS
CAUDAL PROMEDIO MENSUAL - m^3/s

RIO GRANDE DE MATAGALPA
PASO REAL DAMSITE
CRITICAL 50-YEAR FLOW SEQUENCE
AVERAGE MONTHLY DISCHARGE - m^3/s

EST STA	AÑO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
13	701	5	33	85	59	58	58	31	16	12	5	2	1	30.4
13	702	5	31	52	57	81	151	48	21	25	6	4	3	40.4
13	703	5	43	70	47	180	105	30	17	10	[illegible]	3	2	43.1
13	704	4	22	68	21	72	97	30	20	11	6	3	1	29.6
13	705	6	74	116	156	170	32	29	16	8	4	3	2	51.3
13	706	5	21	73	143	128	197	69	19	6	7	3	2	56.1
13	707	6	24	97	252	67	90	22	14	17	8	5	3	50.4
13	708	8	16	71	120	41	171	30	48	17	6	4	3	44.6
13	709	6	29	85	131	74	231	72	12	6	4	1	1	54.3
13	710	5	36	89	273	140	274	51	20	13	7	3	2	76.1
13	711	6	59	99	105	122	101	35	20	7	3	2	1	46.7
13	712	9	124	118	128	127	105	39	19	12	6	4	3	57.8
13	713	12	19	67	51	128	50	28	18	8	5	3	2	32.6
13	714	8	69	72	56	142	216	49	17	13	10	3	2	54.7
13	715	9	57	136	202	109	70	36	43	26	7	4	2	58.4
13	716	3	88	75	48	220	88	40	15	23	9	5	4	51.5
13	717	9	51	72	109	48	148	38	16	11	7	4	3	43.0
13	718	5	10	105	69	69	102	54	20	16	8	4	2	38.7
13	719	7	68	93	86	35	221	31	20	9	6	2	2	48.3
13	720	3	27	69	173	108	111	53	15	11	9	3	2	48.7
13	721	13	72	85	64	121	282	45	17	8	6	1	1	59.6
13	722	3	82	75	49	46	174	38	13	9	7	4	2	41.8
13	723	4	133	63	75	303	325	48	16	9	7	5	4	82.7
13	724	11	111	78	250	73	107	28	41	22	7	2	2	61.0
13	725	4	52	87	65	81	42	28	19	25	11	6	8	35.7
13	726	16	44	73	73	22	113	67	13	20	10	5	4	38.3
13	727	8	12	80	162	170	248	29	66	16	6	3	2	66.8
13	728	5	30	103	203	65	215	70	22	19	8	3	2	62.1
13	729	6	55	87	140	22	58	30	78	24	7	3	2	42.7
13	730	4	39	108	186	109	190	32	26	22	10	5	4	61.2
13	731	6	24	75	223	219	61	25	11	11	9	3	2	55.7
13	732	6	20	80	67	112	67	29	14	20	9	6	6	36.3
13	733	12	54	67	68	29	102	30	17	8	5	2	1	32.9
13	734	2	16	53	73	158	261	95	16	13	5	3	2	58.1
13	735	5	90	59	83	152	180	24	50	20	8	4	2	50.4
13	736	8	25	57	20	80	135	62	19	17	7	3	2	36.2
13	737	2	32	89	105	108	155	35	15	14	7	4	3	47.4
13	738	8	59	117	92	83	282	38	37	18	9	5	4	62.7
13	739	10	39	72	44	40	126	21	55	31	4	3	2	37.3
13	740	4	42	104	136	130	239	44	13	13	5	3	2	61.2
13	741	7	38	63	57	69	181	45	9	7	5	2	1	40.3
13	742	3	43	94	28	26	61	46	16	15	6	3	2	28.6
13	743	4	30	83	47	89	120	31	21	11	8	3	2	37.4
13	744	3	39	71	23	54	42	27	17	11	7	4	2	25.0
13	745	5	108	53	42	109	176	37	23	14	6	3	2	48.2
13	746	12	102	131	136	142	204	49	36	19	6	2	2	70.1
13	747	5	6	57	49	97	177	27	21	15	8	4	2	39.0
13	748	5	67	80	72	57	186	32	20	23	10	5	4	46.8
13	749	6	23	133	93	58	145	32	17	11	6	5	4	44.4
13	750	8	108	93	317	170	164	69	21	17	11	6	6	82.5
PROMEDIO AVERAGE		6.4	49.9	83.6	106.6	102.3	148.7	40.6	23.3	14.9	7.0	3.5	2.5	49.1

Período de 54 meses de volumen mínimo
54-month minimum-volume period

RIO GRANDE DE MATAGALPA
SITIO DE LA PRESA EL CARMEN
SECUENCIA CRITICA DE 50 AÑOS
CAUDAL PROMEDIO MENSUAL - m^3/s

TABLE I.11
RIO GRANDE DE MATAGALPA
EL CARMEN DAMSITE
CRITICAL 50-YEAR FLOW SEQUENCE
AVERAGE MONTHLY DISCHARGE - m^3/s

EST STA	AÑO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
9	701	8	64	168	141	141	130	84	51	40	16	9	9	71.7
9	702	16	87	151	173	181	176	116	58	121	23	13	7	93.5
9	703	10	84	158	192	415	197	75	37	24	14	8	5	101.6
9	704	11	64	154	102	125	167	74	50	28	14	8	7	67.0
9	705	17	132	258	224	373	65	68	36	21	12	7	5	101.5
9	706	13	61	177	239	250	334	186	38	16	16	10	5	112.1
9	707	7	64	220	333	279	150	45	44	48	21	11	8	102.5
9	708	14	58	206	277	156	372	80	78	31	22	12	8	109.5
9	709	16	70	224	221	287	488	160	22	17	8	5	3	126.7
9	710	21	86	280	419	398	383	127	53	39	19	11	5	153.4
9	711	9	114	203	186	250	215	96	49	16	8	4	5	96.2
9	712	24	205	228	196	207	205	96	45	29	17	11	6	105.7
9	713	16	48	136	124	249	137	86	59	18	10	6	4	74.4
9	714	19	146	180	171	292	372	120	50	40	21	12	7	119.2
9	715	41	101	338	222	305	156	94	67	90	22	12	5	121.1
9	716	9	188	190	177	281	162	100	47	83	23	12	7	106.6
9	717	14	103	185	198	198	275	105	35	32	17	10	7	98.2
9	718	8	32	230	159	156	173	146	50	39	18	10	4	85.4
9	719	54	130	206	161	125	334	64	47	21	17	9	7	97.9
9	720	6	68	185	338	232	227	121	41	30	22	11	13	107.8
9	721	51	127	162	149	225	387	106	51	17	11	5	5	108.0
9	722	6	162	166	128	140	330	87	30	22	17	10	6	92.0
9	723	5	186	110	194	521	476	105	37	20	16	10	8	140.5
9	724	22	177	180	338	197	238	60	68	53	25	12	7	114.7
9	725	13	106	180	202	154	140	74	56	86	29	15	10	88.7
9	726	19	88	208	176	82	247	155	28	58	23	13	13	92.5
9	727	16	45	202	300	358	415	63	75	33	17	9	4	128.1
9	728	10	59	279	233	237	401	175	66	58	25	13	6	130.2
9	729	19	111	270	289	133	109	80	79	54	22	12	7	98.7
9	730	8	79	273	391	324	355	80	64	75	25	13	8	141.2
9	731	8	49	224	347	465	68	53	37	31	21	12	7	110.2
9	732	17	57	274	144	299	116	73	43	85	28	14	12	96.8
9	733	17	98	201	176	135	215	75	37	24	14	8	5	83.7
9	734	7	46	230	223	253	338	192	37	25	13	7	6	114.7
9	735	15	187	213	221	275	232	44	69	47	21	12	9	112.1
9	736	27	62	148	93	107	228	152	54	46	18	11	9	79.6
9	737	7	91	237	175	168	303	99	35	43	20	11	4	99.4
9	738	40	116	239	182	258	483	92	67	53	27	14	10	131.8
9	739	18	85	252	139	157	219	33	76	75	20	11	7	91.0
9	740	9	100	230	221	276	394	94	40	34	13	7	5	118.6
9	741	15	70	183	145	130	358	114	10	14	13	7	3	88.5
9	742	8	102	268	95	61	132	121	46	38	19	11	6	75.6
9	743	13	74	141	121	174	163	80	52	30	22	12	6	74.0
9	744	9	81	166	98	122	126	74	54	32	20	11	7	66.7
9	745	7	208	160	127	205	275	83	55	31	20	10	5	98.8
9	746	42	167	242	257	327	337	130	67	42	17	9	5	136.8
9	747	16	32	222	185	184	336	52	57	35	16	10	6	95.9
9	748	14	113	192	190	120	324	71	61	63	22	13	8	99.2
9	749	9	57	352	136	173	298	79	42	31	17	10	7	100.9
9	750	20	187	240	447	358	401	150	57	73	32	15	7	165.6
PROMEDIO AVERAGE		16.4	100.5	210.4	207.5	230.4	263.2	97.8	50.1	42.2	18.9	10.4	6.7	104.5

Período de 54 meses de volumen mínimo
54-month minimum-volume period

RIO GRANDE DE MATAGALPA
SITIO DE LA PRESA COPALAR
SECUENCIA CRITICA DE 50 AÑOS
CAUDAL PROMEDIO MENSUAL - m^3/s

RIO GRANDE DE MATAGALPA
COPALAR DAMSITE
CRITICAL 50-YEAR FLOW SEQUENCE
AVERAGE MONTHLY DISCHARGE - m^3/s

EST STA	AÑO YEAR	MAYO MAY	JUN JUN	JUL JUL	AGO AUG	SEP SEP	OCT OCT	NOV NOV	DIC DEC	ENE JAN	FEB FEB	MAR MAR	ABR APR	PROMEDIO AVERAGE
18	701	13	117	264	210	209	200	129	78	65	25	13	13	111.3
18	702	28	134	240	267	270	265	177	91	192	35	21	15	144.6
18	703	21	141	249	300	550	293	114	51	38	22	13	9	150.1
18	704	18	110	244	145	182	251	112	77	46	22	15	12	102.8
18	705	31	197	394	356	510	105	106	50	33	19	15	10	152.2
18	706	23	101	279	384	368	491	290	51	24	24	16	9	171.7
18	707	11	124	338	546	408	228	71	67	78	32	17	12	161.0
18	708	25	94	322	452	242	548	120	126	51	32	18	13	170.2
18	709	30	108	348	351	412	714	244	24	26	15	12	8	191.0
18	710	36	125	426	710	553	562	192	82	63	29	16	9	233.6
18	711	15	194	315	288	360	320	145	74	25	15	9	8	147.3
18	712	37	284	352	306	306	306	145	66	47	26	21	14	159.2
18	713	35	74	217	184	353	207	131	94	29	17	14	9	113.7
18	714	33	213	284	264	412	543	181	76	63	31	18	13	177.6
18	715	70	128	505	356	434	236	144	106	145	34	20	11	182.4
18	716	16	302	294	271	397	244	152	69	132	35	17	11	161.7
18	717	24	162	290	310	294	407	159	48	51	26	18	14	150.3
18	718	16	61	354	243	232	261	225	75	62	27	15	8	131.6
18	719	76	160	326	249	189	492	96	72	34	25	15	12	145.5
18	720	10	135	287	556	349	338	183	58	48	32	16	17	169.1
18	721	82	156	260	229	328	566	159	77	27	18	7	7	159.7
18	722	7	290	258	187	205	484	131	38	35	26	17	12	140.8
18	723	8	330	170	300	651	689	156	52	31	25	17	14	203.6
18	724	42	247	283	562	303	355	91	110	87	36	16	11	178.6
18	725	22	168	282	318	233	215	113	88	139	43	25	20	138.8
18	726	45	127	326	273	123	369	238	33	91	34	19	20	141.5
18	727	34	70	319	495	502	608	95	121	54	26	15	8	195.6
18	728	16	104	420	370	349	587	269	103	93	37	18	11	198.1
18	729	33	163	411	473	207	171	123	126	88	32	16	12	154.6
18	730	14	143	410	650	465	521	120	102	122	37	21	15	218.3
18	731	15	94	345	574	616	109	83	51	50	31	20	13	166.7
18	732	35	87	419	217	415	178	112	64	136	41	22	20	145.5
18	733	37	146	315	273	205	322	114	52	38	22	12	9	128.8
18	734	11	92	353	353	367	496	301	49	39	20	12	10	175.3
18	735	26	277	329	350	396	344	69	112	77	31	18	15	170.3
18	736	52	84	238	132	155	339	233	83	73	28	17	15	120.7
18	737	12	169	360	267	249	447	148	47	69	29	19	9	152.1
18	738	66	149	372	285	373	707	137	107	86	40	22	18	196.8
18	739	39	126	387	209	232	326	53	126	124	30	17	12	140.1
18	740	15	174	352	348	395	576	141	57	54	20	15	10	179.8
18	741	26	112	289	219	194	526	171	15	22	20	12	7	134.4
18	742	12	182	402	131	84	203	186	69	61	28	17	12	115.6
18	743	24	121	225	178	254	246	122	81	48	32	17	11	113.2
18	744	15	143	261	138	176	193	113	84	51	30	18	14	103.0
18	745	13	338	249	185	294	404	125	86	50	29	15	9	149.8
18	746	62	214	375	418	463	495	197	106	67	26	15	9	203.9
18	747	26	52	347	289	275	494	79	91	58	25	19	13	147.3
18	748	29	175	301	296	182	478	107	97	102	33	22	16	153.2
18	749	19	102	513	201	253	438	118	62	51	26	16	12	150.9
18	750	37	264	369	758	509	589	229	88	117	47	24	15	253.8
PROMEDIO AVERAGE		28.8	157.3	325.4	328.5	329.7	389.7	149.0	76.2	67.8	28.5	16.8	12.1	159.2

Período de 54 meses de volumen mínimo
54-month minimum-volume period

of some sequences of below average precipitation lasted as long as four years. The average discharge of the 54-month minimum-volume period for the extended and generated records is shown in Table I.13. In general, other minimum discharge periods for durations of 6, 18, 30, 42 and 66 months occurred within, or as part of, the 54-month minimum period.

1.4.5 RESERVOIR NET EVAPORATION

The construction of a reservoir generally increases the exposed water surface above that of the natural stream and increases the evaporation loss. The evaporation from a free water surface is nearly always in excess of the actual evapotranspiration from a land surface, therefore, there is usually a net loss of water as a result of the reservoir construction. Assuming that streamflow values obtained represent flow at the damsite, the net evaporation loss as a result of the reservoir is:

$$E_w - E_a \approx E_w - (P-q)$$

where:

E_w = free water surface evaporation
E_a = actual evapotranspiration from the land area flooded by the reservoir
P = precipitation on the same land area
q = runoff from the same land area prior to flooding

Table I.14 shows estimates of net evaporation based on average monthly values of pan evaporation, precipitation and runoff at appropriate sites in the vicinity of the reservoir of each damsite. A coefficient of 0.7 was applied to the Class A pan evaporation values. Runoff was based on extended records of streamflow.

Calculations of reservoir net evaporation during Phase I produced negative values for some months, indicating the posssibility of a net gain of water in those months as a result of reservoir construction. A more conservative estimate of reservoir net evaporation was adopted for Phase II studies by making negative values equal to zero. Reservoir net evaporation at El Carmen, and Copalar was adjusted slightly to vary as a fixed percentage of that of Paso Real for use in reservoir operation studies.

1.4.6 CONSTRUCTION FLOODS

Flood frequency curves developed for selected gaging stations and damsites in the study reach of the Rio Grande de Matagalpa are shown on Figure I.4. The frequency-magnitude relations are based on the Gumbel Type I extreme-value distribution of the historical record of annual maximum instantaneous discharges.

The frequency curve for Paiwas is based on thirteen values of instantaneous maximum discharge, including a value presumed to be somewhat greater than any recorded and estimated to have occurred about 1952. Five of these values are uncertain because actual maximums may have occurred during periods of missing record.

TABLA I.13
TABLE I.13
RIO GRANDE DE MATAGALPA
CAUDAL PROMEDIO PARA PERIODO DE 54 MESES DE VOLUMEN MINIMO
AVERAGE DISCHARGE FOR 54-MONTH MINIMUM-VOLUME PERIOD
REGISTRO EXTENDIDO Y GENERADO
EXTENDED AND GENERATED RECORDS

ESTACION STATION	SITIO DE LA PRESA DAMSITE	CAUDAL PROMEDIO DE 54 MESES- m^3/s AVERAGE DISCHARGE OF 54-MONTH MINIMUM PERIOD- m^3/s	
		REGISTRO EXTENDIDO EXTENDED RECORD	REGISTRO GENERADO GENERATED RECORD
Trapichito	Paso Real	39	30
El Carmen*	El Carmen	88	70
Ubu	Copalar	135	107

* No hay estacion. Derivado en base incremental dentro de Nicarey y Paiwas

* No station. Derived on incremental basis between Nicarey and Paiwas

TABLA I.14
TABLE I.14
RIO GRANDE DE MATAGALPA
EVAPORACION NETA DE LOS EMBALSES - mm
RESERVOIR NET EVAPORATION-mm

SITIO DE LA PRESA	M	J	J	A	S	O	N	D	E	F	M	A
DAMSITE	M	J	J	A	S	O	N	D	J	F	M	A
Paso Real	60	0	0	0	0	12	34	27	36	106	146	130
El Carmen	30	0	0	0	0	6	17	14	18	53	73	65
Copalar	30	0	0	0	0	6	17	14	18	53	73	65

FIG. I . 4

RIO GRANDE DE MATAGALPA

CURVAS DE FRECUENCIA DE CRECIDAS DURANTE CONSTRUCCION

CONSTRUCTION FLOOD - FREQUENCY CURVES

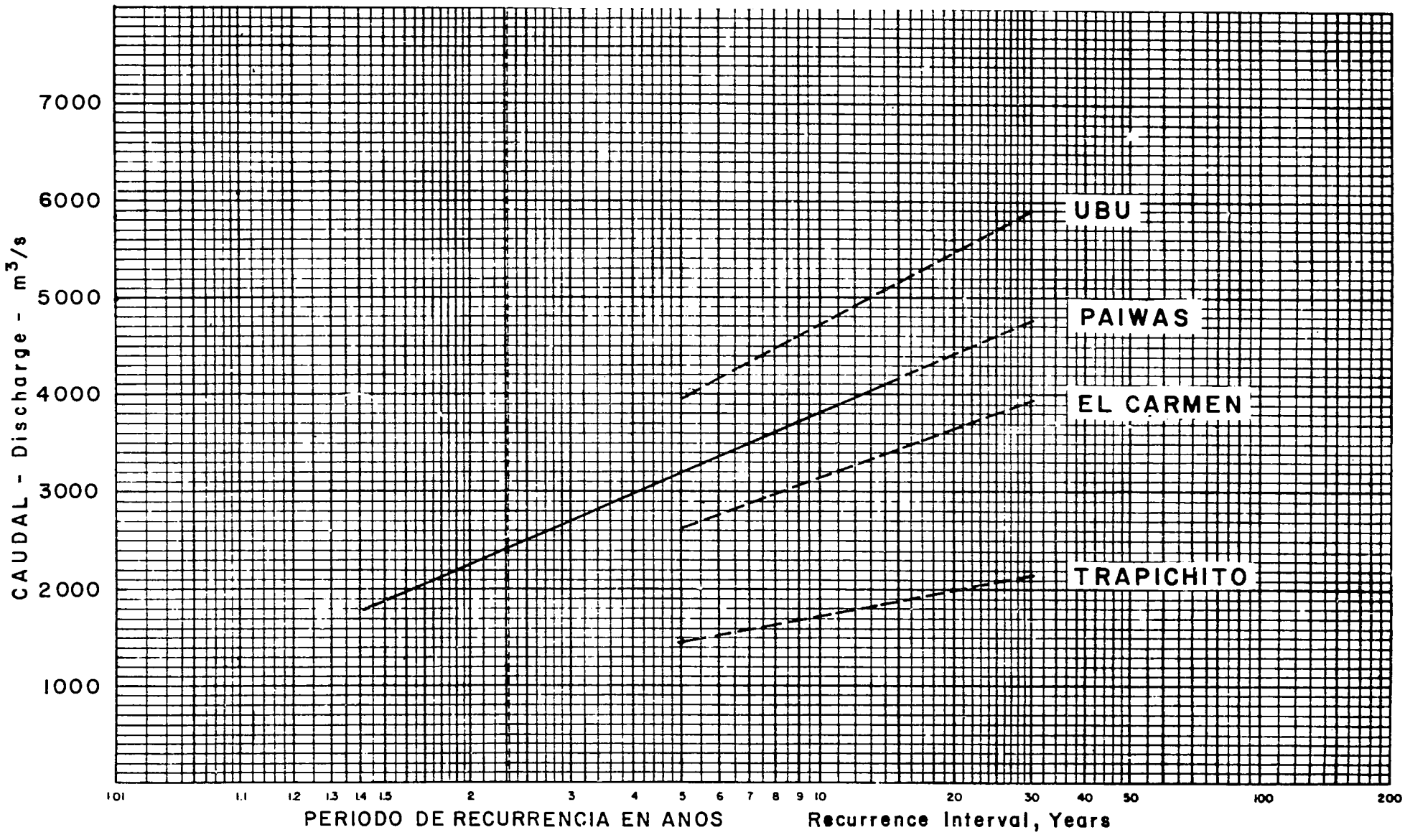


FIG. I . 4

Development of flood frequency relations for the shorter-term records of Trapichito, Nicarey, and Ubu largely depends on evidence that the annual maximum at each station is generally caused by the same flood event that occurs at Paiwas. Fair evidence of this correlation, particularly between Paiwas and Ubu, was utilized to develop the frequency curves required for the Phase I study. Further evidence, providing a more reliable correlation of Trapichito and Nicarey data with that of Paiwas, is based on peak discharges recently obtained from floodmarks left by the Hurricane Fifi flood of September 1974 during which the Trapichito recorder was not functioning and the Nicarey gage was overtopped. That flood produced maximum recorded peak discharges at all four gaging stations in the project study reach of the Rio Grande de Matagalpa.

Together with the frequency-magnitude correlations thus obtained, the frequency curves at Trapichito, Nicarey, and Ubu were further defined by average values based on the relation between the ratio of discharges and drainage areas for the appropriate gage and Paiwas. The curve shown for Trapichito is applicable to the Paso Real damsite. The frequency curve for El Carmen damsite is based on an adjustment of Nicarey data, and the curve for Ubu is applicable to the Copalar damsite. The curves are based on a project construction sequence that commences with the Copalar Project and proceeds upstream.

1.4.7 SPILLWAY FLOODS

The proposed construction sequence begins with the Copalar Project and proceeds upstream to the Paso Real Project. Each dam is, therefore, subjected to the full natural flood hydrograph at the damsite until the next upstream dam is constructed. Data for flood inflow hydrographs to be used as a basis for spillway design for the assumed sequence of construction are shown in Table I.15.

Data usable for design storm configurations have not been adequately developed for Nicaragua. The probable maximum 24-hour point precipitation as determined by the Hershfield Statistical Method is a partial alternative, but is considered to be too extreme. Precipitation values calculated by this method for several long-term precipitation stations in the basin varied from about 400 to 700 millimeters.

In middle latitudes, maximum probable floods seem to be about three times the maximum historic floods of a return period of approximately 50 to 100 years. The ratio seems to be lower in tropical latitudes, between 2 and 2.5. From the construction flood-frequency curves derived for the Rio Grande de Matagalpa at Trapichito, El Carmen and Ubu, peak discharge values of inflow flood hydrographs at Paso Real, El Carmen and Copalar were estimated to be approximately 6,200, 10,200 and 15,300 cubic meters per second, respectively.

Shapes of the inflow flood hydrographs were obtained by averaging the largest two or three flood events at Trapichito, Nicarey and Ubu gaging stations by the dimensionless-hydrograph technique. The Hurricane Fifi flood was registered completely only at Paiwas and Ubu gages. The volumes of the flood hydrographs for Paso Real and El Carmen projects seem smaller than expected because of a lack of similar data for these locations.

TABLA I.15
RIO GRANDE DE MATAGALPA
CRECIDA AFLUENTE PARA
DISEÑO DEL VERTEDERO

TABLE I.15
RIO GRANDE DE MATAGALPA
FLOOD INFLOW FOR SPILLWAY DESIGN

PASO REAL		EL CARMEN		COPALAR	
HORA HOUR	CAUDAL AFLUENTE INFLOW m^3/s	HORA HOUR	CAUDAL AFLUENTE INFLOW m^3/s	HORA HOUR	CAUDAL AFLUENTE INFLOW m^3/s
0	200	0	250	0	300
2	460	3	760	3	450
4	1,240	6	2,050	6	760
6	2,340	9	3,930	9	1,610
8	4,100	12	7,110	12	4,010
10	5,800	15	9,770	15	7,940
12	6,100	18	9,850	18	12,300
14	4,800	21	7,550	21	15,000
16	3,380	24	5,270	24	15,300
18	2,440	27	3,700	27	13,600
20	1,780	30	2,910	30	11,200
22	1,450	33	2,170	33	8,810
24	1,190	36	1,760	36	6,460
26	990	39	1,470	39	4,830
28	810	42	1,210	42	3,900
30	695	45	1,010	45	3,080
32	600	48	850	48	2,490
34	520	51	730	51	2,040
36	455	54	630	54	1,690
38	405	57	550	57	1,340
40	360	60	490	60	1,130
42	325	63	440	63	945
44	300	66	400	66	830
46	275	69	360	69	705
48	250	72	320	72	615
50	225	75	290	75	490
52	200	78	250	78	390
				80	340
				82	300

Pico = 6,200 m^3/s
en hora 11
Peak = 6,200 m^3/s
at 11 hours

Pico = 10,250 m^3/s
en hora 16.5
Peak = 10,250 m^3/s
at 16.5 hours

Pico = 15,300 m^3/s
en hora 24
Peak = 15,300 m^3/s
at 24 hours

1.4.8 SEDIMENT TRANSPORT

Details of the calculation of estimated sediment load at damsites studied in Phase I are contained in Appendix III A, Sedimentation Study for Damsite Selection, of the Phase I Report. Table IIIA.8 of that appendix shows estimates of average annual and 50-year sediment volumes passing the damsites. The table is arranged to show total sediment transport of the contributing drainage area at a selected damsite and incremental contributions between damsites.

Phase I calculations of sediment transport in the project area of the Rio Grande de Matagalpa were based largely on sediment sampling at the Trapichito and Paiwas gaging stations. Interpolation between these stations was required for the El Carmen damsite to determine the appropriate concentration and sediment yield rates. An extrapolation of the curve data for concentration and yield rates had to be made for the Copalar damsite; therefore, the results are considered to be less accurate than those obtained using the interpolation technique.

Dimensionless daily flow duration curves were developed during Phase I from monthly flow duration data for sediment transport calculations at Trapichito and Paiwas. Phase II studies used revised discharge data for Paiwas to extend discharge records at Trapichito thereby affecting some months in water year 1972 to 1974. The correlation resulted in changes in the magnitude-time sequence of extended Trapichito monthly discharges. A comparison was made of monthly flow-duration curves based on Phase I and Phase II monthly discharge data for Paiwas and Trapichito and no significant differences were noted.

The dimensionless method of plotting sediment rating and flow duration curves requires that the discharge at which individual sediment samples are obtained and the flow duration intervals be divided by the long-term average discharge. Average discharge developed in Phase II for Paiwas and Trapichito differed from Phase I results by only four percent and one percent, respectively.

Estimated average annual and 50-year sediment volumes at the selected project damsites on the Rio Grande de Matagalpa are taken; therefore, directly from Table IIIA.8 of Appendix IIIA. Data given for Aguas Calientes are applicable to the El Carmen Project. Table I.16 summarizes the sediment volumes to be considered. It shows the volume for each dam as an individual structure with no other dam being considered and also shows the resulting volumes if two or three dams act in combination. The construction sequence for both the two dam and three dam solution is based on constructing Copalar first and continuing construction in an upstream direction to Paso Real.

1.5 ADDITIONAL DATA AND STUDIES REQUIRED

1.5.1 GENERAL

Additional data and studies are required for the feasibility phase and final project design. Streamflow records on the Rio Grande de Matagalpa should be updated to incorporate newly available or revised data. All possible means of extending the existing 11-year record of streamflow at

TABLA I.16
RIO GRANDE DE MATAGALPA
VOLUMENES DE SEDIMENTOS - $m^3 x\ 10^6$

TABLE I.16
RIO GRANDE DE MATAGALPA
SEDIMENT VOLUMES - $m^3 x 10^6$

PROYECTOS INDIVIDUALES INDIVIDUAL PROJECTS	VOLUMEN PROMEDIO ANUAL MEAN ANNUAL VOLUME	VOLUMEN DE 50 AÑOS 50-YEAR VOLUME
Copalar	0.68	34
El Carmen	0.61	30
Paso Real	0.44	22
SOLUCION CON 2 PRESAS 2 DAM SOLUTION		
Copalar	0.24	12
Paso Real	0.44	22
SOLUCION CON 3 PRESAS 3 DAM SOLUTION		
Copalar	0.07	4
El Carmen	0.17	8
Paso Real	0.44	22

Paiwas should be investigated. Construction flood-frequency estimates should be improved as revised or additional data become available. More detailed estimates of spillway design floods are required for the project configuration finally selected. Additional streamgaging stations must be installed to accurately determine discharges and tailwater variations at the selected project sites.

1.5.2 STREAMFLOW

The extension of short-term streamflow records in the project area of the Rio Grande de Matagalpa at Trapichito, Nicarey and Ubu was achieved by correlation of these records with discharge at Paiwas. The mean discharge values obtained are considered reliable, but are only representative of the 11-year period available at Paiwas. Extension of the Paiwas record is desirable to obtain a measure of a longer-term mean and the greater variability inherent in longer records of streamflow.

Principal data available for extension of the Paiwas record are the Ciudad Dario streamflow records which begin in May 1952 and a few precipitation records in the headwaters of the Rio Grande de Matagalpa, which begin at the same time. These data are supplemented by short-term precipitation records of four to five years duration providing fair basin coverage. Reliable extension of short-term data by long-term precipitation records will depend largely on the quality of these data and the degree of correlation achieved. A rainfall-runoff correlation should be attempted, perhaps utilizing appropriate basin calibration characteristics derived as part of the modeling process for definitive spillway design flood determination.

Table I.4 shows generally long extensions of the stage-discharge relationship from the maximum measured discharge to the peak discharge experienced. Efforts should be made to increase the frequency of discharge measurements during the wet months and to utilize appropriate heavy sounding equipment.

Missing gage-height record is largely due to water-level recorder malfunction. The loss is often further compounded by absence of supplementary staff-gage readings. Monthly discharge for missing periods of record can usually be obtained by correlation techniques, but flood peaks estimated to have occurred during some of these periods often have not been ascertained by other means available; such as the use of crest-stage gages or slope-area measurements. Measures must be implemented to improve the quality and frequency of discharge measurements and to obtain reliable flood discharge data for use in future project design.

1.5.3 SPILLWAY DESIGN FLOOD

The severity of Hurricane Fifi of September 1974 experienced in Honduras may be the most appropriate data on which to base an estimate of probable maximum precipitation together with depth-area and depth-intensity relationships to prepare a design storm for estimating spillway design floods. Hurricane Fifi passed from east to west along the northern coast of Honduras. Precipitation and flood data are being compiled with the

assistance of the Hydrometeorological Project for Central America. A hurricane of possibly greater intensity pursued an east to west path along the Nicaragua-Honduras border in 1935. This event and Hurricane Fifi are apparently the most extreme storms in 40 years.

A computerized hydrologic model of the area of interest in the Rio Grande de Matagalpa basin can be calibrated by simulating known daily flows for the wet season of a selected year using hourly or daily precipitation data and obtaining soil moisture and infiltration characteristics. The design storm can then be applied to the model to obtain inflow hydrographs at project damsites.

1.5.4 TAILWATER AT DAMSITES

The tailwater stage-discharge relation must be known at each selected damsite on the Rio Grande de Matagalpa. The Paso Real damsite is about five kilometers upstream of the gage at Trapichito. To provide sufficiently accurate data with which to design this project, a staff-gage must be installed nearer to the damsite and discharge measurements should be made.

A staff-gage installation is required at the El Carmen damsite and discharge measurements are necessary to determine the increased flow below the Nicarey gage. A staff-gage installation will suffice at the Copalar damsite because discharge can be obtained from the Ubu gage about one kilometer downstream.

Staff-gages or water level recorders should be installed at a suitable location a short distance downstream of the toe of each dam to determine the water levels caused by powerhouse and spillway discharge. Staff-gage installations should cover considerably more than the recorded variation in the downstream water levels in order to establish adequate gage-height correlations with nearby recording streamgages.

1.6 SOURCES OF BASIC DATA

The basic hydrological and meteorological data used in preparing all tables and figures contained in this chapter was provided by the Basic Studies Section of ENALUF. The records were completed by IECO during both phases of this investigation for stations and periods for which there was no data. This was done by several methods including transposition from and correlation with other stations where data was available. Special computer programs were used to extend the data to longer periods of time than available from the records.

Tailwater levels were estimated from 1:50,000 scale topographic maps prepared by Instituto Geografico Nacional (IGN) at a 20-meter contour interval. These maps were also used in preparing reservoir area-capacity curves. Base maps used for some of the figures were obtained from various governmental agencies.

CAPITULO II

GEOLOGIA

CHAPTER II

GEOLOGY

CHAPTER II

GEOLOGY

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GEOLOGY

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CHAPTER II

GEOLOGY

2.0 INTRODUCTION

This chapter presents the findings of the geologic investigation performed during the Prefeasibility Study which was divided into two phases. Phase I was performed between August 1974 and February 1975. Phase II was performed between February and June 1975.

Phase 1 investigation consisted of a geologic reconnaissance of thirteen potential hydroelectric sites and one possible pumped-storage plant site. The sites which were studied include La Majada, Paso Real, Nicarey, El Carmen, Aguas Calientes, Paiwas, Copalar Downstream Site and Copalar Upstream Site on the Rio Grande de Matagalpa; Corriente Lira and Namasli on the Rio Coco; Nicaragua, Rafael Mora Upstream Site and Rafael Mora Downstream Site on the Rio Viejo; and a pumped-storage site at Laguna de Apoyo. The hydroelectric sites are located approximately 50 to 180 kilometers north and east of Managua and the pumped-storage site is about 35 kilometers southeast of Managua. The locations of all sites are shown on Annex III-1 of Chapter III, Technical Evaluation of this report for Phase II.

The scope of geologic work for the Phase I investigation consisted of:

1. A review of reports describing the geologic and seismic conditions in the region.

2. Geologic reconnaissance of each site.

3. Preliminary geologic mapping at a scale of 1:50,000 at each site.

4. Tentative locations of construction materials at each site.

It was concluded from the Phase I Study that no geologic conditions were observed that would preclude the construction of hydroelectric facilities at any of the proposed sites. However, the Nicaragua site appeared to be geologically impractical, due to the possibility of high water loss through pervious volcanic material which underlay the dam and reservoir.

The geologic conditions determined during the Phase I reconnaissance of each site are described in Chapter IV, Geology, of the Phase I Report.

Hydroelectric projects selected for a further geologic investigation during Phase II of the Prefeasibility Study were Paso Real, El Carmen, Copalar Downstream Site and the pumped-storage project at Laguna de Apoyo.

The scope of geologic work for the Phase II investigation consisted of:

1. Geologic surface mapping of the proposed damsites and appurtenant structures.

2. Geologic reconnaissance of the reservoir areas for each site.

3. Investigation for construction materials.

4. Preparation of a program for additional geologic investigations of the site selected for study during the feasibility stage.

5. Preparation of a geologic report for Phase II.

All surface geologic mapping was recorded on general layout drawing prepared for the Phase I investigations because the time schedule required that the field work be completed before Phase II drawings could be prepared more precisely. The changes in project features are minor and do not necessitate revisions to the drawings used for this level of investigation.

Consulting geologist Dr. W.I. Gardner inspected the Copalar, Paso Real, El Carmen and Laguna de Apoyo sites in March, 1975. A report of Dr. Gardner's conclusions and recommendations is included in Appendix A. Mr. Edwin S. Smith, Chief of the Geotechnical Department and the Chief Soils Engineer of International Engineering Company, Inc., also reviewed the geologic program, examined the construction materials and assisted in the development of a geotechnical program for the feasibility stage studies.

2.1 CONCLUSIONS

A geologic investigation was made of Copalar, El Carmen, and Paso Real damsites on the Rio Grande de Matagalpa and the Laguna de Apoyo pumped-storage project. Specific conclusions are given in the text for each project site. Some general conclusions are:

1. Geologic conditions were not observed that would preclude the construction of the hydroelectric facility at any of the sites. However, the Laguna de Apoyo site should be carefully evaluated in the next stage of investigation because the seismic and volcanic risks appear to be high and the foundation conditions appear to be unfavorable.

2. All sites are underlain by volcanic bedrock consisting predominantly of lava flows and pyroclastics.

3. Curtain grouting will be necessary to reduce water percolation along joints and fractures at all damsites.

4. Excessive seepage is not expected to be a problem at any of the reservoirs located on the Rio Grande de Matagalpa.

5. Major landslides were not observed in any of the reservoir areas.

6. Suitable borrow and quarry materials for construction are available within a few kilometers of all proposed sites.

2.2 REGIONAL GEOLOGY

Numerous articles and reports have been written and published on the geology, volcanology, and seismology of Nicaragua. A 1:1,000,000 scale map of Nicaragua, published in 1973 by the Ministerio de Obras Publicas, Instituto Geografico Nacional, was available for use in performing the geological investigations for this study. Geologic mapping at a scale of 1:50,000 which was helpful in

Phase I studies, is included in a report entitled "The Geology of Western Nicaragua", prepared under the supervision of Parsons Corporation in March 1972 for the CATASTRO Project.

Most of Nicaragua is underlain by volcanic rocks of Tertiary and Quaternary age. Older metamorphic and igneous rocks occur locally in the northern and eastern part of the country. The proposed hydroelectric sites of the Phase I investigation are underlain by volcanic rocks except for the reservoirs of Namasli and Corriente Lira, which are underlain by metamorphic rocks. The three damsites of the Phase II investigation on the Rio Grande de Matagalpa are underlain by Tertiary volcanic rocks and the pumped-storage project is underlain by Quaternary and Recent volcanic rocks.

One of the major geologic features of Nicaragua is a broad northwest trending structural depression (graben) in which Lago de Nicaragua, Lago de Managua, smaller lakes, and numerous volcanoes and calderas are located. This graben extends the full length of the country and has been actively subsiding for approximately two million years, since the beginning of the Quaternaty Period. Within the graben there are many tectonically active northwest, northeast, and north trending faults. The earthquake of December 23, 1972, which had a magnitude of 6.2 on the Richter Scale and destroyed much of the central portion of Managua, occurred along northwest trending faults. Proposed hydroelectric sites investigated during Phase I within the graben area are Laguna de Apoyo, Nicaragua and the two at Rafael Mora. Outside the graben, the major structural features trend northwest and northeast.

Volcanism, since the end of the Miocene epoch, approximately five million years ago, has been concentrated along a line of cones and calderas near the southwestern margin of the structural depression. A few volcanoes occur along the northeast side of the graben and near the Atlantic coast. Most of these volcanoes are intermittently active. Laguna de Apoyo is reported to be one of the most explosive and potentially desvastating volcanoes in Nicaragua; however, it appears to be dormant at present. The nearest active volcano to any project site is Volcan Santiago, which is located about 13 kilometers northwest of Laguna de Apoyo. Smoke and gases are presently erupting from Volcan Santiago.

2.3 SEISMICITY

Historically, damaging earthquakes have occurred frequently in Nicaragua. Damaging earthquakes were reported to have occurred in 1844, 1849, 1858, 1859, 1862, 1865, 1867, 1870, 1881, 1882, 1885, 1898, 1913, 1916, 1918, 1921, 1926, 1928, 1931, 1938, 1940, 1951, 1955, 1956, 1961, 1965, 1967, 1968 and 1972. The epicenters for most of these shocks were either within the Nicaragua depression or southwest of the depression. Relatively few epicenters have been located northeast of the graben structure. Although a large number of shocks are listed with Richter Scale magnitudes of 6.0 and greater in the "Catalog of Nicaraguan Earthquakes" by David J. Leeds (1974), none larger than 7.7 is known.

Nearly all of the proposed damsites of this prefeasibility study are north and east of the major area of seismic activity in Nicaragua. Laguna de Apoyo is the only project included in the Phase II investigation that is located in the historically, highly active earthquake zone. An earthquake of Richter magnitude of 8 is considered possible at Laguna de Apoyo or any site within the graben area.

The proposed Paso Real, El Carmen, and Copalar damsites are in an area of infrequent earthquake activity. However, a few epicenters with Richter magnitudes between 5 and 6 and one between 6 and 7 have occurred within the drainage basin. Therefore, a magnitude 7 event is considered possible at these sites.

The likelihood of a large earthquake occurring at any of the sites should be evaluated in the feasibility study for each particular site. Suggestions regarding seismic zoning of the country are contained in a report entitled, "A Study of Seismic Risk for Nicaragua, Part I (of II)", January 1975, by Haresh C. Shah, et, al., of the John A. Blume Earthquake Engineering Center at Standford University, California. Serious considerations should be given to the early installation of a strong motion seismograph at any of the hydroelectric sites considered likely for future development.

2.4 GEOLOGY AT PROJECT SITES

2.4.1 COPALAR PROJECT

A. SITE DESCRIPTION

The proposed Copalar site was designated as Copalar Downstream Site in the Phase I investigations, but is referred to herein as the Copalar site because the upstream site has been eliminated from further consideration. The Copalar site is located approximately 300 meters downstream of the confluence of Cano de Agua and the Rio Grande de Matagalpa. The general layout for this site is shown on Annex III-6, III-7 and III-8. The site can be reached by helicopter, horseback, or by a combination of foot and canoe, since there are no roads in the vicinity. Ground surface elevations at the site range from approximately 70 meters at river level to above 210 meters on both abutments. Two dam heights were under consideration for this site at the time of the geologic surface mapping and selection of the dam height will be made in accordance with the results of topographic and economic studies regarding the use of two or three dams to develop the energy potential of the river. The data contained in this section is applicable to both heights, except as otherwise noted. The higher crest level is at elevation 210 meters and requires dikes in the low saddle areas of the reservoir rim. According to the 20-meter contour interval topographic maps, four areas are possibly below the higher crest elevation. The lower crest level is at elevation 162 meters and requires no dikes. The damsite area is covered by dense vegetation, except for the left abutment, which has been partially cleared for agricultural purposes.

B. GENERAL SITE GEOLOGY

The proposed damsite and reservoir are underlain by volcanic rocks of Tertiary age, including welded tuff, welded lapilli tuff, volcanic breccia, dacite and basalt. These rocks have undergone various amounts of weathering. Most outcrops which were observed are composed of hard and slightly jointed rock, but bedrock is generally mantled by slope wash on most hillsides and by alluvial deposits along the river.

Geologic structural features, such as faults, are not readily apparent at the damsite and reservoir area due to soil cover and dense vegetation. Bedding attitudes were not established for the intermixed volcanic and pyroclastic rocks. However, the north-northeast trending valley of the Rio Grande de Matagalpa upsteam of the damsite, may be controlled by the strike of beds which might dip at

a low angle to the west. A parallel valley, about 300 meters to the west, may also be a strike valley, or perhaps a fault which might, if projected, pass west of the damsite. A curving, linear valley west of the damsite may be the topographic surface expression of a fault, which, if projected would pass through the left abutment. Another possibility is that this feature curves rather sharply and passes about 700 meters south of the damsite.

The proposed axis is located in a relatively narrow portion of the canyon. Contacts between the various rock types were not exposed on the surface. However, an interpretation of the relationship between the geologic units is shown on the geologic map and cross sections contained on Annex II-1 and Annex II-2.

The natural slope of the left abutment is generally flatter than 2:1 (horizontal to vertical). Dacite forms an extensive outcrop at the base of the abutment and along the river. The dacite is usually brown, hard, silicified, slightly jointed, and weathered, where observed in outcrops. This rock, although mapped as dacite, contains silicified volcanic breccia and welded tuff. Quartz veinlets, generally less than five millimeters, are scattered throughout the rock. Two springs issuing small flows were observed in the dacite. A small exposure of welded tuff is located approximately 25 to 35 meters above the river. The welded tuff is soft to moderately hard and weathered brown. Above the outcrop there is a small slump feature and spring. Flow from this spring was estimated to be one liter per minute at the time of the site investigation. Elsewhere the abutment is covered by overburden containing reddish-brown sandy clay and yellow-brown silty sand with scattered angular rock fragments. The depth of overburden is believed to gradually increase with higher elevations on the abutment. Consequently, foundation quality rock is believed to be relatively deep near the proposed crest elevation.

The valley floor at the proposed dam axis is approximately 100 meters wide. Bedrock on the right bank is covered by a gravel bar, which is about 40 meters wide and consists mostly of gravels and cobbles, although it also contains a few rounded, hard boulders of volcanic rock up to three meters in diameter. Groutable quality bedrock is believed to be deep beneath these gravels, even though hard basalt and volcanic breccia are exposed a short distance downstream. The bedrock surface is assumed to be irregular, based on other rock exposure in the channel. A water depth of nine meters was measured at the axis and 19 meters at the downstream toe of the high dam.

The right abutment has an average slope of nearly 1:1, and is much steeper than the left abutment. Bedrock exposures consist of volcanic breccia and welded tuff along the axis, welded lapilli tuff above crest elevation and dacite in the area of the upstream toe of the dam. A five meter high bedrock ledge of volcanic breccia was observed about 70 meters above the river on the dam axis. The volcanic breccia is gray-brown, hard, massive and slightly weathered. Massive, hard, gray tuff crops out above the river. Massive, hard, gray welded lapilli tuff is exposed on top of the ridge above crest elevation.

Deposits of rocky slope wash masks the bedrock downslope of the outcrops located on the axis of the right abutment. These deposits are believed to be shallow above elevation 140 and somewhat deeper below the elevation. Scattered large talus blocks of volcanic breccia are visible in the rocky slope wash near the base of the abutment. The depth to groutable quality rock is believed to be shallow.

The proposed spillway is located in the left abutment. Only one outcrop of bedrock was observed along the spillway alignment. This outcrop is a hard basalt exposed by the river in the tailrace area. Competent foundation quality basalt and welded tuff are believed to occur at the proposed grade elevation shown on Annex II-2. Bedrock along the alignment is overlain by a deposit of slope wash believed to be relatively deep in the vicinity of the crest section. The slope wash is composed mainly of a brown silty sand containing scattered angular rock fragments. The spillway excavation should be stable at cut slopes of 0.5:1 (horizontal to vertical) in competent rock and 1.5:1 in overburden.

The diversion tunnel is located in the right abutment and will penetrate volcanic rocks, including dacite, volcanic breccia, and basalt. These rocks range from moderately hard to hard and moderately jointed to massive. Sound rock for the proposed upstream portal is believed to be relatively shallow. Alluvial and slope wash deposits overlie basalt rock at the downstream portal. Sound rock for the downstream portal excavation is believed to be relatively deep.

The proposed power tunnel is located in the left abutment. The intake structure is located adjacent to the spillway in an area of probable deep overburden. However, suitable quality foundation rock is believed to occur at the proposed elevation of the intake structure. An outcrop of slightly jointed, moderately hard and weathered, brown welded lapilli tuff was observed in the approach channel area. The tunnel excavation will probably encounter welded lapilli tuff and dacite. Groundwater inflows are not expected to be a major problem, even though two springs having very small flow were observed on the abutment. Slightly jointed, hard, silicified dacite is exposed near the river at the outlet portal.

The proposed powerhouse location is underlain by slightly jointed, hard, silicified dacite. The dacite bedrock is covered by a fine-grained alluvium, believed to be shallow.

Dikes will be required in areas of the reservoir rim which are below the proposed high dam crest elevation. According to the 20-meter contour interval topographic quadrangle maps, there are two saddle areas below elevation 220, one saddle area below elevation 200 and one below elevation 180.

One saddle area below elevation 220 is located on the left bank of the reservoir and adjoins the hill forming the left abutment of the dam. More accurate topography could result in this dike not being required. It is approximately 100 meters wide at elevation 220, as shown on the map and the abutments have a slope of approximately 4:1 (horizontal to vertical). Volcanic bedrock at the saddle is covered by slope wash and consists predominantly of brown, gravelly silty sand. It may be desirable to use this saddle for an emergency spillway.

The other saddle area below elevation 220 is approximately four kilometers south of the damsite on the right bank of the reservoir. This saddle is a relatively narrow ridge which separates Quebrada El Guarumo from Quebrada El Cacao. Pyroclastic rocks underlie this saddle area at depth. However, the surface is covered by brown, clayey, residual soils believed to be relatively deep. This saddle could also be considered for use as an emergency spillway.

The saddle area below elevation 200 is on the left bank of the reservoir near Cerro El Trompillo and the headwaters of Rio Malacaguas, approximately 18 kilometers west of the damsite. This saddle area is swampy and underlain by pyro-

clastic rocks. Overburden is believed to be deep and to be composed of both decomposed rock and slope wash.

The saddle area below elevation 180 is located about 29 kilometers almost due south of the main dam near La Olosica and Cano La Vaca. The necessity of a saddle dike at this location was not readily apparent at the time of the geologic investigations and consequently it was not inspected. However, an inspection of this area will have to be made during subsequent project studies. According to the 20-meter contour interval topographic quadrangle maps, the crest length of this dike will be about 1,500 meters. Less than 100 meters of the total length is below elevation 180 meters and less than 800 meters below elevation 200 meters. There are several dam crest alignment possibilities in this vicinity and no problem is anticipated in locating a suitable axis. Provisions for this dike have been included in all other aspects of project planning.

The reservoir area is underlain by volcanic rocks consisting predominantly of lavas and pyroclastics. Both rock types are usually hard and massive where exposed; however, moderate to strong weathering is evident in some areas. Slope wash mantles most hillsides, and fine-grained alluvial deposits occur along the river.

Evidence of major landslides and instability problems were not observed during the geologic reconnaissance of the reservoir. However, there are minor slumps in over-steepened areas along the river and on some hillsides.

Excessive seepage from the reservoir is not expected to be a problem. Highly permeable rock strata were not observed in the reservoir. Most joints and fractures are relatively tight where observed in outcrops. Much of the overburden materials are clayey and have a low permeability.

C. CONSTRUCTION MATERIALS

Suitable sources of borrow material and quarry rock occur within five kilometers of the site, provided the enbankment is designed for the physical properties of the materials. These borrow areas are suitable for both dam heights being considered. The location of these construction materials is shown on Annex II-3. Potential impervious core sources are designated by "M" and quarry by "Q".

Investigation for borrow materials during this study consisted of a geophoto study, surface geologic reconnaissance, and excavation of a limited number of test pits in potentially favorable impervious borrow areas. Additional investigation in the area may locate other suitable sources of construction materials.

The impervious core material can be obtained from source areas designated M-1 through M-4. In addition, impervious materials can be derived from the spillway and saddle dike excavations. Other potential sources in the area include slope wash and fine-grained alluvial deposits. Borrow areas M-1, M-2, and M-3 are alluvial flood plain or terrace deposits located along the river. The deposits contain primarily sand, silt and clay and are suitable for impervious core. In places the material is estimated to be five meters deep. Slope wash from the hillsides interfingers with the alluvial material. At the time of inspection the in situ moisture seemed acceptable for construction purposes. The moisture content of the alluvial material was less than that of the more clayey slope wash and decomposed rock at the M-4 borrow site. The quantity of available

core material from areas M-1, M-2, and M-3 is estimated to exceed 3,000,000 cubic meters.

Borrow area M-1 is located on both sides of the river, four to five kilometers downstream of the damsite. The area begins where the topography changes from a mountainous terrain to a flood plain and continues downstream of the area outlined on Annex II-3; therefore, additional exploration may confirm a larger volume of suitable core material. Three test pits were excavated in representative areas and all encountered brown silty sand with some clay. Water was not encountered in the trenches and the area appears to be well drained. The available volume of core material is estimated to be 1,000,00 cubic meters. Depth of the overlying organic topsoil is quite variable, but averages 30 centimeters.

Borrow area M-2 is located along the left bank of the river, approximately two kilometers downstream of the damsite. The area is a relatively flat, well-drained terrace deposit with slope wash interfingering from the hillside. Four test pits were excavated at selected location to aid in determining the quantity and quality of available core material. Suitable core material generally ranges in depth from two to four meters and is overlain by an average of 30 centimeters of organic topsoil. The available volume of core material is estimated to be 1,000,000 cubic meters.

Borrow area M-3 is located along the right bank of the river, approximately two kilometers upstream of the damsite. This area is in part a terrace deposit, somewhat similar to M-2. Six test pits were excavated at selected locations. Alluvial deposits, slope wash and decomposed rock were encountered in the trenches. The slope wash and decomposed rock appear to contain a much higher percentage of clay and moisture than the alluvial deposit. The depth to bedrock is believed to range from one to five meters. Organic topsoil averages 50 centimeters in thickness. The available volume of core material is estimated to be 1,000,000 cubic meters.

Borrow area M-4 is located along the left bank of the river, approximately four kilometers downstream of the damsite. The deposit consists of slope wash and interfinger with alluvial materials of the adjacent M-1 borrow area. Two test pits were excavated at representative sites within the area. This material is rocky in places and contains a higher percentage of clay and moisture than the alluvial material. Scattered outcrops of bedrock were observed within the limits of the borrow area. Topsoil averages 50 centimeters in depth. The available volume of core material is estimated to be 200,000 cubic meters. This area appears less favorable than the alluvial deposits because of the bedrock outcrops and higher percentage of clay and moisture.

Sand and gravel deposits in significant quantities were not located along the Rio Grande de Matagalpa during this investigation. Therefore, the filter material and concrete aggregate will have to be manufactured from suitable quarry rock or hauled from distant areas. Additional investigation along the river during the feasibility study may locate usable quantities of alluvial sand and gravel.

Basalt suitable for dam embankment, filter material, and concrete aggregate can be obtained from potential quarry areas, Q-1 and Q-2. Also, the harder pyroclastic rocks from required excavations and the ridge above the right abutment can be used for a dam embankment designed for the physical properties of these rocks.

Quarry areas Q-1 and Q-2 are located approximately three kilometers downstream of the damsite. They consist of two ridges separated by the Rio Grande de Matagalpa. These ridges are underlain by a moderately jointed, hard, gray basalt. Exposures indicated that suitable rock will be encountered at a mininal stripping depth. The quantity of usable quarry rock is estimated to be 12,000,000 cubic meters in area Q-1 and 4,000,000 cubic meters in area Q-2.

D. CONCLUSIONS

The Copalar Project is geologically suitable for the proposed rockfill dam and appurtenant structure. Final layout of structures and dikes will require accurate topographic maps.

The proposed damsite and reservoir are underlain by volcanic rocks of Tertiary age. Much of the bedrock is masked by slope wash and alluvium. Geologic structural features such as faults, folds, and bedding are not readily apparent at the site. However, linear topographic features suggest the possibility of a fault passing through the left abutment of the damsite. North-northeast trending valleys may be controlled by the erosion along the strike of volcanic beds.

The damsite is underlain by volcanic rocks of suitable quality for the foundation of the proposed dam. Although most rock outcrops are slightly jointed to massive, grouting is advisable to reduce water percolation along joints, fractures and rock contacts. In general, overburden is believed to be relatively shallow on both abutments, with the exception of the river channel and near the crest elevation on the left abutment where the overburden is believed to be deep. The water depth measured in the river channel was nine meters at the axis and 19 meters at the downstream toe.

Suitable foundation rock underlies the appurtenant structures. Hard welded lapilli tuff and dacite are expected at the proposed excavation depth for the spillway and in the power tunnel excavation. The intake structure will be founded on competent welded lapilli tuff and the outlet portal and powerhouse on hard, silicified dacite. A relatively shallow excavation should expose bedrock at the inlet portal of the diversion tunnel which will penetrate hard volcanic rock, but there may be relatively deep excavation at the outlet portal.

Available topographic maps indicate that four dikes will be required in topographic low areas to maintain a reservoir rim at elevation 210. Three of the low saddles may be suitable for the location of an emergency spillway.

Highly permeable strata were not observed in the reservoir area and excessive seepage is not expected. Major landslides and stability problems were not observed during the reservoir reconnaissance, but minor slumping should be expected.

Suitable borrow and quarry areas are located within five kilometers of the damsite. An estimated 3,000,000 cubic meters of impervious core material are located in three borrow areas adjacent to the Rio Grande de Matagalpa and consist predominantly of alluvial deposits of sand, silt and clay. Basalt suitable for dam embankment, filter material and concrete aggregate can be obtained from two potential quarry areas downstream of the axis. An estimated 16,000,000 cubic meters of suitable rock is available in these two areas. Additional potential areas for impervious and quarry materials exist, but appear to be less suitable than those selected. They may be considered during the feasibility study if the selected areas prove to be inadequate.

2.4.2 EL CARMEN PROJECT

A. SITE DESCRIPTION

The proposed El Carmen damsite is located approximately two kilometers downstream of the confluence of Rio Quisara with the Rio Grande de Matagalpa. The general layout for this site is shown on Annex III-5. Access to the project is by jeep trail to Hacienda Santa Bertha, which is approximately fourteen kilometers upstream of the damsite. The ground surface at the site varies from approximately elevation 150 meters at the river to more than elevation 220 meters on the abutments. The axis is located in a steep, narrow, rocky gorge. The dam crest is at elevation 212 meters. Thick brush, grass and scattered trees grow on both abutments. Grass and cultivated fields are located in a saddle area on the right bank.

B. GENERAL SITE GEOLOGY

The proposed damsite and reservoir are underlain by volcanic rocks of Tertiary age. They consist mainly of interbedded flows and pyroclastics which are well exposed along the river and locally on steep hillsides. The poorly exposed bedding trends east-northeast and dips from 20 to 40 degrees to the south at the damsite area. The bedded lavas in the region are usually less than 10 meters thick; however, the basalt at the proposed axis appears much thicker and may be the plug of an old volcano. A thin mantle of slope wash overlies bedrock on most hillsides. Alluvial deposits consisting of various combination of silt, sand and gravel occur along the river. A geologic map and cross sections of the dam site are shown on Annex II-4.

There is moderately jointed, slightly weathered, hard, gray basalt exposed in a cliff approximately 30 meters high above the river at the base of the left abutment. The rock exposure can be observed for a considerable distance along the river. A series of benches are developed along joint planes in the basalt. The cliff has an average slope angle of 1:1 and flattens to about 2:1 (horizontal to vertical) above the cliff. This area is assumed to be the contact with the overlying lapilli tuff. There is a small exposure of moderately hard, massive, red flow breccia at the base of this contact. The lapilli tuff is gray, massive, moderately hard, and moderately weathered. In general, it is covered by a shallow deposit of brown slope wash. Depth to groutable quality rock is believed to be shallow.

The river completely fills the channel section at the proposed axis and is about 30 meters wide, narrowing in some places to about 15 meters. A water depth of 25 meters was measured by one sounding at the axis. The character of the rock in the riverbed and the depth of alluvium is not known. Basalt is exposed on both sides of the river in the vicinity of the damsite.

The morphology and geology of the right abutment is similar to that of the left abutment. Moderately jointed, hard, gray basalt is exposed in a series of benches and vertical cliffs along the river. These cliffs extend approximately 40 meters above the river at the axis. Scattered small basalt outcrops and rocky slope wash are exposed on the slope for another 10 meters in elevation. There is a gradual flattening of the slope and a marked decrease in the percentage of rock fragments approximately 50 meters above the river. There is also a probable increase in depth of overburden in this area, although groutable rock is estimated to be relatively shallow at crest elevation.

A low area of the ridge forming the right abutment of the main dam will require a saddle dike. The low saddle area is covered by slope wash composed of scattered basalt fragments in a brown silty sand and clayey sand matrix. A small outcrop of weathered basalt was observed on the left abutment of the saddle dike. Massive, gray lapilli tuff caps the hill above crest elevation on the right abutment of the saddle dike. Groutable foundation rock is estimated to be relatively deep beneath the proposed dike axis.

The proposed spillway is located in the right abutment. Foundation quality basalt is expected to be encountered at the proposed foundation elevation, but outcrops were not observed on the surface along the alignment except in the discharge area. The overburden is believed to be relatively shallow in the spillway chute area. Cut slopes in the overburden should be relatively flat; whereas, cut slopes in the basalt can be quite steep, based on the generally cubic joint pattern exhibited on the canyon walls.

The diversion tunnel is located in the right abutment. Hard, moderately jointed basalt is exposed on the surface at both portal locations. Alignment of the tunnel is through hard, blocky, gray basalt.

The proposed power tunnel is in the left abutment. Shallow slope wash consisting of scattered basalt and lapilli tuff fragments in a brown sandy clay was observed at the intake portal location. Relatively flat cut slopes should be stable in this overburden material. The intake structure will be founded on massive, moderately hard, gray lapilli tuff. The power tunnel will encounter some lapilli tuff and flow breccia, but hard, blocky basalt will be encountered throughout most of the tunnel alignment. The downstream portal will require a shallow excavation to reach suitable foundation rock.

The proposed powerhouse location is underlain by moderately jointed, hard gray basalt. Foundation quality bedrock will be encountered in a shallow excavation.

The reservoir area is underlain by volcanic bedrock. There is a geologic contact between basalt and flow breccia, immediately upstream of the toe of the proposed dam. Both rock types are essentially hard and massive; however, erosion has occurred along the contact which is covered by overburden. It appears that the flow breccia dips upstream and overlies the basalt. Scattered outcrops of bedded volcanic lavas and pyroclastics occur throughout the reservoir. Slope wash mantles most hillsides. Alluvial deposits occur along the river.

A geologic reconnaissance of the reservoir indicated no major landslides or stability problems. However, minor slumps occur in the fine-grained alluvial deposits that have been locally over-steepened by the river. The reservoir is believed to be essentially water tight since the volcanic beds dip upstream and none are known to be highly permeable.

C. CONSTRUCTION MATERIALS

Suitable sources of borrow material and quarry rock occur within three kilometers of the site, provided the embankment is designed for the physical properties of the materials. The location of these construction materials is shown on Annex II-5. Potential impervious core sources are designated by "M" and quarry by "Q". Additional investigation in the area may locate other suitable sources of construction materials.

The impervious core material can be obtained from areas designated M-1 through M-5. Limited quantities of impervious materials can be derived from the spillway and saddle dike excavations. Other potential sources in the damsite include slope wash and fine-grainded alluvial deposits.

Borrow areas M-1 through M-4 are deposits of intermixed slope wash and decomposed in situ rock. Five test pits were dug to a maximum depth of two meters at these four areas. Typically, the materials encountered in the test pits were sandy clay with a few gravel fragments. The material contains a high clay and moisture content and is overlain by generally less than 50 centimeters of organic topsoil.

Borrow area M-5 is an alluvial flood plain or terrace deposit along the river downstream of the damsite. The deposit contains sand, silt and clay and is suitable for impervious core. In places the material is more than 5 meters deep. Slope wash from the hillsides interfingers with the alluvial material. The moisture content of the alluvium was less than that of the more clayey slope wash and decomposed rock at the other potential borrow areas. Quantity of available core material from M-5 is estimated to exceed 250,000 cubic meters.

Sand and gravel deposits in significant quantities were not located along the river during this investigation. Therefore, the filter material and concrete aggregate will have to be manufactured from suitable quarry rock. More studies during the feasibility stage may locate usable quantities of alluvial sand and gravel.

Basalt from the quarry sites is suitable for dam embankment, filter, riprap and concrete aggregate. Two potential quarry sites, Q-1 and Q-2, are shown on Annex II-5. Most of the basalt from the required tunnel and spillway excavation will be suitable for the manufacture of filter and concrete aggregate. Basalt crops out in other nearby areas, which could be investigated for quality and quantity of available material for construction.

Area Q-1 is a potential quarry site on the left bank immediately downstream of the damsite and is underlain by basalt, welded tuff and volcanic breccia. These rocks are usually hard, although within the area there are local zones of moderately hard, weathered, zeolitic, amygdaloidal basalt, which is generally unsuitable for embankment. The quantity of suitable rock from area Q-1 is estimated to be 2,000,000 cubic meters.

Area Q-2 is underlain by hard basalt which forms a cliff that is 10 meters high and extends laterally for approximately 100 meters. Exploration will be necessary to define the limits of the basalt and depth of stripping.

D. CONCLUSIONS

The proposed El Carmen damsite is geologically suitable for the proposed rockfill dam or a concrete dam. Both abutments are underlain predominantly by a competent, gray basalt. Water depth in the river channel is about 25 meters and is probably underlain by a competent basalt. Lapilli tuff is exposed near crest elevation on the left abutment and above crest elevation on the right abutment of the dike. Grouting will be necessary to reduce percolation along joints and fractures at the main dam and saddle dike. Overburden is generally shallow on the abutments, but is believed to be relatively deep beneath the dike alignment.

Suitable foundation rock underlies the appurtenant structures. Hard basalt is expected at the proposed excavation depth in the spillway. The diversion tunnel, power tunnel and power plant are located predominantly in good quality basalt. Suitable borrow and quarry areas are located within three kilometers of the damsite.

Major landslides were not observed during a reconnaissance of the reservoir. Excessive seepage from the reservoir is not expected to be a problem, since the bedding dips upstream, most joints appear to be tight and the rock is covered by overburden in most places.

2.4.3 PASO REAL PROJECT

A. SITE DESCRIPTION

The proposed Paso Real damsite is located about two kilometers downstream of the confluence of the Rio Olama with the Rio Grande de Matagalpa. The general layout of this project is shown on Annex III-4. Access is by a dirt road that ends at a ranch house approximately three kilometers north of the site. The ground surface at the site varies from approximately elevation 205 at the river to above elevation 320 on both abutments. Four alternate crest elevation varying from elevation 267 to elevation 307 were considered during Phase I from which crest elevation 275 was selected for the Phase II investigation. The proposed axis is at a relatively steep, narrow portion of the canyon covered by dense vegetation on both abutments.

B. GENERAL SITE GEOLOGY

The damsite and reservoir are underlain by volcanic rocks of Tertiary age. Scattered outcrops occur along the river and on some steep hillsides, although most hillsides are mantled by slope wash. Stream and terrace deposits exist along the river.

The proposed axis is in a canyon where the river flows across the strike of resistant, interbedded volcanic rocks. Beds dip upstream from 12 to 18 degrees. Contacts between the various rock types are gradational to irregular, but are essentially water tight where exposed in outcrops. A geologic map and cross sections of the damsite is shown on Annex II-6.

The ground surface on the left abutment has an average slope of 2:1 (horizontal to vertical). Interbedded basalt and volcanic breccia are exposed locally in cliffs from one to three meters high along the base of the abutment and continue to approximately 30 meters above the river. The volcanic breccia is typically reddish-gray, massive, hard and slightly weathered. Large talus blocks of the volcanic breccia are at the base of the abutment. A massive, thin bed of reddish flow breccia occurs at the base of the basalt. The basalt is gray, hard, moderately jointed and slightly weathered. From 30 meters above the river to crest elevation, bedrock is masked by slope wash which appears to be shallow. The slope wash consists of scattered angular rock fragments in a brown silty sand. A relatively shallow excavation from the surface should expose groutable bedrock in the cutoff trench.

The valley floor is relatively narrow at the proposed dam axis. Fine grained alluvium is exposed on the left bank of the river, which flows near the base of the left abutment. Bedrock, consisting of hard, slightly jointed volcanic breccia

and basalt, is exposed in the channel at low water along the right bank of the river. Bedrock is exposed almost continously across the valley floor upstream of the axis. It consists of interbedded basalt, volcanic breccia and welded tuff. Erosion has created an irregular surface and many potholes in the bedrock. Locally, this surface is overlain by a thin layer of alluvium, mainly sand, which sometimes contains large boulders. A water depth of 7.5 meters was measured upstream of the axis.

The right abutment is steep with an average slope of 1:1. Massive volcanic breccia is exposed at the base of the abutment. The breccia is overlain by a hard, slightly jointed, gray basalt which forms a cliff 10 meters high along the axis. A one meter thick red flow breccia occurs at the contact of the two units. This contact is somewhat irregular, but is essentially tight and dips upstream at 12 degrees. Above the cliff, bedrock is masked on the steep hillside by a shallow deposit of slope wash. Groutable rock is estimated to occur at a shallow depth.

The proposed spillway is in the right abutment. Bedrock consisting of moderately weathered volcanic breccia and lapilli tuff crops out locally along the spillway alignment. Elsewhere along the alignment, bedrock is hidden by slope wash estimated to be relatively shallow. Minor local slumps have occurred in the slope wash where slopes have been oversteepened by erosion. An alluvial deposit of brown silty sand is estimated to be relatively deep in the stilling basin area. Suitable foundation rock should occur at the proposed excavation depth.

The combined diversion and power tunnel is located in the left abutment. The foundation for the inlet portal of the diversion tunnel will be in hard, moderately jointed, gray basalt. The intake structure of the power tunnel is located in slope wash, which is believed to cover massive volcanic breccia at a shallow depth. Underlying the volcanic breccia is hard, jointed basalt, which may be exposed in the approach channel excavation. Most of the tunnel will be excavated through massive, hard and moderately hard, reddish-gray volcanic breccia. The outlet portal of the tunnel will be located in a deposit of slope wash and alluvium containing large blocks of volcanic breccia. Some blocks are as much as six meters in diameter.

Hard, jointed, slightly weathered, gray basalt crops out along the river at the proposed powerhouse location. Local shallow deposits of alluvium, consisting of a fine silty sand, cover the basalt bedrock. Water in the river channel is estimated to be 10 meters deep.

Volcanic rock is exposed along the river and on steep slopes of the proposed reservoir area. The rock is masked by overburden of various depths in most areas. The volcanic rocks consist mainly of flows and interbedded pyroclastics. Bedding is well developed and usually strikes northeast-southwest and dips from 12 to 18 degrees to the northwest. Stream erosion is occuring along the strike of the beds. The northeast trending valleys in the reservoir area are a result of stream erosion rather than faulting.

Unconsolidated sediments in the reservoir are mainly of slope wash and alluvial origin. Slope wash mantles most hillsides. Terrace deposits containing fine-grained alluvial materials are located along the river. Sand and gravel occurs in some terrace depostis and also along the river channel. Minor slumping was

observed in fine-grained alluvial materials along locally oversteepened river banks. A minor landslide has occurred along the left bank of Cano El Balsamo about 75 meters above the valley floor. The slide is apparently along the dip slope of the bedding.

Major landslides were not observed during a reconnaissance of the reservoir. The upstream dip of the beds and relatively tight fractures in the rock indicate that there will be no problem of excessive seepage from the reservoir.

C. CONSTRUCTION MATERIALS

Suitable sources of borrow material and quarry rock for construction occur within six kilometers of the site. Locations of construction material are shown on Annex II-7. Potential impervious core sources are designated by "M" and quarry sites by "Q". Additional investigation in the area may locate other suitable sources of construction materials.

Alluvial flood plain or terrace deposits along the Rio Grande de Matagalpa contain sand, silt and clay suitable for impervious core material. These deposits contain intermixed slope wash from the adjacent hills. The alluvial materials are available in various quantities from borrow areas M-1 through M-4. Area M-1 is on the left bank of the river immediately upstream of the dam. Exposures in the river bank and five test pits indicate that alluvial material varies from two to eight meters deep. The available quantity of core material from area M-1 is estimated to be 250,000 cubic meters. Additional quantities of similar material can be obtained from areas M-2, M-3 and M-4.

Borrow source M-5 covers a large area located approximately three kilometers upstream of the damsite. The area is rolling and drainage may be a problem. Organic topsoil, up to one meter in depth, overlies tuff which is decomposed for an average depth of one meter. This decomposed tuff contains a high clay and moisture content, based on two test pits.

Significant deposits of sand and gravel suitable for filter and concrete aggregate were not observed along the river. It is assumed that these materials will be manufactured from suitable quarry rock.

Three potential quarry sites are designated on Annex II-7. The spillway excavation is located within site Q-1 which contains interbedded volcanic breccia and basalt. A sufficient quantity of rock is available that can be used for the rockfill embankment in a dam designed for the physical properties of the rock. The filter material, concrete aggregate, and riprap could be obtained from the basalt. Site Q-2 is principally a bedded deposit of welded tuff. Site Q-3 is a deposit of basalt. Additional investigation is necessary at all the quarry sites to define the quality of available rock. However, it appears that there is sufficient rock near the site to supply the material for an embankment designed for the physical properties of the rock.

D. CONCLUSIONS

The Paso Real Project is geologically suitable for the proposed rockfill dam and appurtenant structures. Overburden is relatively shallow on both abutments and in the river channel. Foundation rock consists primarily of hard, interbedded volcanic material dipping upstream at a low angle. Even though much of the rock is massive, grouting will be necessary to reduce water losses through the joints

and fractures. Suitable foundation rock is expected at the proposed excavation depth of the spillway. The outlet portal for the combined diversion and power tunnel is located in an area of slope wash and alluvium containing large talus blocks. Suitable sources for impervious core and quarry rock are within six kilometers of the site.

Reservoir seepage losses will be within normal limits attributable to bank storage and should stabilize soon after reservoir filling. Also, no geologic evidence of major landslides, which would be critical to construction of a dam at the Paso Real site, were observed.

2.4.4 LAGUNA DE APOYO PROJECT

A. SITE DESCRIPTION

The proposed Laguna de Apoyo Pumped-storage Project is located on the west side of Laguna de Apoyo, which is a caldera lake approximately five kilometers in diameter. The rim of the caldera varies in elevation from 160 meters on the east side to 600 meters on the west near the location of the proposed upper level reservoir. The site is about one kilometer north of the small village of Catarina in the Department of Masaya.

The upper level reservoir site is on the side of a small hill near the rim of the caldera. The ground surface at the proposed damsite varies from approximately elevation 530 to above elevation 560 on the ridges forming the abutments. The proposed dam crest is at elevation 553 and the water surface in Laguna de Apoyo is elevation 80. The depth of the lake is reportedly over 200 meters. Agricultural crops, brush and scattered trees are growing at the reservoir site and along the penstock alignment.

A surface pumping-generating plant and an underground installation were under consideration at the time of the geologic investigation. The following discussions apply only to the surface installation because no subsurface investigation have been performed from which conclusion can be reached regarding the underground installation and only surface geology is considered during this phase of the study. The general layouts of the surface and underground installations are shown on Annex III-9 and Annex III-10 respectively.

B. GENERAL SITE GEOLOGY

The proposed project is within a graben structure that trends northwest across an active seismic and volcanic region of Nicaragua. Numerous earthquakes have been felt at Laguna de Apoyo and several epicenters of earthquakes having a magnitude greater than 5.0 on the Richter Scale have occurred within a 50 kilometer radius. A magnitude 8 event is considered possible at this site.

Laguna de Apoyo is a caldera lake in alignment with other calderas and volcanoes; some of which are active. Although it appears to be dormant at presen . it is one of the most explosive and potentially desvastating volcanoes in Nicaragua, according to A. R. McBirney, "The Origin of the Nejapa Pits Near Managua, Nicaragua", 1955. On June 8, 1852, Laguna de Masaya and Laguna de Apoyo began to "boil", probably as a result of emission of gases from the lake bottoms, as reported by R. D. Brown, et. al., "Geologic and Seismologic Aspects of Managua, Nicaragua, Earthquakes of December 23, 1972", 1973, USGS Professional Paper 838. The nearest active volcano is Volcan Santiago which is located 13 kilometers to

the northwest and is emitting gases and sulfur fumes. Hot springs occur near the edge of the water on the southwest side of Laguna de Apoyo.

The project area is underlain by volcanic rocks of Quaternary age. The geologic surface mapping and cross section of the project geology is shown on Annex II-8. Many different rock types, including pumice, tuff, volcanic breccia, basalt, lapilli tuff, flow breccia and scoria are locally exposed in the walls of the caldera. Slope wash consisting of brown clayey sand covers the bedrock in most places. Talus and landslide deposits are common inside the caldera. No faults were observed to cross the upper level reservoir or penstock alignment; however, two faults are mapped at the south end of Laguna de Apoyo on the Masaya quadrangle geologic map.

The proposed upper level reservoir area is underlain by a shallow deposit of bedded tuff locally masked by slope wash. The tuff is contiguous over a large area of Masaya and, according to reports, was deposited from eruptions at Laguna de Apoyo. The tuff is quarried locally for building stone. It is usually brown, fine-grained, firm, moderately indurated, moderately weathered and slightly fractured to massive where exposed in gullies. Loose pumice is quarried locally and caps the hill above the right abutment of the dam, which is mapped as a volcanic cone on the geologic quadrangle map. A highly pervious pumice deposit, varying from loose to locally moderately indurated, is beneath the tuff layer in the reservoir. Pumice is also exposed in a nearby railroad cut and in gullies on the caldera walls. These exposures indicate that this pumice deposit may exceed 100 meters in thickness. Where stratified, it has a low dip angle toward the caldera, the same as the tuff. Tuff, basalt, volcanic breccia and lapilli tuff are exposed in the railroad cut in addition to the pumice. Surface investigations indicate that the dam and upper level reservoir will be founded mainly on the loose, highly pervious deposits of pumice and partly in tuff.

The intake structure is located in the reservoir and will have its foundation on pumice. The pumice is loose to poorly consolidated. It stands well in steep cut slopes along the railroad alignment.

The presently proposed penstock alignment will be in a tunnel for about the first third of its length from the intake. The remainder will be a cut and cover structure to the powerhouse on the shore of the Laguna. It is anticipated that the tunnel section will be in the same pumice deposit as the intake structure. The cut and cover section is on a ridge that has an average slope of 2:1 (horizontal to vertical), but is locally 1:1. Pumice, tuff, slope wash and landslide debris are exposed on the surface of the ridge. The slope wash is shallow, but the heterogeneous landslide deposits may be deep. Landslide scarps are visible on the steeper parts of the ridge.

The powerhouse location is underlain by landslide material, which is believed to be deep. This material is heterogeneous and, where exposed in the road cut, consists of large, angular rock fragments which are up to three meters in diameter, all incorporated in a gravelly, clayey sand. Exploration is necessary to determine the depth to bedrock and its physical properties. The hot springs previously mentioned are located approximately two kilometers south of the powerhouse site.

C. CONSTRUCTION MATERIALS

Suitable material for an earthfill embankment can be obtained within two kilometer of the site. Impervious core material can be obtained in limited quantities

from deposits of slope wash and decomposed tuff within the reservoir and nearby. The underlying tuff is suitable for a dam embankment that has been designed for its physical properties. This borrow area is designated M-1 on Annex II-8. Sand and gravel deposits suitable for filter and concrete aggregate were not observed near the site. This material can be manufactured from suitable quarry rock.

A suitable quarry site is located within 500 meters of the reservoir, and is designated Q-1 on Annex II-8. Basalt is exposed at this site for 100 meters along a 10 meter deep railroad cut. It is gray, coarse-grained, massive and hard and would be suitable for filter, concrete aggregate and riprap. An estimated 30,000 cubic meters are available; however, the quantity could be considerably greater because the basalt is believed to be a part of an old volcanic plug which could extend to great depth. In addition to Q-1, limited quantities of hard basalt are exposed elsewhere in the caldera walls.

D. CONCLUSIONS

The construction of the proposed Laguna de Apoyo Project appears to be tecnically feasible. However, this area has a long history of seismic and volcanic activity. Therefore, it is essential that these potential geologic hazards be carefully considered in the project design. The report of the consulting engineering geologist, Dr. W.I. Gardner, contains conclusions and suggestions regarding this project. Some conclusions reached during this investigation by geologists and engineers who inspected this site include the following observations:

1. The occurrence of an earthquake having a magnitude 8 on the Richter Scale is possible at this location.

2. Laguna de Apoyo is reported to be one of the most explosive and potentially devastating volcanoes in Nicaragua.

3. An active volcano, Volcan Santiago, is located about 13 kilometers northwest of the site.

4. The upper level reservoir and penstock alignment are not known to be crossed by faults; however, two faults are mapped at the south end of Laguna de Apoyo on the Masaya quadrangle geologic map.

5. A hot spring is at the edge of the lake about two kilometers south of the powerhouse location.

6. The powerhouse location is in landslide debris believed to be deep.

7. The lower part of the penstock alignment will be in landslide debris.

8. The penstock tunnel will probably be in pumice.

9. The upper level reservoir is underlain by pumice that is typically loose and highly permeable.

10. The upper level reservoir will require lining.

11. The impervious core material, earthfill embankment, and quarry sources occur within two kilometers of the project.

2.5 GEOTECHNICAL INVESTIGATION PROGRAM

The scope of work for the Phase II Prefeasibility Study includes the preparation of a geotechnical investigation program to be performed at the site that is selected for the feasibility study. The Copalar Project has been recommended for that study.

The purpose of the geotechnical investigation program is to provide sufficient data to make a positive evaluation of the geological suitability of the site, to evaluate the quantity and quality of available construction materials and to provide data for preliminary design and a reasonably accurate cost estimates of the various projects features.

Geotechnical investigations to be performed during the feasibility study include geologic mapping, subsurface exploration and laboratory testing. Accurate topographic maps and field surveys of the explorations are essential to the efficient execution of the study. The investigation program must remain flexible so that modifications can be made as new data is developed. The exploration and testing programs are, in part, dependent on geotechnical conditions encounter; therefore, final details will be developed as the study proceeds.

In addition to detailed field mapping, the geologic mapping program will include a geophoto study consisting of a review of:

1. Existing aerial photographs.

2. New or recent aerial photographs made for the project studies.

3. Any available Earth Resource Technology Satellite (ERTS) and similar satellite photographs.

Geologic field mapping should be performed on new topographic base maps. Detailed engineering geologic mapping is necessary at the damsite, appurtenant structures and dike locations. However, less detailed geologic mapping would be suitable within the reservoir except in those areas where special problems are apparent; such as leakage and landslides.

Subsurface explorations should be performed at the damsite, appurtenant structures, dikes and borrow and quarry locations. Geophysical techniques, drill holes, test pits and adits will be used. A suggested exploration program for the Copalar Project High Dam is summarized in Table II.1. The exploration program for a low dam would be very slightly less than that required for a high dam. The proposed locations of explorations at the damsite for the low dam are shown on Annex II-9 and those for the high dam are shown on Annex II-10.

Geophysical investigations will be limited to seismic refraction surveys. The data from them will be used to extrapolate geologic information between drill holes and test pits at the damsite, dike locations, borrow areas and quarries.

Drill holes will be bored by rotary drills. Sampling of the overburden material will be by split spoon samplers and Shelby tubes. Core drilling will be NX size. The maximum hole depth anticipated is about 100 meters.

TABLE II.1
COPALAR PROJECT - HIGH DAM
PRELIMINARY GEOTECHNICAL EXPLORATORY PROGRAM

	SEISMIC	DRILL HOLES		TEST PITS
	Meters	Number	Total Meters	Number
Left Abutment	500	5	280	5
Valley Section	200	5	260	2
Right Abutment	400	3	190	3
Spillway	1,700	4	190	5
Diversion Tunnel	700	3	120	2
Power Tunnel	600	4	200	2
Powerhouse	400	3	100	4
Dikes (4)	2,000	6	210	10
Borrow Areas	10,000	10	100	30
Quarry Areas	500	5	150	10
TOTAL	17,000	48	1,800	73

All holes will be water tested by gravity flow tests in overburden and pressure tests in rocks. Standpipes will be installed in selected holes and the groundwater levels monitored. All drilling, sampling and testing operations should be performed under the direct field supervision of qualified personnel.

Test pits will be hand dug to a depth and size that is practical. Depths greater than ten meters are not anticipated. In the impervious borrow areas, test pits will be field located to optimize ground conditions and define the borrow limits. Sampling of the soils by qualified personnel will be necessary.

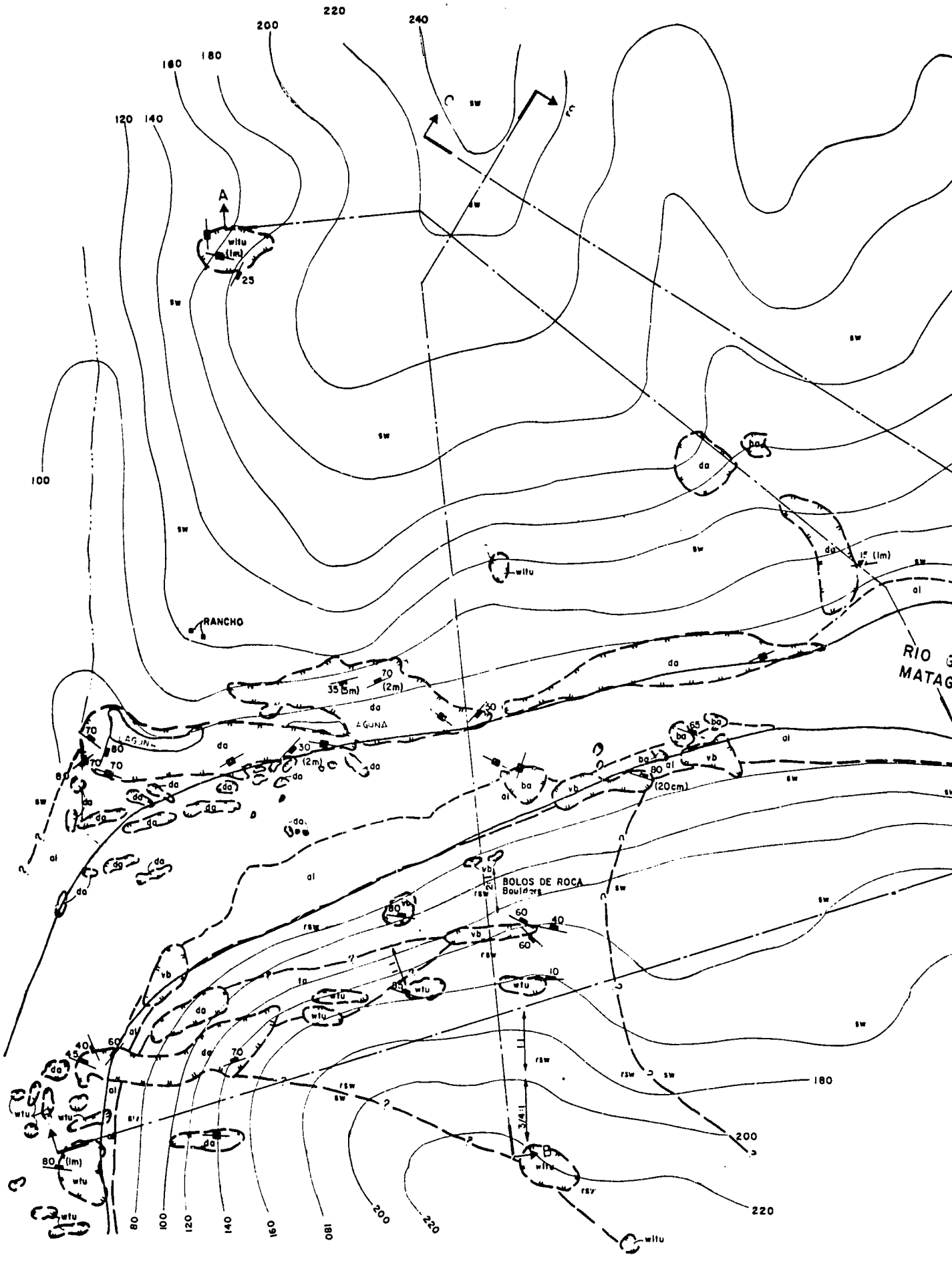
Two exploratory adits will be excavated in the left abutment to determine in situ rock conditions; one at the proposed location of the intake structure and the other at about elevation 75, near the dam axis. The size of the adits should be approximately 2.0 by 2.5 meters.

The testing program will include both field and laboratory tests. The field tests to be performed are the Standard Penetration Test and water tests in drill holes. In addition, blasting tests are desirable in the quarry areas to determine the rock breakage characteristics, such as size, shape, and gradation for various combinations of drill hole spacing and explosive charges.

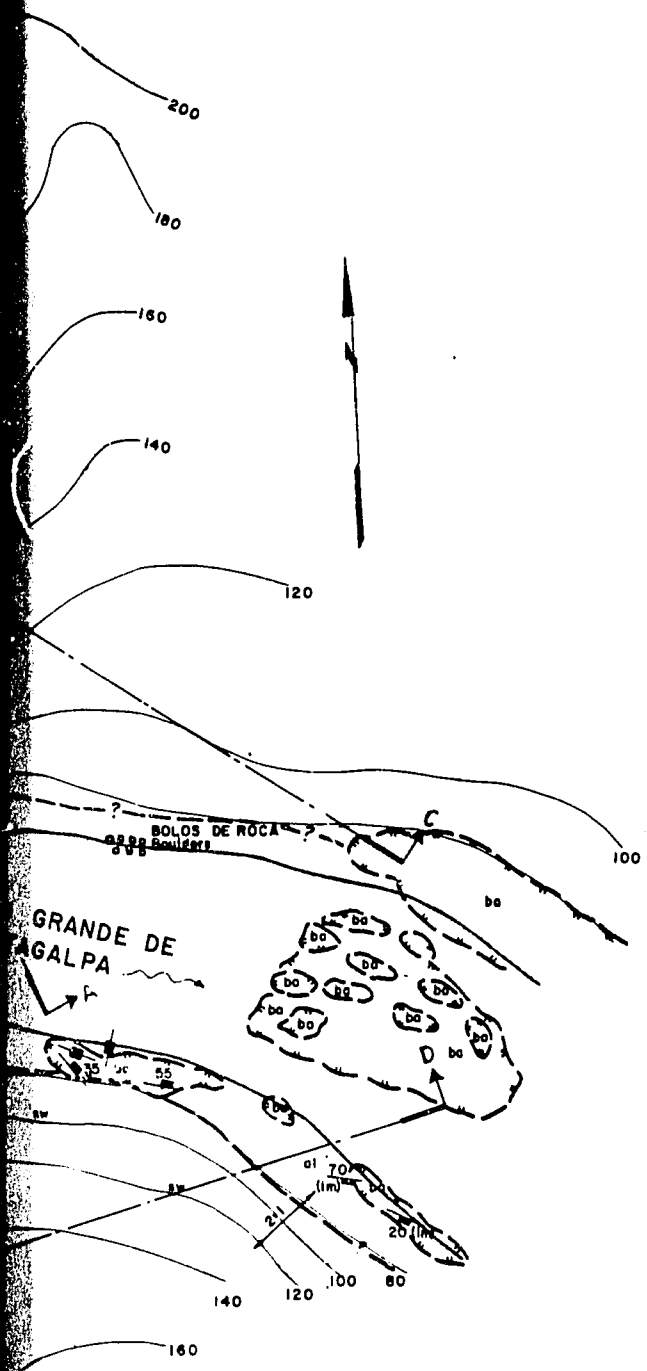
The laboratory testing program is designed to determine the physical and engineering properties of the foundation soils and borrow materials. Test to be performed during the feasibility study should include, but not necessarily be limited to those shown in Table II.2.

TABLE II.2
PRELIMINARY MATERIALS TESTING PROGRAM

Soil Tests	Applicable Specification
Specific Gravity	ASTM D 854
Grain Size Analysis	ASTM D 422, ASTM D 1140 & ASTM D 1524
Atterberg Limits	
Liquid Limit	ASTM D 423
Plastic Limit	ASTM D 424
Shrinkage	ASTM D 427
Moisture Content	ASTM D 2216
Standard Proctor	ASTM D 698
Aggregate and Rock Tests	
Specific Gravity	ASTM C 128
Absorption	ASTM C 127
Abrasion Loss	ASTM C 131 & ASTM C 535
Petrographic Analysis	ASTM C 295
Soundness	ASTM C 88
Alkali Reactivity	ASTM C 227


RANCHO
LAGUNA
RIO
MATAG
BOLOS DE ROCA
Boulders
A
B
3/4:1
sw
da
al
vb
rsw
wltu
ba
100
120
140
160
180
200
220
240

PLANTA
PLAN



LEYENDA
Legend

al — ALUVION - PRINCIPALMENTE DEPÓSITOS DE ARENA COLOR CAFÉ Y GRAVAS LOCALES.
Alluvium - mainly brown sand, locally gravels.

sw — DESLAVE DE LADERA - PRINCIPALMENTE ARENAS ARCILLOSAS Y LIMOSAS.
Slope Wash - mainly brown silty sand or clayey sand.

rsw — DESLAVE ROCOSO - FRAGMENTOS ROCOSOS ANGULARES EN UNA MATRIZ DE ARENA, ARCILLA Y LIMO
Rocky Slope Wash - angular rock fragments in a matrix of sand, silt and clay.

to — TALUD DETRITICO - PRINCIPALMENTE FRAGMENTOS ROCOSOS ANGULARES.
Talus - mainly angular rock fragments.

ba — BASALTO - CASI SIEMPRE GRIS, DURO, LIGERAMENTE METEORIZADO Y DIACLASADO.
Basalt - typically gray, hard, slightly weathered, and slightly jointed.

vb — BRECHA VOLCANICA - TIPICAMENTE GRIS, MASIVA, DURA Y LEVEMENTE METEORIZADA.
Volcanic Breccia - typically gray, massive, hard, slightly weathered.

da — DACITA - TIPICAMENTE COLOR PARDO, DURA, SILICIFICADA, LEVEMENTE METEORIZADA, MASIVA.
Dacite - typically buff, hard, silicified, slightly weathered, massive.

wtu — TOBA SOLDADA - TIPICAMENTE COLOR GRIS, DURA, POCO FRACTURADA.
Welded Tuff - typically gray, hard, slightly fractured.

wltu — TOBA SOLDADA - DE COLOR PARDO A GRIS, MODERADAMENTE METEORIZADA MODERADAMENTE DURA, MASIVA.
Welded Lapilli Tuff - typically gray to buff, moderately weathered, moderately hard, massive.

AFLORAMIENTO ROCOSO - UBICACION APROXIMADA, LOCALMENTE CUBIERTO POR MATERIAL DE COBERTURA.
Rock Outcrop - Approximate location, locally masked by overburden.

CONTACTO GEOLOGICO - CON LINEA A TRAZOS DONDE ES APROXIMADO, SIGNO DE PREGUNTA INDICA CONTACTO SUPUESTO O DUDOSO.
Geologic contact - dashed where approximately located, question marks where inferred.

65 (1m) — RUMBO Y BUZAMIENTO DE LAS DIACLASAS (DISTANCIA ENTRE JUNTAS).
Jointing - strike and dip (spacing).

(50 cm) — RUMBO DE DIACLASAS VERTICALES (DISTANCIA ENTRE JUNTAS).
Jointing - vertical (spacing).

NACIMIENTO DE AGUA.
Spring.

1:1 — INCLINACION DEL TERRENO.
Slope.

20 0 50 100 METROS
Meters
ESCALA
Scale

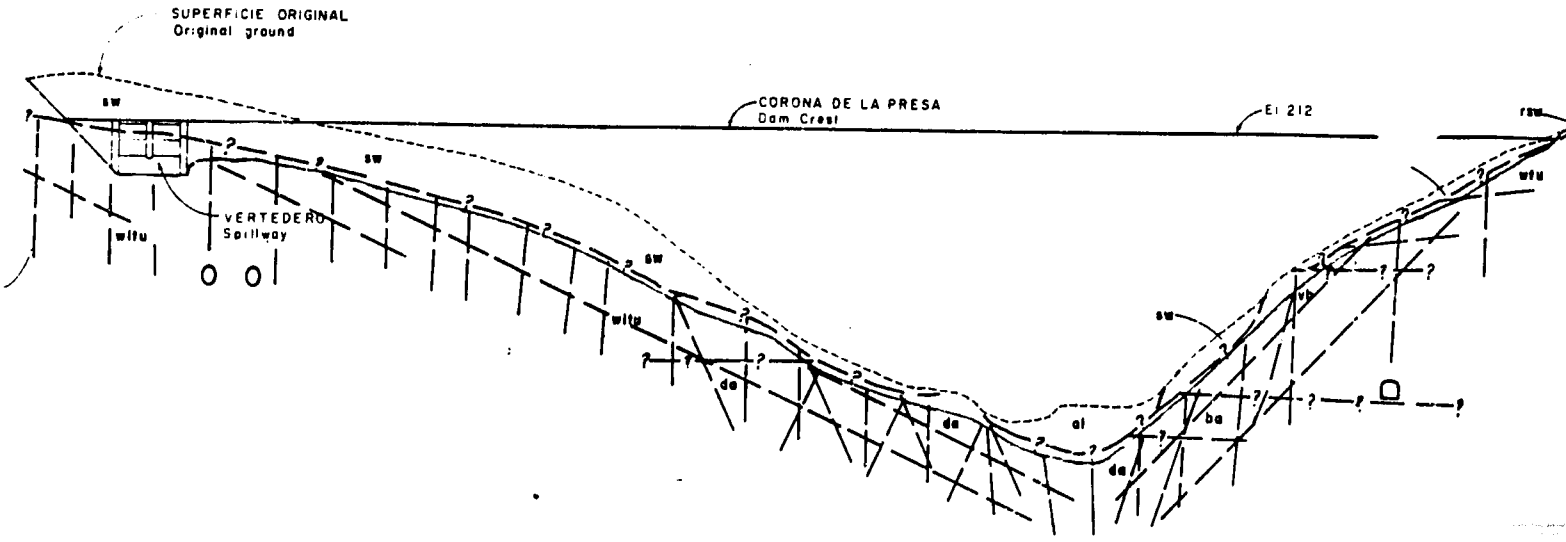
PLANO DE REFERENCIA DE FASE I
PHASE I REFERENCE DRAWING
ANEXOS (ANNEXES) V-12, V-14 Y V-15

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

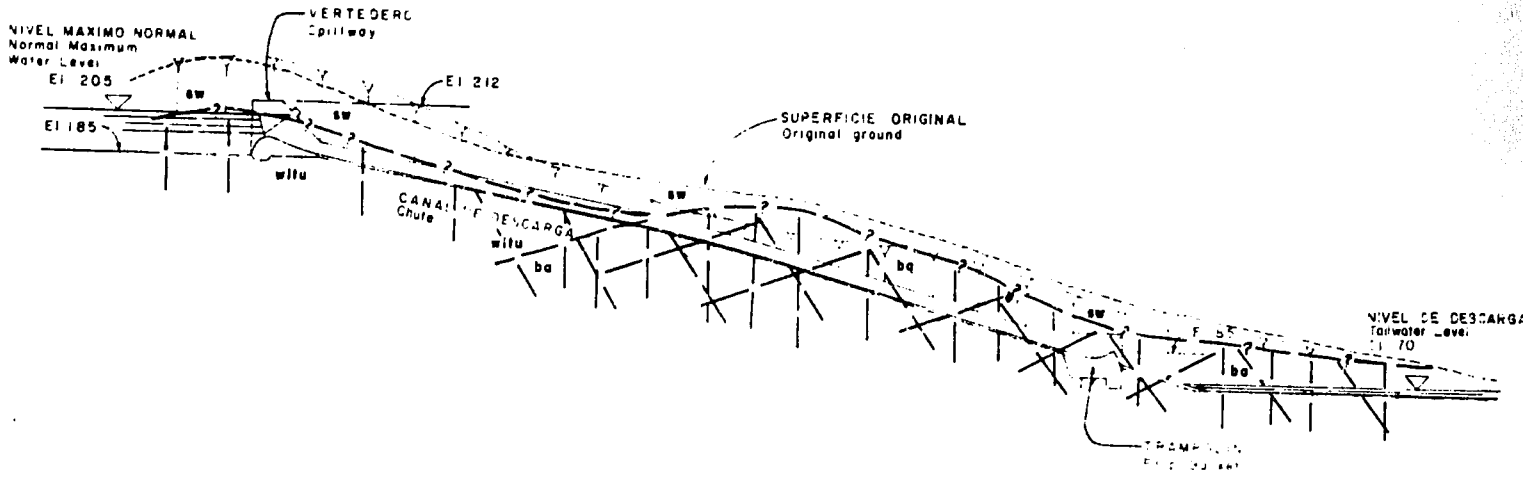
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
PROYECTO COPALAR-PRESA ALTA Y PRESA BAJA
COPALAR PROJECT - HIGH DAM AND LOW DAM
GEOLOGIA SUPERFICIAL - SURFACE GEOLOGY
PLANTA - PLAN

INTERNATIONAL ENGINEERING COMPANY, INC.

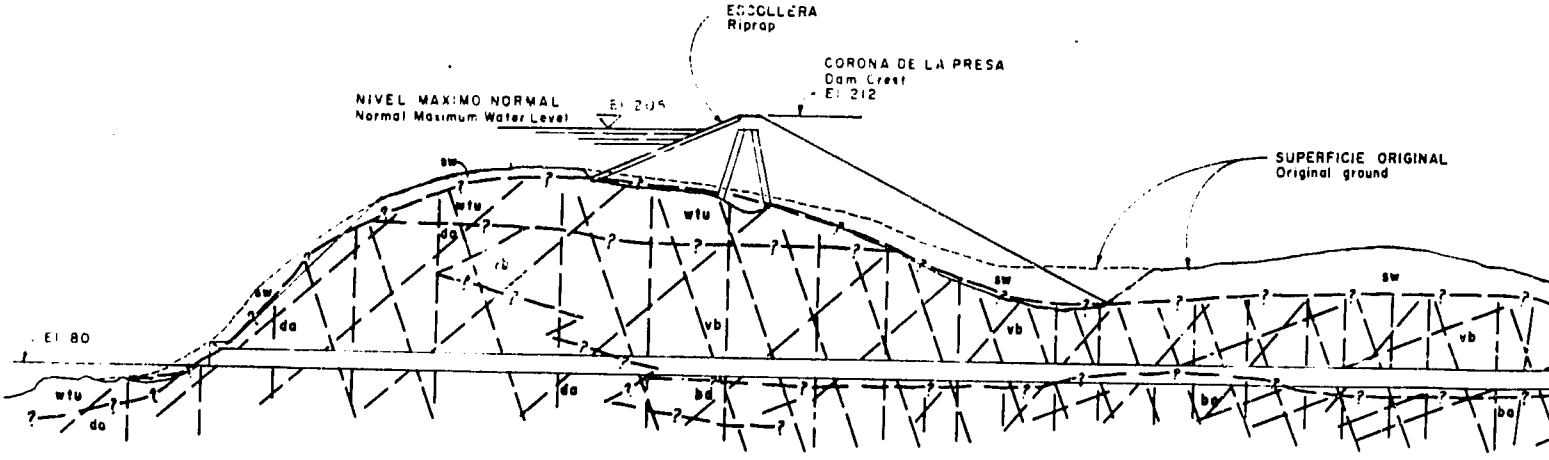
DIBUJO S. F.	REVISO	APROBADO
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975



SECCION LONGITUDINAL B - B
LONGITUDINAL SECTION B - B

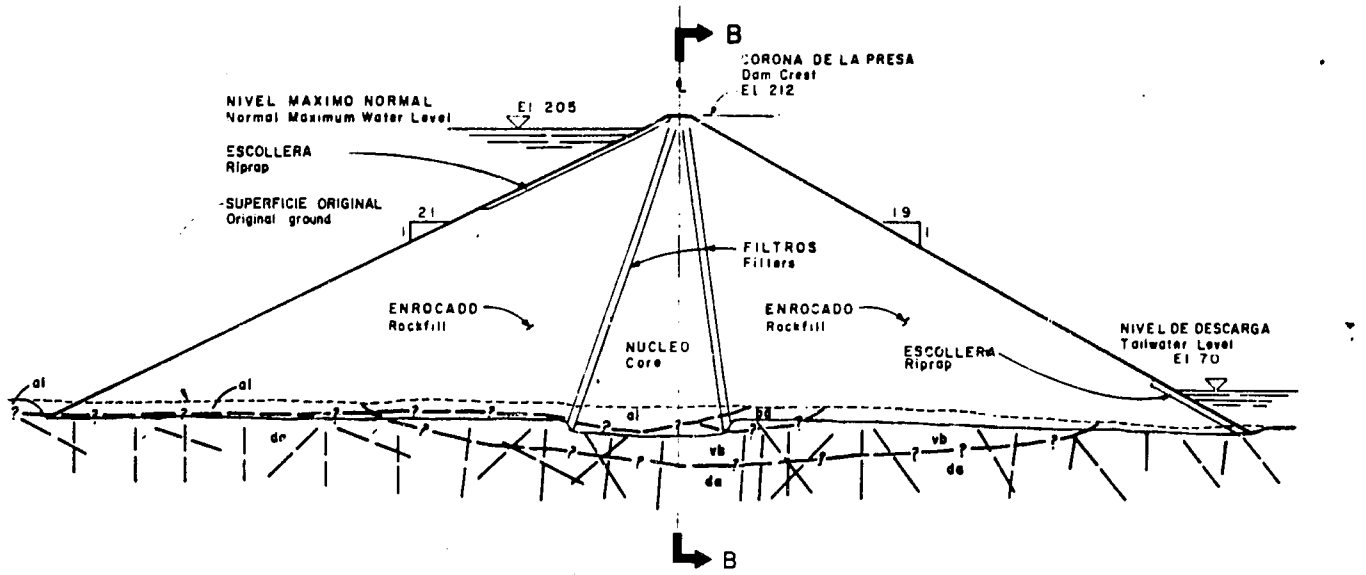


SECCION LONGITUDINAL C - C
VERTEDERO
LONGITUDINAL SECTION C - C
SPILLWAY

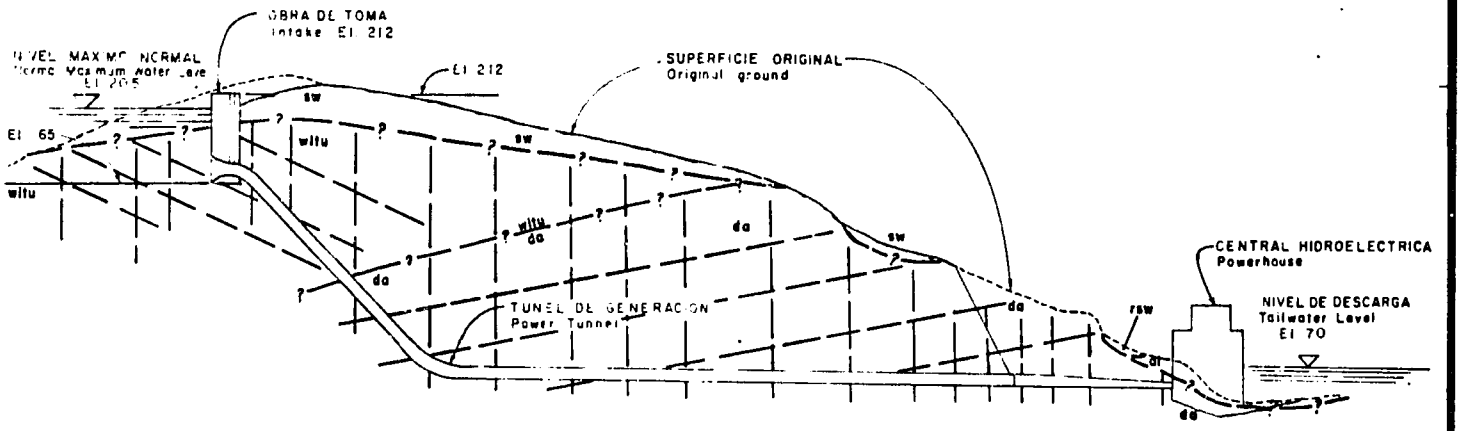


SECCION LONGITUDINAL D - D
TUNEL DE DESVIO

LONGITUDINAL SECTION D - D
DIVERSION TUNNEL



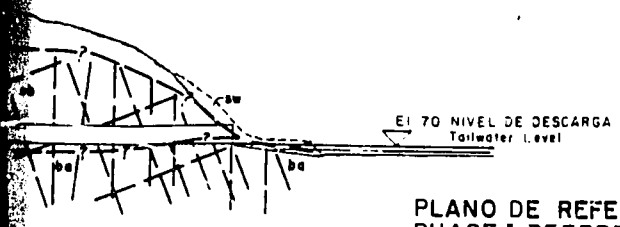
SECCION TRANSVERSAL (ESQUEMATICO)
TRANSVERSAL SECTION (SCHEMATIC)



SECCION LONGITUDINAL A - A
TUNEL DE GENERACION

LONGITUDINAL SECTION A - A
POWER TUNNEL

20 0 50 100 METROS
Meters
ESCALA
Scale



PLANO DE REFERENCIA DE FASE I
PHASE I REFERENCE DRAWING
ANEXOS (ANNEXES) V-14 Y V-15

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

PROYECTO COPALAR-PRESA ALTA
COPALAR PROJECT - HIGH DAM
GEOLOGIA SUPERFICIAL - SURFACE GEOLOGY
SECCIONES - SECTIONS

INTERNATIONAL ENGINEERING COMPANY, INC.

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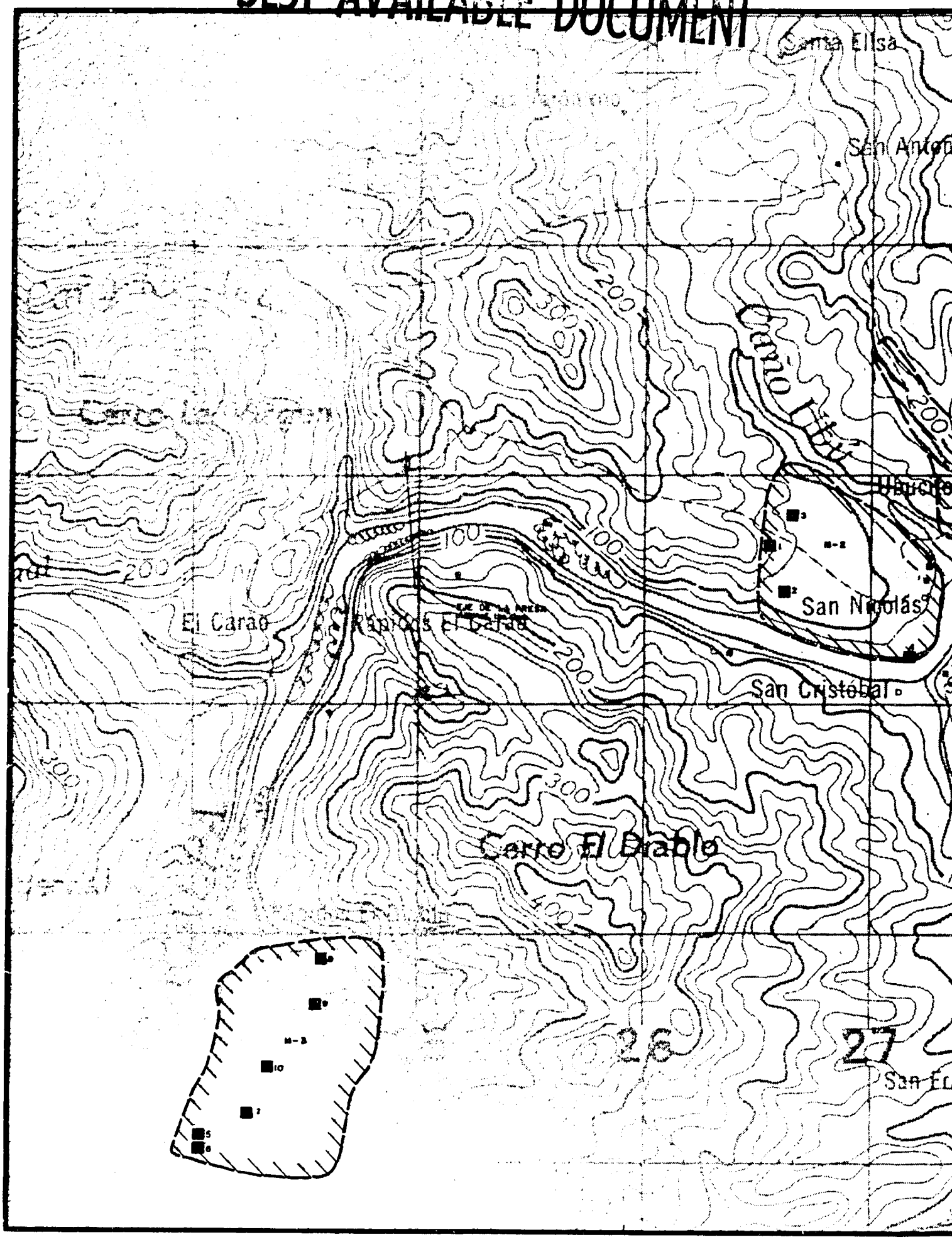
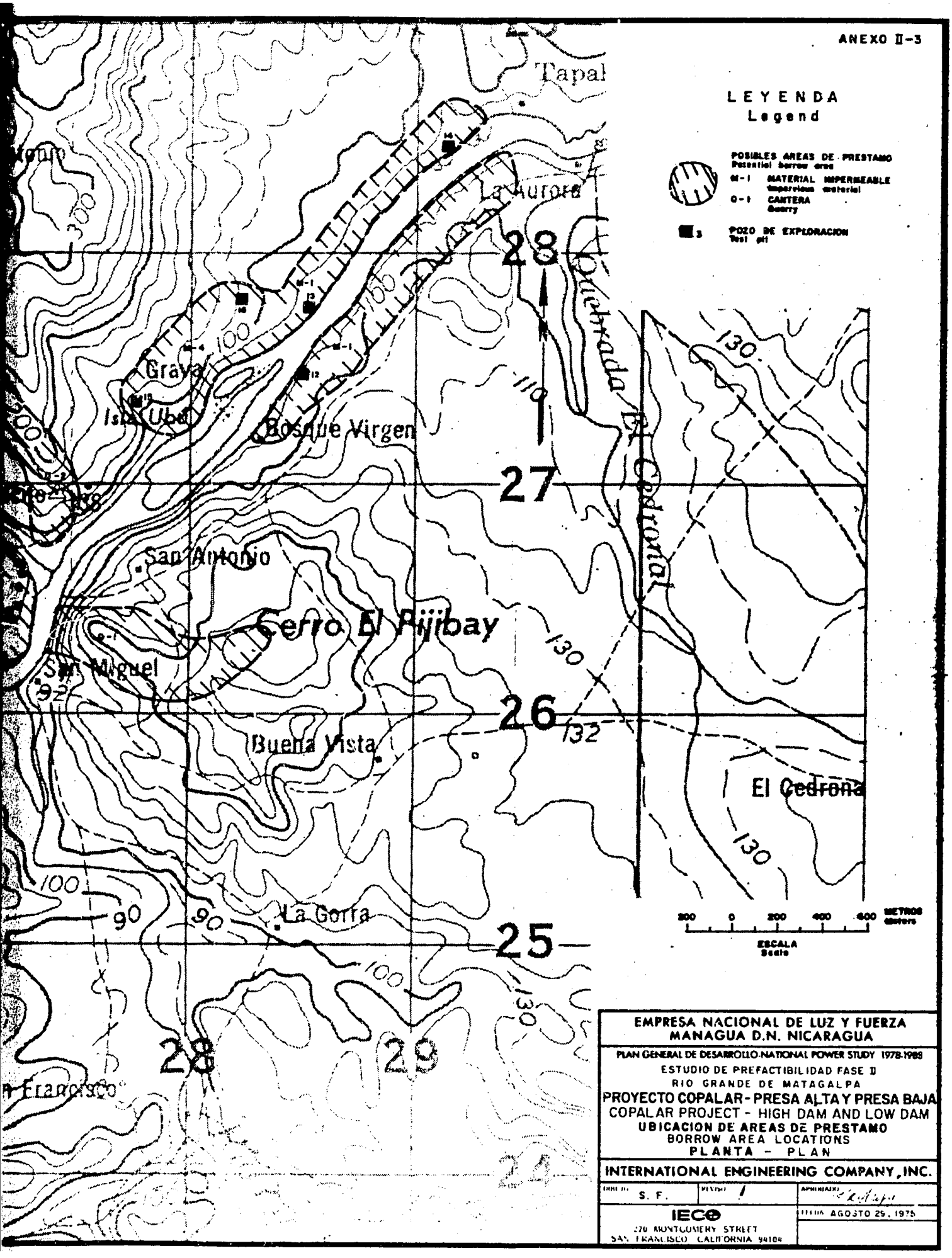
BEST AVAILABLE DOCUMENT



ANEXO II-3

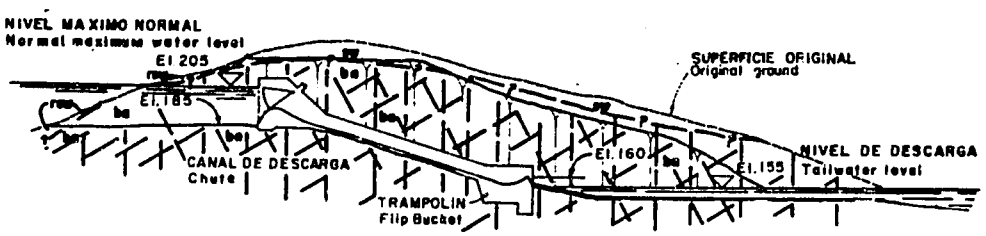

LEYENDA
Legend
POSIBLES AREAS DE PRESTAMO
Potential borrow area
M-1 MATERIAL IMPERMEABLE
Impervious material
C-1 CANTERA
Quarry
POZO DE EXPLORACION
Test pit
Tapal
La Aurora
Quebrada El Cedronal
Grava
Isla Ubé
Bosque Virgen
San Antonio
Cerro El Pijibay
San Miguel
Buena Vista
El Cedrona
La Gorra
28
27
26
25
29
130
132
110
100
90
92
300
200
METROS
Meters
ESCALA
Scale
EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
PROYECTO COPALAR - PRESA ALTA Y PRESA BAJA
COPALAR PROJECT - HIGH DAM AND LOW DAM
UBICACION DE AREAS DE PRESTAMO
BORROW AREA LOCATIONS
PLANTA - PLAN
INTERNATIONAL ENGINEERING COMPANY, INC.
S. F.
IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104
AGOSTO 29, 1975

BOLOS DE ROCA
Boulders

RIO GRANDE DE MATAGALPA

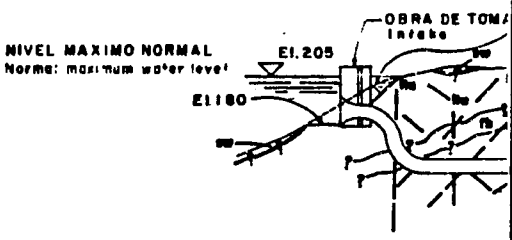
PLANTA

PLAN



SECCION LONGITUDINAL C-C
VERTEDERO

LONGITUDINAL SECTION C-C
SPILLWAY



PLANO DE REFERENCIA DE FASE I
PHASE I REFERENCE DRAWING
ANEXO (ANNEX) V-8

LEYENDA
Legend

al - ALUVIÓN - PRINCIPALMENTE DEPÓSITOS DE ARENA COLOR CAFÉ
Alluvium - mainly brown sand

sw - DESLAVE DE LADERA - PRINCIPALMENTE ARENAS ARCILLOSAS Y LIMOSAS.
Slope Wash - mainly brown silty sand or clayey sand

rsw - DESLAVE ROCOSO - FRAGMENTOS ROCOSOS ANGULARES EN UNA MATRIZ DE ARENA, ARCILLA Y LIMO.
Rocky Slope Wash - angular rock fragments in a matrix of sand, silt and clay.

ta - TALUD DETRÍTICO - PRINCIPALMENTE FRAGMENTOS ROCOSOS ANGULARES.
Talus - mainly angular rock fragments.

ba - BASALTO - CASI SIEMPRE GRIS, DURO, LIGERAMENTE METEORIZADO Y DIACLASADO.
Basalt - Typically grey, hard, slightly weathered, and slightly jointed.

fb - BRECHA DE FLUJO - TÍPICAMENTE COLOR CAFÉ-ROJIZO, MODERAMENTE DURA, MASIVA, Y MODERAMENTE METEORIZADA.
Flow Breccia - Typically red-brown, moderately hard, moderately weathered, massive.

tla - TOBA LAPILICA - TÍPICAMENTE GRIS, MASIVA, MODERAMENTE DURA Y METEORIZADA.
Lapilli Tuff - typically grey, moderately hard, moderately weathered, massive.

AFLORAMIENTO ROCOSO - UBICACIÓN APROXIMADA, LOCALMENTE CUBIERTO POR MATERIAL DE COBERTURA.
Rock Outcrop - Approximate location, locally masked by overburden.

CONTACTO GEOLÓGICO - CON LÍNEA A TRAZOS DONDE ES APROXIMADO. SIGNO DE PREGUNTA INDICA CONTACTO SUPUESTO O DUDOSO.
Geologic contact - dashed where approximately located, question marks where inferred.

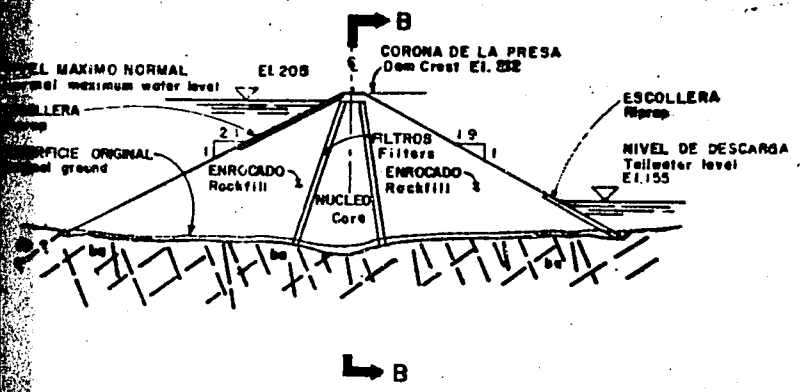
20 - RUMBO Y BUZAMIENTO DE LAS CAPAS.
Bedding - strike and dip.

65 (3m) - RUMBO Y BUZAMIENTO DE LAS DIACLASAS (DISTANCIA ENTRE JUNTAS).
Jointing - strike and dip (spacing).

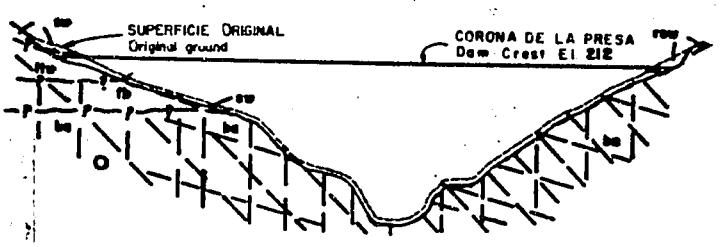
(30 cm) - RUMBO DE DIACLASAS VERTICALES (DISTANCIA ENTRE JUNTAS).
Jointing - vertical (spacing).

Q_{sp} - NACIMIENTO DE AGUA.
Spring

11 - INCLINACIÓN DEL TERRENO.
Slope

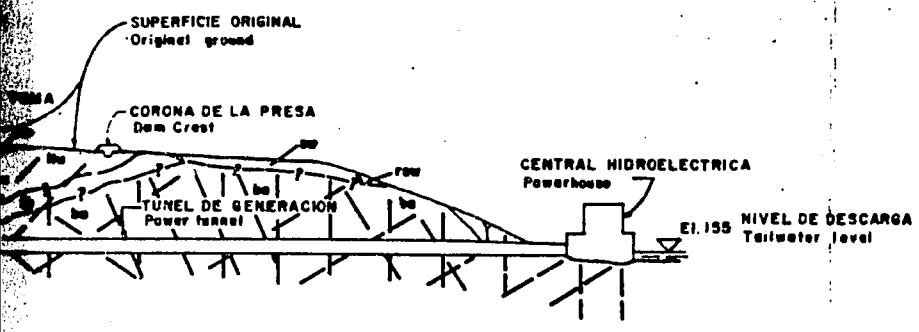


SECCION TRANSVERSAL -(ESQUEMATIC)
TRANSVERSAL SECTION -(SCHEMATIC)



SECCION LONGITUDINAL B-B
LONGITUDINAL SECTION B-B

20 0 50 100 METROS
Meters
ESCALA
Scale



ECCION LONGITUDINAL A-A
UNEL DE GENERACION
ONGITUDINAL SECTION A-A
OWER TUNNEL

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

PROYECTO EL CARMEN

GEOLOGIA SUPERFICIAL - SURFACE GEOLOGY
PLANTA Y SECCIONES - PLAN AND SECTIONS

INTERNATIONAL ENGINEERING COMPANY, INC.

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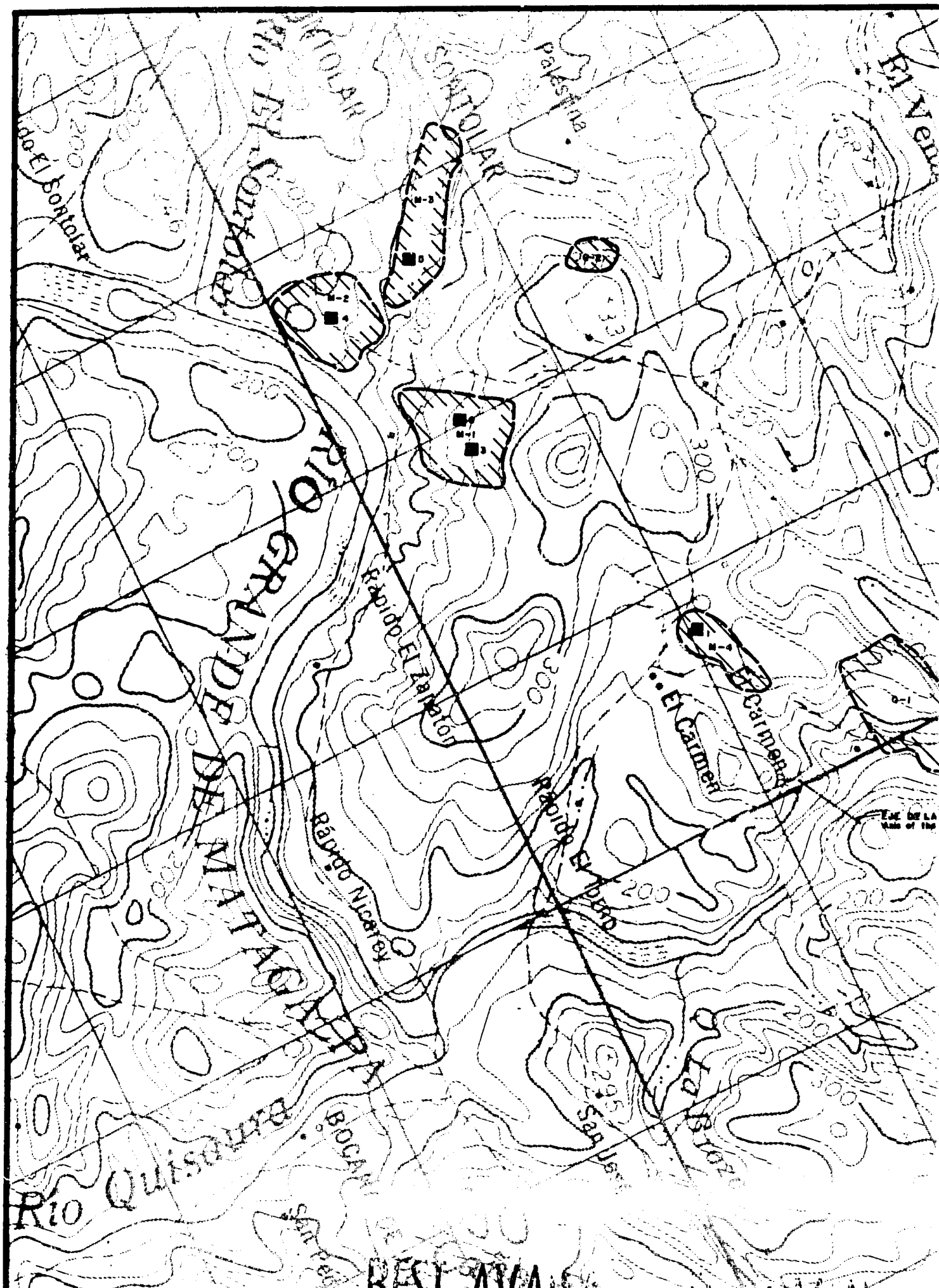
SAN FRANCISCO CALIFORNIA 94104

FECHA AGOSTO 29, 1979



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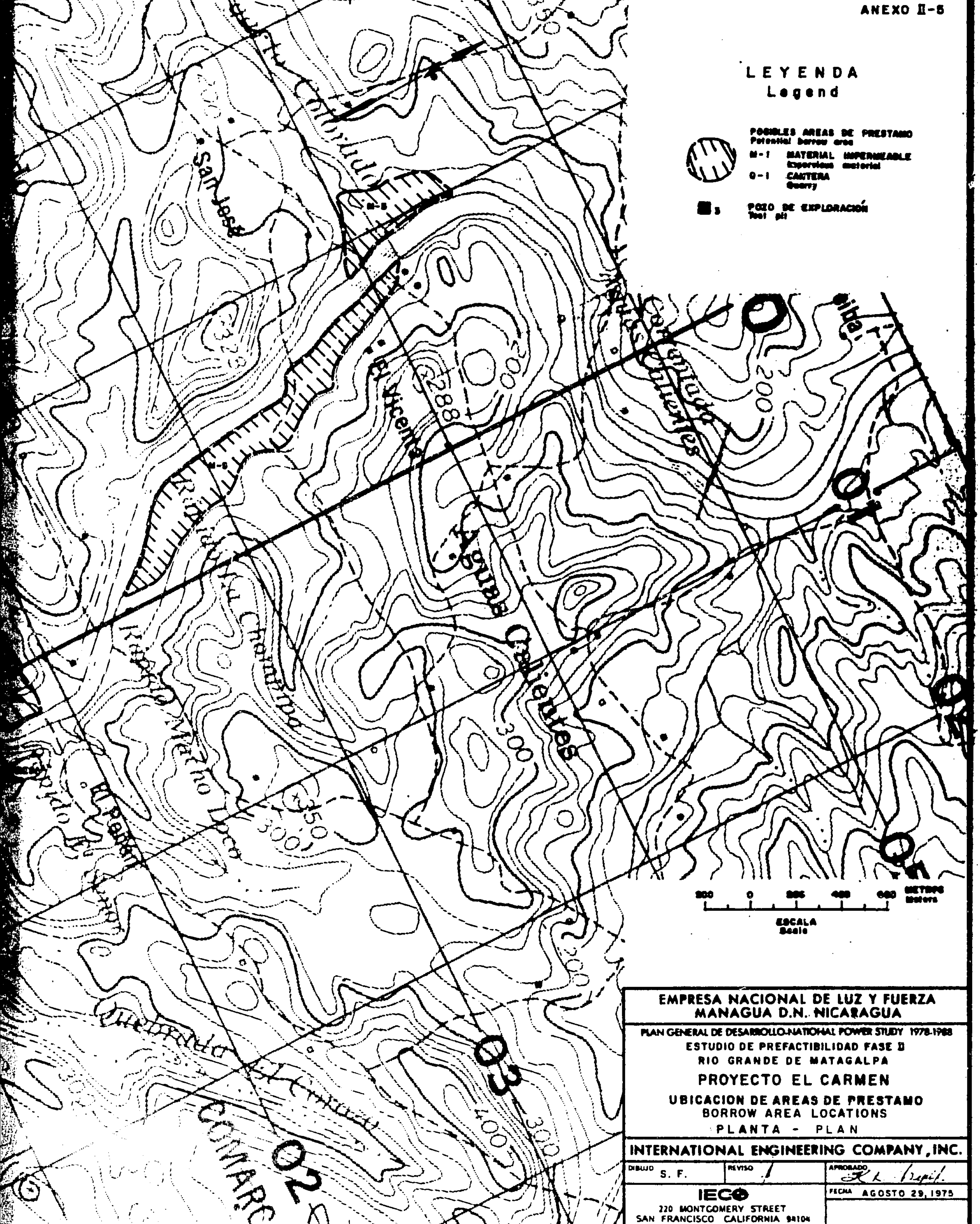
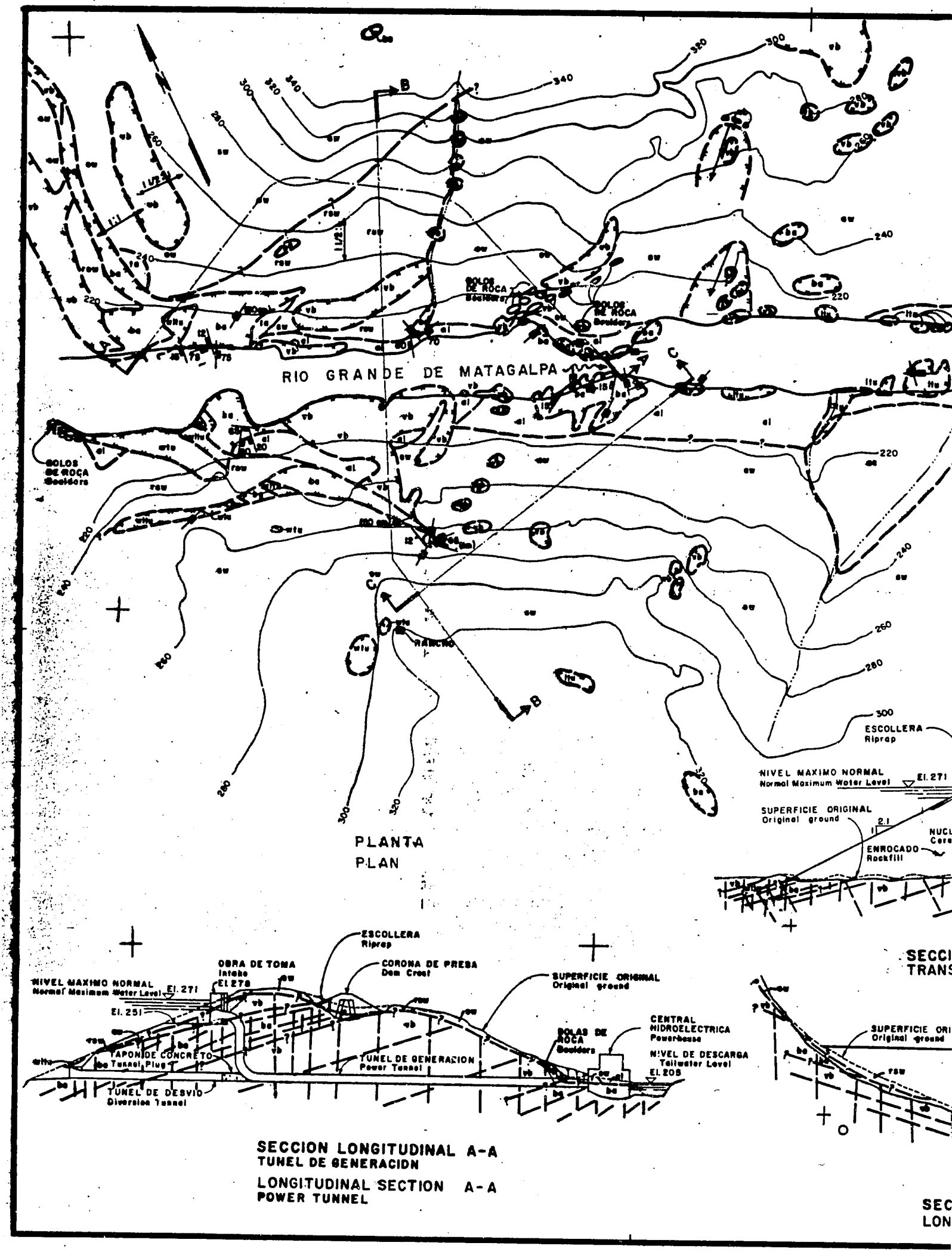

ANEXO II-5
LEYENDA
Legend
POSIBLES AREAS DE PRESTAMO
Potential borrow area
M-1 MATERIAL IMPERMEABLE
Impervious material
Q-1 CANTERA
Quarry
POZO DE EXPLORACIÓN
Test pit
200 0 200 400 600 METROS Meters
ESCALA
Scale
EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
PROYECTO EL CARMEN
UBICACION DE AREAS DE PRESTAMO
BORROW AREA LOCATIONS
PLANTA - PLAN
INTERNATIONAL ENGINEERING COMPANY, INC.
DIBUJO S. F.
REVISO
APROBADO
FECHA AGOSTO 29, 1975
IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104


RIO GRANDE DE MATAGALPA
BOLOS DE ROCA
Boulders
RANCHO
PLANTA
PLAN
ESCOLLERA
Riprap
NIVEL MAXIMO NORMAL
Normal Maximum Water Level
El. 271
SUPERFICIE ORIGINAL
Original ground
ENROCADO
Rockfill
OBRA DE TOMA
Intake
El. 278
CORONA DE PRESA
Dam Crest
El. 251
TAPON DE CONCRETO
Tunnel Plug
TUNEL DE GENERACION
Power Tunnel
TUNEL DE DESVIO
Diversion Tunnel
CENTRAL HIDROELECTRICA
Powerhouse
NIVEL DE DESCARGA
Tailwater Level
El. 208
SECCION LONGITUDINAL A-A
TUNEL DE GENERACION
LONGITUDINAL SECTION A-A
POWER TUNNEL

BEST AVAILABLE DOCUMENT

PLANO DE REFERENCIA DE FASE I
PHASE I REFERENCE DRAWING
ANEXO (ANNEX) V-4

LEYENDA
Legend

al — ALUVIÓN - PRINCIPALMENTE DEPÓSITOS DE ARENA COLOR CAFÉ.
Alluvium - mainly brown sand.

sw — DESLAVE DE LADERA - PRINCIPALMENTE ARENAS ARCILLOSAS Y LIMOSAS.
Slope Wash - mainly brown silty sand or clayey sand.

rsw — DESLAVE ROCOSO - FRAGMENTOS ROCOSOS ANGULARES EN UNA MATRIZ DE ARENA, ARCILLA Y LIMO.
Rocky Slope Wash - angular rock fragments in a matrix of sand, silt and clay.

cac — CONO ALUVIAL - PRINCIPALMENTE LIMO, ARENA, Y GRAVA CON POCAS BOLAS DE ROCA.
Alluvial Cone - mainly silt, sand, gravel, with scattered boulders.

bs — BASALTO - CASI SIEMPRE GRIS, DURO, LIGERAMENTE METEORIZADO Y DIACLASADO.
Basalt - typically grey, hard, slightly weathered, and slightly jointed.

vb — BRECHA VOLCANICA - TIPICAMENTE GRIS, MASIVA, DURA Y LEVEMENTE METEORIZADA.
Volcanic Breccia - typically grey, massive, hard, slightly weathered.

wto — TOBA SOLDADA - TIPICAMENTE COLOR GRIS, DURA, MASIVA.
Welded Tuff - typically grey, hard, massive.

lto — TOBA LAPILICA - TIPICAMENTE GRIS, MASIVA, MODERADAMENTE DURA Y METEORIZADA.
Lapilli Tuff - typically grey, moderately hard, moderately weathered, massive.

AFLORAMIENTO ROCOSO - UBICACION APROXIMADA, LOCALMENTE CUBIERTO POR MATERIAL DE COBERTURA.
Rock Outcrop - Approximate location, locally masked by overburden.

CONTACTO GEOLOGICO - CON LINEA A TRAZOS DONDE ES APROXIMADO. SIGNO DE PREGUNTA INDICA CONTACTO SUPUESTO O DUDOSO.
Geologic contact - dashed where approximately located, question mark where inferred.

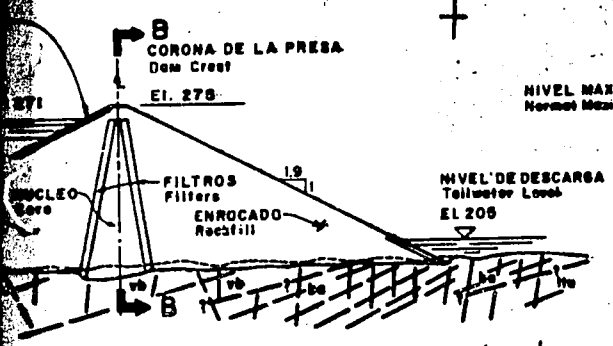
DERRUMBE
Landslide

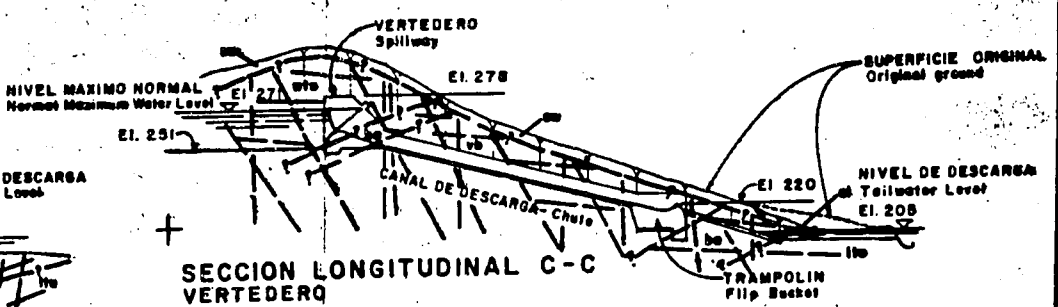
RUMBO Y BUZAMIENTO DE LAS CAPAS
Bedding - strike and dip.

RUMBO Y BUZAMIENTO DE LAS DIACLASAS (DISTANCIA ENTRE JUNTAS).
Jointing - strike and dip (spacing).

RUMBO DE DIACLASAS VERTICALES (DISTANCIA ENTRE JUNTAS).
Jointing - vertical (spacing).

INCLINACION DEL TERRENO.
Slope.

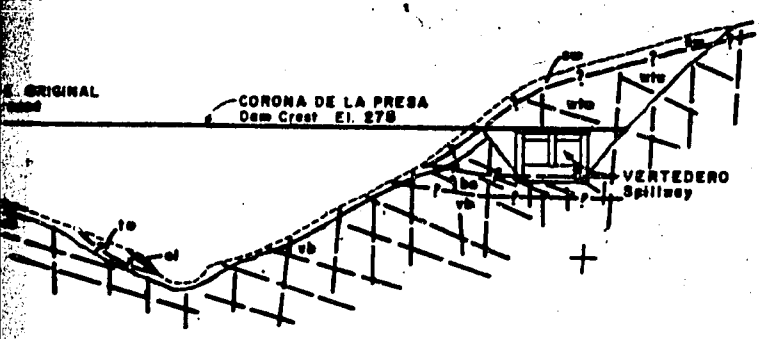




SECCION LONGITUDINAL C-C
VERTEDERO
LONGITUDINAL SECTION C-C
SPILLWAY

20 0 50 100 METROS
Meters
ESCALA
Scale

CCION TRANSVERSAL
ANSVERSAL SECTION



SECCION LONGITUDINAL B-B
LONGITUDINAL SECTION B-B

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

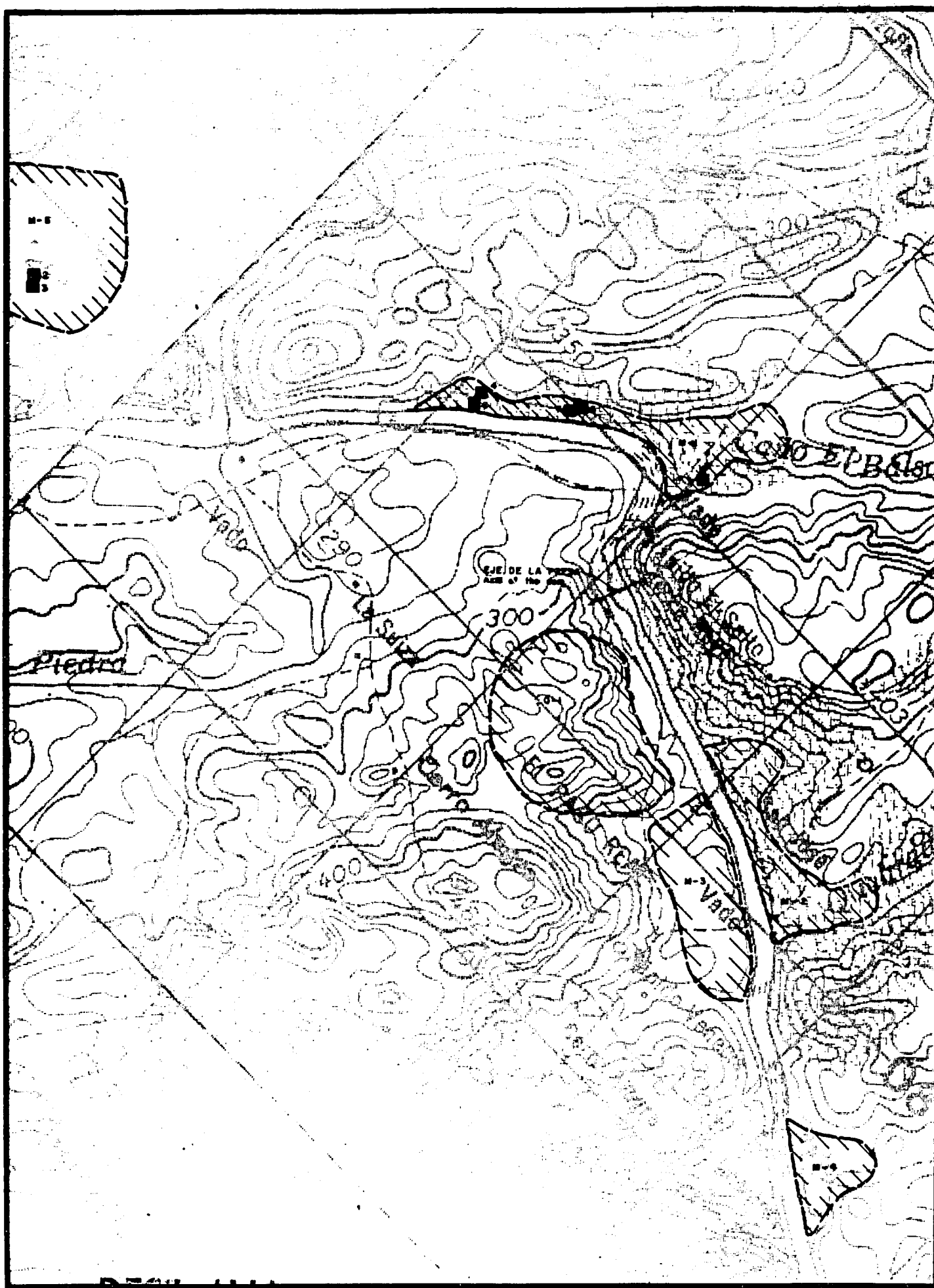
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1980
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATASALPA

PROYECTO PASO REAL

GEOLOGIA SUPERFICIAL - SURFACE GEOLOGY
PLANTA Y SECCIONES - PLAN AND SECTIONS

INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO S. F.	REVISO	APROBADO
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1978



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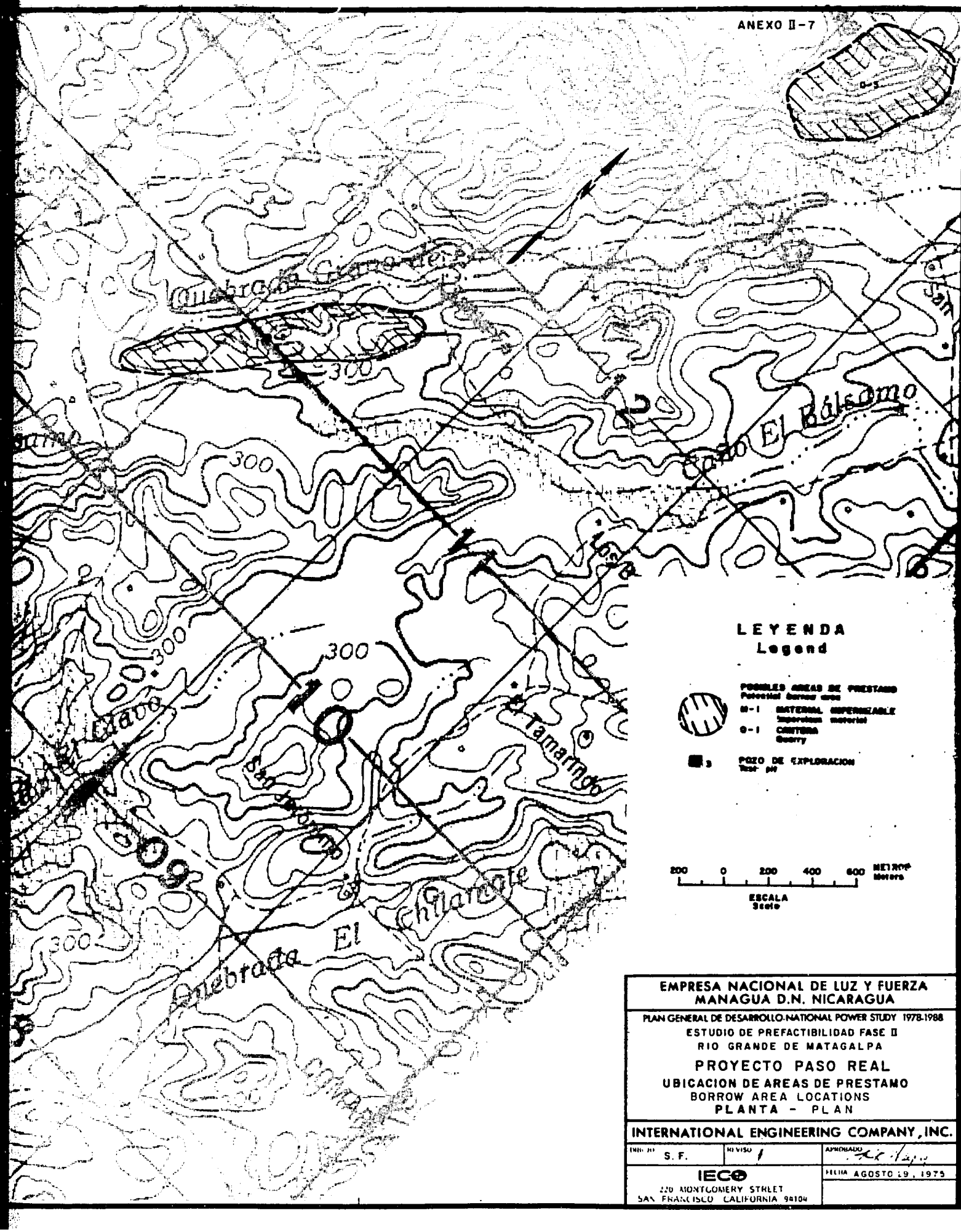
ANEXO II-7



EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

PROYECTO PASO REAL

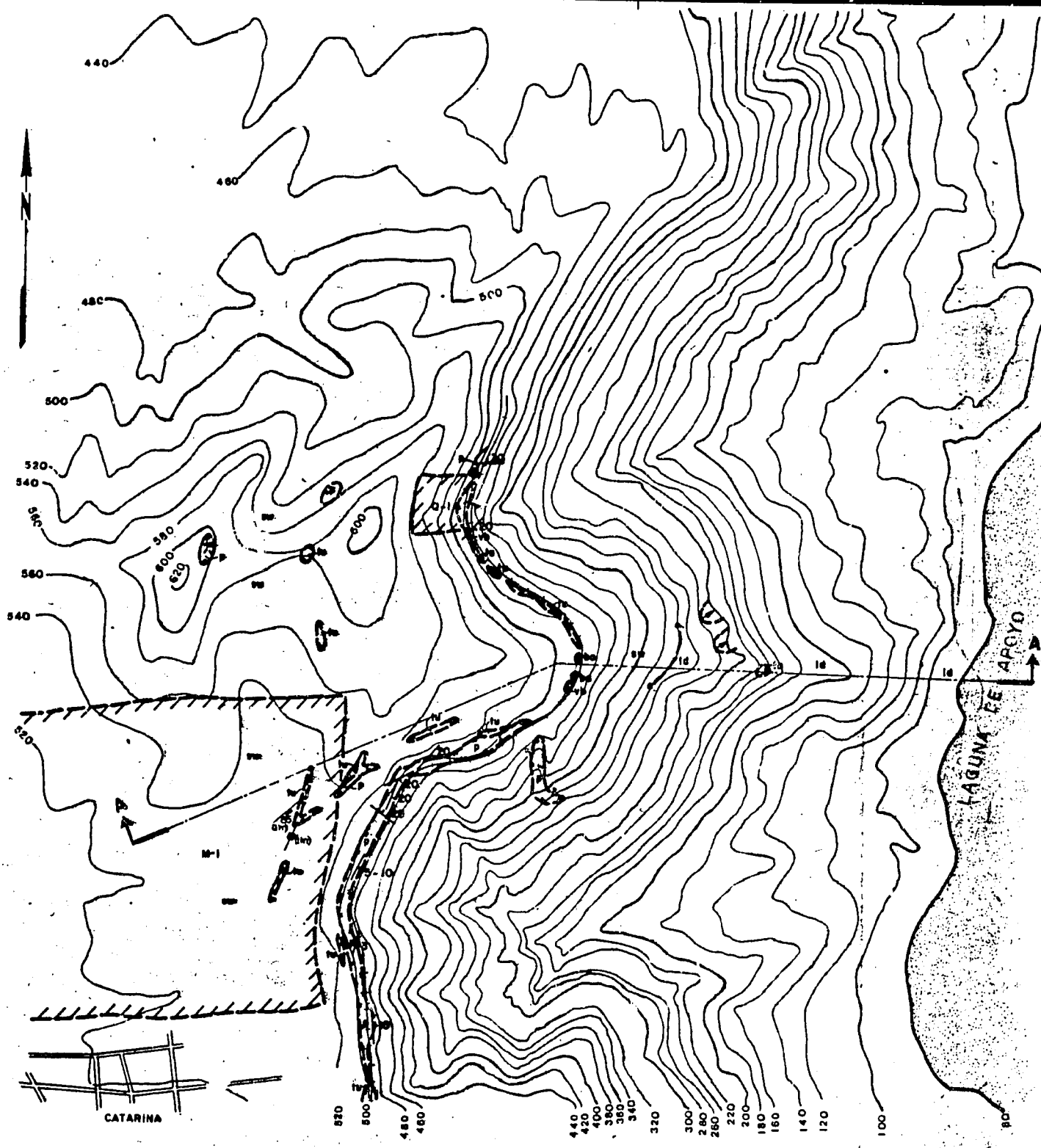
UBICACION DE AREAS DE PRESTAMO
BORROW AREA LOCATIONS
PLANTA - PLAN

INTERNATIONAL ENGINEERING COMPANY, INC.

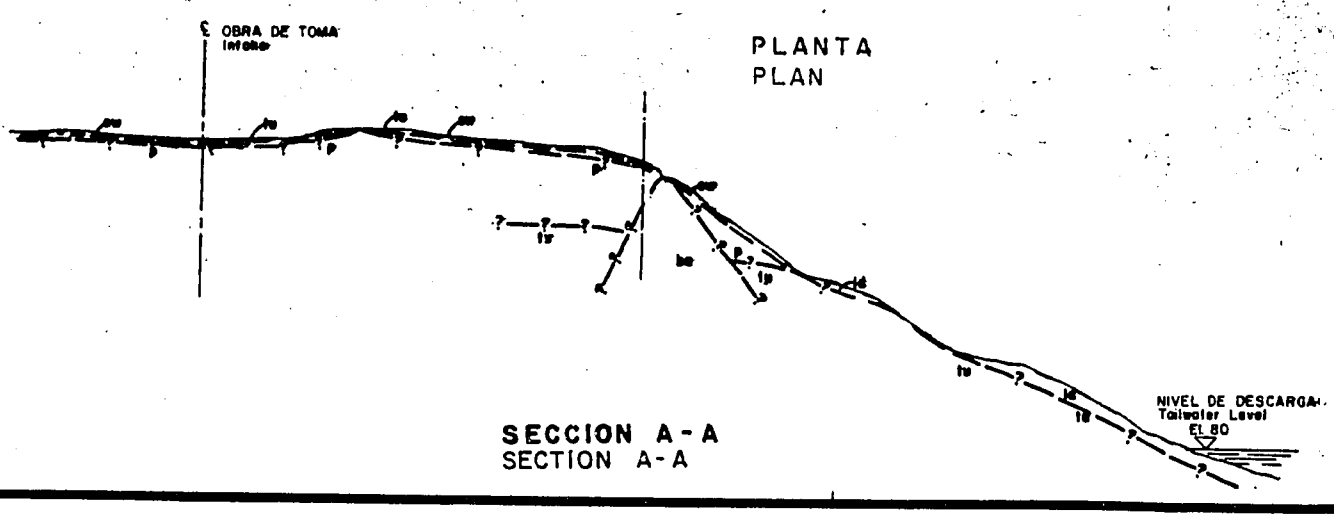
DIBUJO	REVISO	APROBADO
S. F.	1	

IEC
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104

FECHA AGOSTO 19, 1975



PLANTA
PLAN



SECCION A-A
SECTION A-A

LEYENDA
Legend

sw — DESLAVE DE LADERA - PRINCIPALMENTE ARENAS ARCILLOSAS Y LIMOSAS.
Slope Wash - mainly brown silty sand or clayey sand.

ld — ESCOMBROS DE LADERA - FRAGMENTOS ANGULARES ROCOSOS EN UNA MATRIZ DE ARENA, LIMO Y ACRILLA.
Landslide Debris - angular rock fragments in a matrix of sand, silt and clay.

p — POMEZ - TIPICAMENTE DE COLOR PARDO, FRIABLE, POBREMENTE CEMENTADA, MASIVA.
Pumice - typically buff, friable to uncemented, massive.

ts — TOBA - TIPICAMENTE COLOR CAFE, SUAVE, FRIABLE, MASIVA, CON LECHOS.
Tuff - typically brown, soft, friable, massive, bedded.

bs — BASALTO - TIPICAMENTE GRIS, DURO, MASIVA.
Basalt - typically gray, hard, massive.

vb — BRECHA VOLCANICA - TIPICAMENTE GRIS, MODERADAMENTE METEORIZADA, FRIABLE, MASIVA.
Volcanic Breccia - typically gray, moderately weathered, friable, massive.

AFLORAMIENTO ROCOSO - UBICACION APROXIMADA, LOCALMENTE CUBIERTO POR MATERIAL DE COBERTURA.
Rock Outcrop - Approximate location, locally masked by overburden.

CONTACTO GEOLOGICO - CON LINEA A TRAZOS DONDE ES APROXIMADO, SIGNO DE PREGUNTA INDICA CONTACTO SUPUESTO O DUDOSO.
Geologic contact - dashed where approximately located, question marks where inferred.

DERRUMBE.
Landslide

20 — RUMBO Y BUZAMIENTO DE LAS CAPAS.
Bedding - strike and dip.

60 (1m) — RUMBO Y BUZAMIENTO DE LAS DIACLASAS (DISTANCIA ENTRE JUNTAS).
Jointing - strike and dip (spacing).

(50 cm) — RUMBO DE DIACLASAS VERTICALES (DISTANCIA ENTRE JUNTAS).
Jointing - vertical (spacing).

POSIBLES AREAS DE PRESTAMO
Potential borrow area

M-1 MATERIAL IMPERMEABLE
Impervious material

Q-1 CANTERA
Quarry

20 0 50 100 METROS
Meters
ESCALA
Scale

PLANO DE REFERENCIA DE FASE I
PHASE I REFERENCE DRAWING
ANEXO (ANNEX) V-32

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II

PROYECTO LAGUNA DE APOYO

GEOLOGIA SUPERFICIAL - SURFACE GEOLOGY
UBICACION DE AREAS DE PRESTAMO
BORROW AREA LOCATIONS
PLANTA Y SECCION - PLAN AND SECTION

INTERNATIONAL ENGINEERING COMPANY, INC.

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IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975

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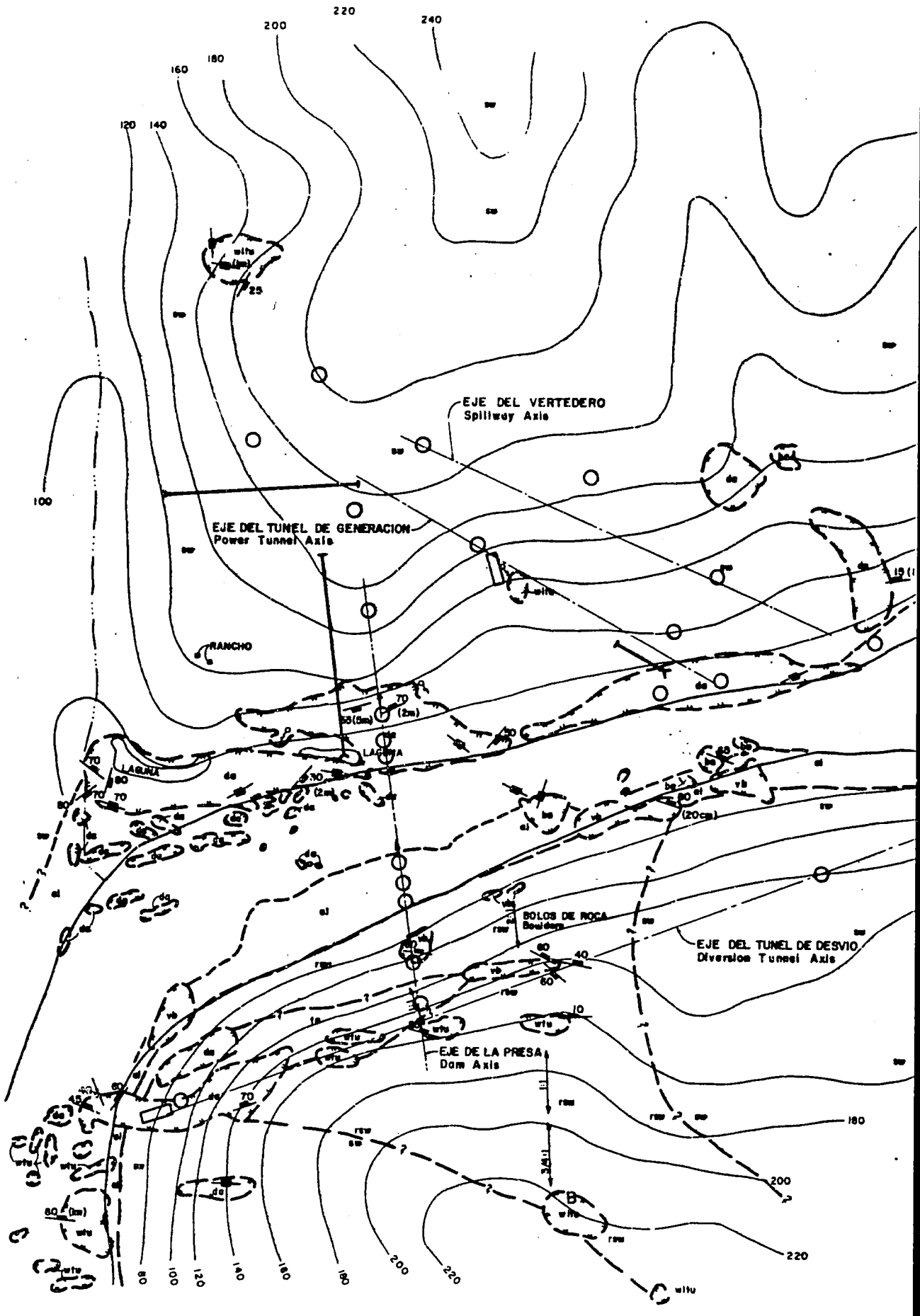
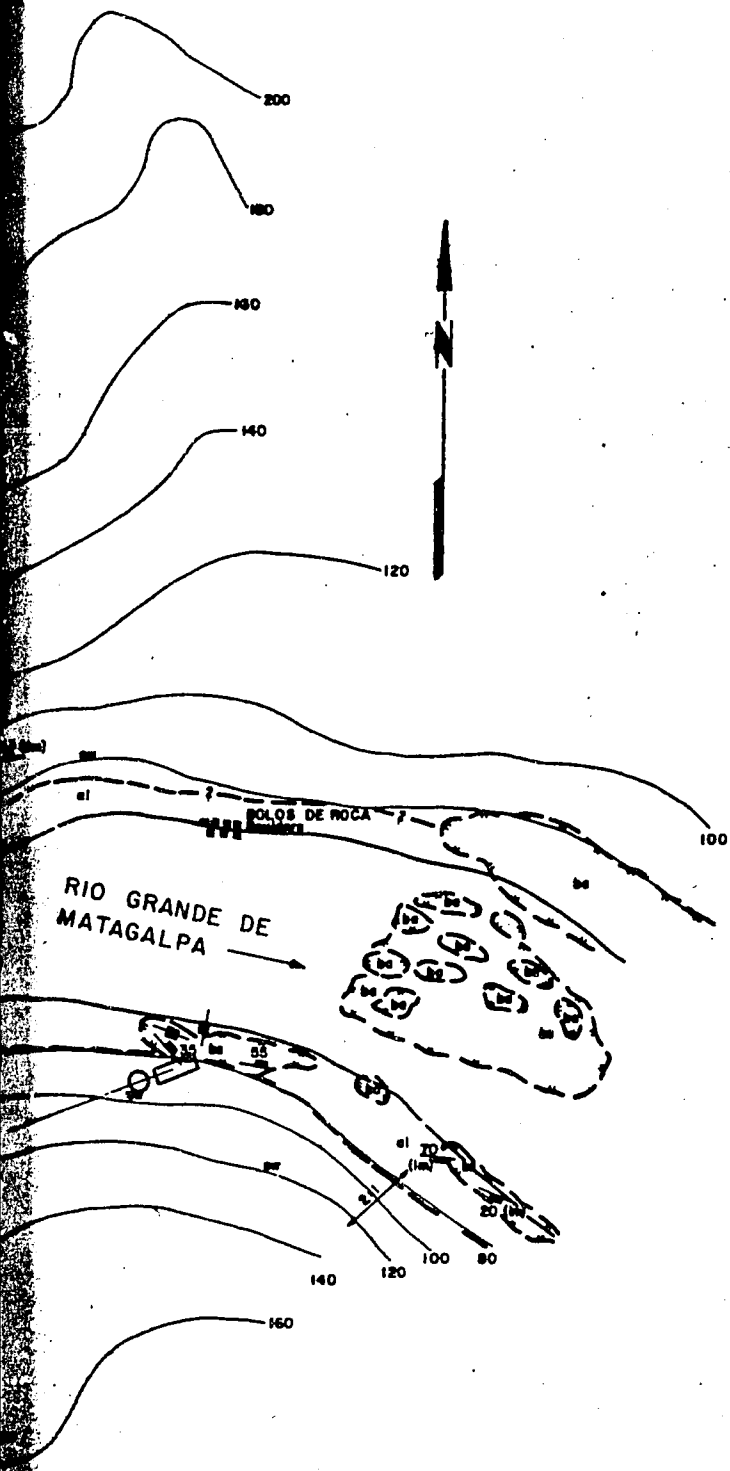

EJE DEL VERTEDERO
Spillway Axis
EJE DEL TUNEL DE GENERACION
Power Tunnel Axis
RANCHO
LAGUNA
LAGUNA
BOLOS DE ROCA
Boulders
EJE DEL TUNEL DE DESVIO
Diversion Tunnel Axis
EJE DE LA PRESA
Dam Axis

PLANTA
PLAN



LEYENDA
Legend

al — ALUVION - PRINCIPALMENTE DEPOSITOS DE ARENA COLOR CAFE Y GRAVAS LOCALES
Alluvium - mainly brown sand, locally gravels.

sw — DESLAVE DE LADERA - PRINCIPALMENTE ARENAS ARCILLOSAS Y LIMOSAS
Slope Wash - mainly brown silty sand or clayey sand.

rsw — DESLAVE ROCOSO - FRAGMENTOS ROCOSOS ANGULARES EN UNA MATRIZ DE ARENA, ARCILLA Y LIMO
Rocky Slope Wash - angular rock fragments in a matrix of sand, silt and clay.

ta — TALUD DETRITICO - PRINCIPALMENTE FRAGMENTOS ROCOSOS ANGULARES
Talus - mainly angular rock fragments.

ba — BASALTO - CASI SIEMPRE GRIS, DURO, LIGERAMENTE METEORIZADO Y DIACLASADO
Basalt - typically grey, hard, slightly weathered, and slightly jointed.

vb — BRECHA VOLCANICA - TIPICAMENTE GRIS, MASIVA, DURA Y LEVEMENTE METEORIZADA
Volcanic Breccia typically grey, massive, hard, slightly weathered.

da — DACITA - TIPICAMENTE COLOR PARDO, DURA, SILICIFICADA, LEVEMENTE METEORIZADA, MASIVA.
Dacite - typically buff, hard, silicified, slightly weathered, massive.

wtu — TOBA SOLDADA - TIPICAMENTE COLOR GRIS, DURA, POCO FRACTURADA
Welded Tuff - typically grey, hard, slightly fractured.

wltu — TOBA SOLDADA - DE COLOR PARDO A GRIS, MODERADAMENTE METEORIZADA, MODERADAMENTE DURA, MASIVA.
Welded Lapilli Tuff - typically grey to buff, moderately weathered, moderately hard, massive.

AFLORAMIENTO ROCOSO - UBICACION APROXIMADA, LOCALMENTE CUBIERTO POR MATERIAL DE COBERTURA
Rock Outcrop - Approximate location, locally masked by overburden.

—— ? CONTACTO GEOLOGICO - CON LINEA A TRAZOS DONDE ES APROXIMADO SIGNO DE PREGUNTA INDICA CONTACTO SUPUESTO O DUDOSO
Geologic contact - dashed where approximately located, question marks where inferred

65 (m) RUMBO Y BUZAMIENTO DE LAS DIACLASAS (DISTANCIA ENTRE JUNTAS)
Jointing - strike and dip (spacing).

(50 cm) RUMBO DE DIACLASAS VERTICALES (DISTANCIA ENTRE JUNTAS)
Jointing - vertical (spacing)

NACIMIENTO DE AGUA
Spring

INCLINACION DEL TERRENO
Slope

LEYENDA - Legend
PROGRAMA DE EXPLORACIONES PROPUESTO
PROPOSED EXPLORATORY PROGRAM

SONDEO
Drill hole

POZO DE EXPLORACION
Test pit

GALERIA DE EXTRACCION
Adit

20 0 20 100 METROS Meters
ESCALA
Scale

PLANO DE REFERENCIA DE FASE I
PHASE I REFERENCE DRAWING
ANEXO (ANNEX) V-12

BEST AVAILABLE DOCUMENT

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

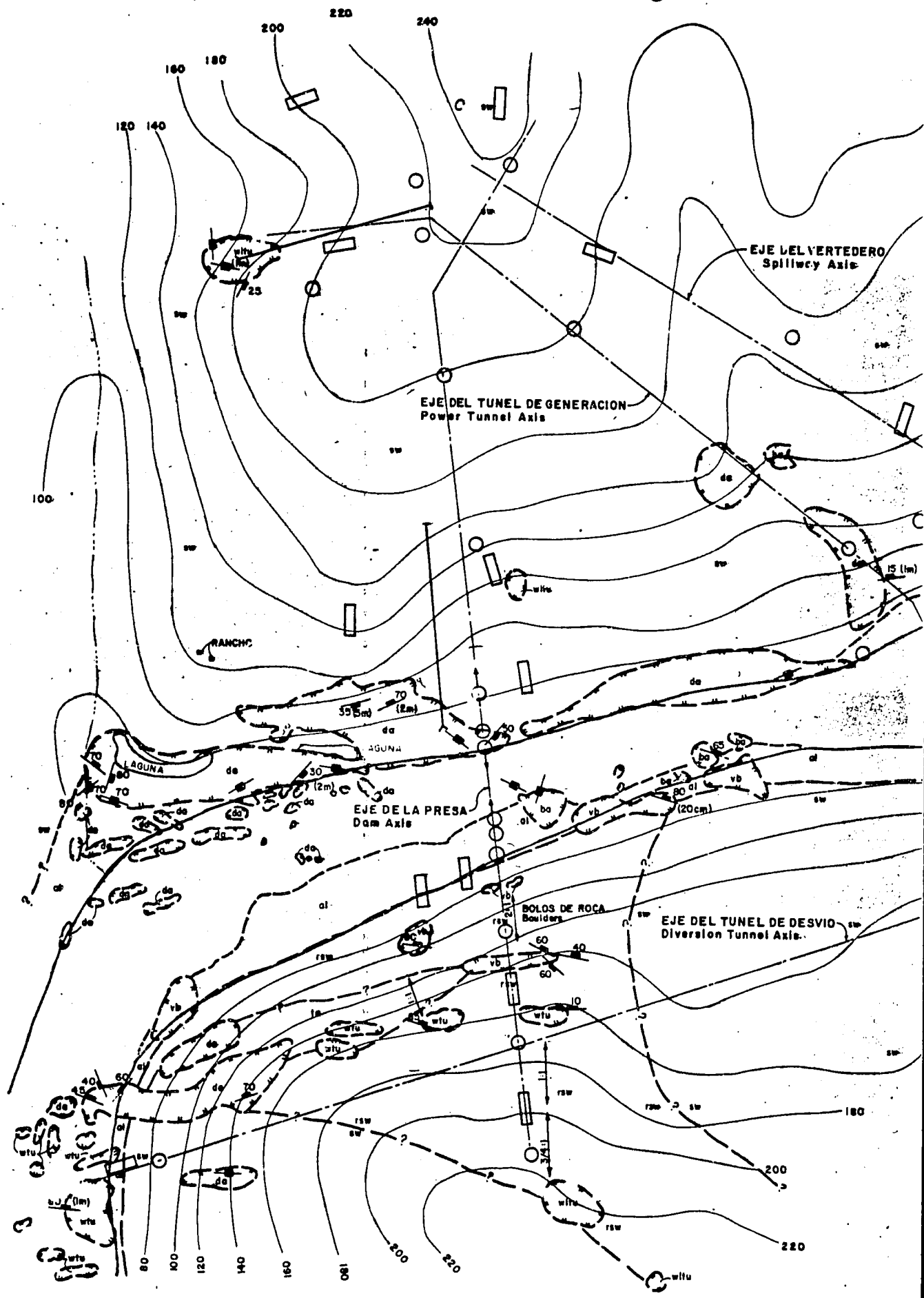
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
PROYECTO COPALAR - PRESA BAJA
COPALAR PROJECT - LOW DAM
PROGRAMA DE EXPLORACIONES PROPUESTO
PROPOSED EXPLORATORY PROGRAM

INTERNATIONAL ENGINEERING COMPANY, INC.

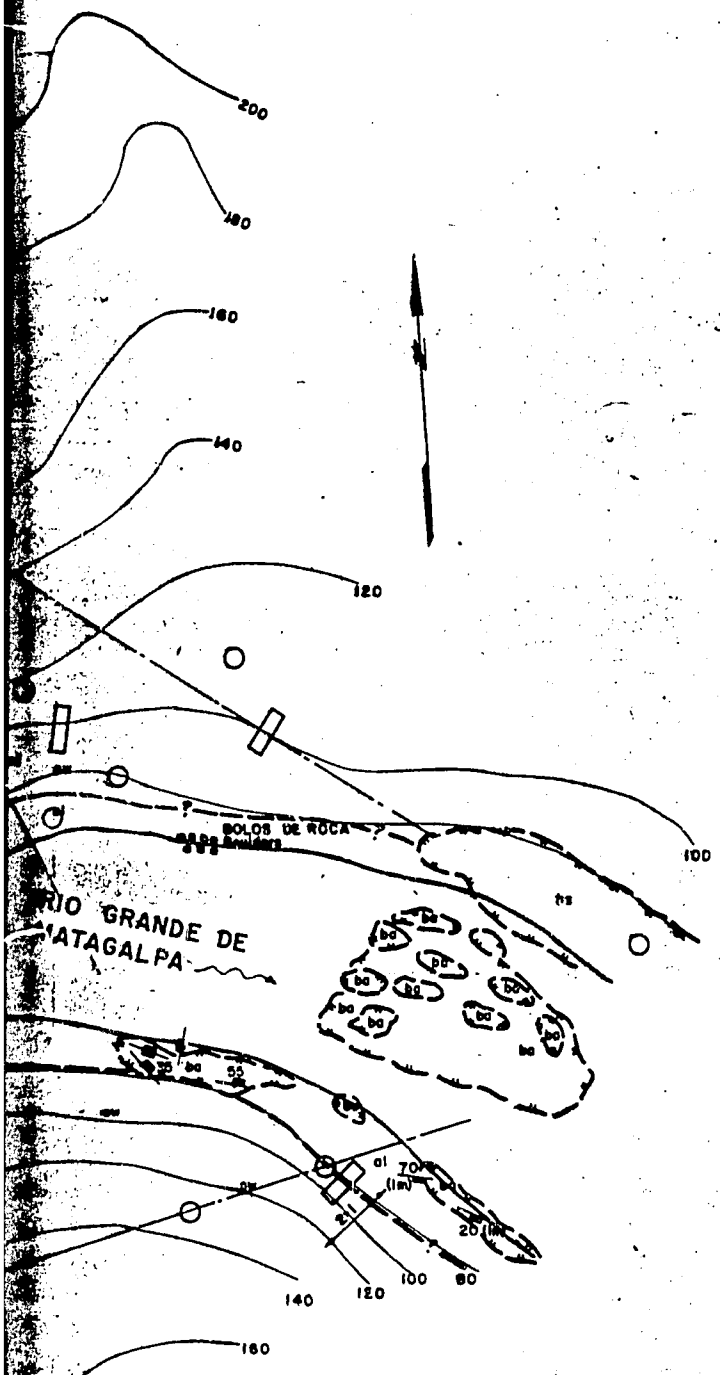
DIBUJO	REVISO	APROBADO

IEC
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104

FECHA AGOSTO 29, 1975


EJE DEL VERTEDERO
Spillway Axis
EJE DEL TUNEL DE GENERACION
Power Tunnel Axis
EJE DE LA PRESA
Dam Axis
EJE DEL TUNEL DE DESVIO
Diversion Tunnel Axis
BOLOS DE ROCA
Boulders
LAGUNA
RANCHO
120
140
160
180
200
220
240
100
80

PLANTA
PLAN



LEYENDA
Legend

al — ALUVION - PRINCIPALMENTE DEPÓSITOS DE ARENA COLOR CAFE Y GRAVAS LOCALES.
Alluvium - mainly brown sand, locally gravels.

sw — DESLAVE DE LADERA - PRINCIPALMENTE ARENAS ARCILLOSAS Y LIMOSAS.
Slope Wash - mainly brown silty sand or clayey sand.

rsw — DESLAVE ROCOSO - FRAGMENTOS ROCOSOS ANGULARES EN UNA MATRIZ. DE ARENA, ARCILLA Y LIMO.
Rocky Slope Wash - angular rock fragments in a matrix of sand, silt and clay.

ta — TALUD DETRITICO - PRINCIPALMENTE FRAGMENTOS ROCOSOS ANGULARES.
Talus - mainly angular rock fragments.

ba — BASALTO - CASI SIEMPRE GRIS, DURO, LIGERAMENTE METEORIZADO Y DIACLASADO.
Basalt - typically gray, hard, slightly weathered, and slightly jointed.

vb — BRECHA VOLCANICA - TIPICAMENTE GRIS, MASIVA, DURA Y LEVEMENTE METEORIZADA.
Volcanic Breccia - typically gray, massive, hard, slightly weathered.

da — DACITA - TIPICAMENTE COLOR PARDO, DURA, SILICIFICADA, LEVEMENTE METEORIZADA, MASIVA.
Dacite - typically buff, hard, silicified, slightly weathered, massive.

wtu — TOBA SOLDADA - TIPICAMENTE COLOR GRIS, DURA, POCO FRACTURADA.
Welded Tuff - typically gray, hard, slightly fractured.

wltu — TOBA SOLDADA - DE COLOR PARDO A GRIS, MODERADAMENTE METEORIZADA, MODERADAMENTE DURA, MASIVA
Welded Lapilli Tuff - typically gray to buff, moderately weathered, moderately hard, massive.

AFLORAMIENTO ROCOSO - UBICACION APROXIMADA, LOCALMENTE CUBIERTO POR MATERIAL DE COBERTURA.
Rock Outcrop - Approximate location, locally obscured by overburden.

CONTACTO GEOLOGICO - CON LINEA A TRAZOS DONDE ES APROXIMADO. SIGNO DE PREGUNTA INDICA CONTACTO SUPUESTO O DUDOSO.
Geologic contact - dashed where approximately located, question marks where inferred.

65 (1m) — RUMBO Y BUZAMIENTO DE LAS DIACLASAS (DISTANCIA ENTRE JUNTAS).
Jointing - strike and dip (spacing).

(50 cm) — RUMBO DE DIACLASAS VERTICALES (DISTANCIA ENTRE JUNTAS).
Jointing - vertical (spacing).

NACIMIENTO DE AGUA.
Spring.

INCLINACION DEL TERRENO.
Slope.

LEYENDA - Legend
PROGRAMA DE EXPLORACIONES PROPUESTOS
PROPOSED EXPLORATORY PROGRAM

SONDEO
Drill Hole

POZO DE EXPLORACION
Test Pit

GALERIA DE EXTRACCION
Adit

20 0 50 100 METROS
Meters
ESCALA
Scale

PLANO DE REFERENCIA DE FASE I
PHASE I REFERENCE DRAWING
ANEXO (ANNEX) V-14

BEST AVAILABLE DOCUMENT

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
PROYECTO COPALAR PRESA ALTA
COPALAR PROJECT - HIGH DAM
PROGRAMA DE EXPLORACIONES PROPUESTO
PROPOSED EXPLORATORY PROGRAM

INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO	REVISO	APROBADO
S. F.		

IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104

FECHA AGOSTO 29, 1978

CAPITULO III

EVALUACION TECNICA

CHAPTER III

TECHNICAL EVALUATION

CHAPTER III

TECHNICAL EVALUATION

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TECHNICAL EVALUATION

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CHAPTER III

TECHNICAL EVALUATION

3.1 INTRODUCTION

3.1.1 GENERAL

This chapter contains the results of the technical investigations of the hydroelectric projects recommended for further study during Phase II as a result of the Phase I analyses. The recommended projects are those designated as Paso Real, El Carmen and Copalar on the Rio Grande de Matagalpa which are combined into the two dam and three dam alternatives discussed in Chapter V, Preliminary Investigation of Hydroelectric Projects of the Phase I Report. Some topography maps of the Copalar site differ from others by what could be as much as 20 meters in elevation. New topography maps are presently under preparation for the damsite and reservoir. A final selection of the two or three dam alternative cannot be made until the new topography maps are available. The Phase II investigation also includes analyses of the surface and underground installations of the pumped-storage project at Laguna de Apoyo, in accordance with the recommendations for project studies for this phase of investigation. The work performed during this phase followed the same general rules, procedures, standards and design considerations adopted for Phase I. It is a continuation, review, revision and up-dating of the earlier work for the selected projects and incorporates the latest available data. It also refines the earlier work and goes into further detail and additional analyses than previously performed.

3.1.2 SELECTION METHODOLOGY

The project selection methodology is basically the same as presented in detail in Section 5.1 of the Phase I Report. The selection parameters used during that phase of the investigation consisted of the following procedures, conditions and considerations:

1. Study of all available reports for projects previously investigated.
2. Office and map studies for other potential project sites.
3. Aerial and ground reconnaissance of all potential sites.
4. Hydrological and meteorological studies of all sites under consideration.
5. Geologic reconnaissance of all major project sites.
6. Project cost estimates.
7. Reservoir operation studies to determine the generation capabilities of each project.
8. Ability to economically satisfy the forecasted power and energy requirements.

The exploitation of the entire head available in the study reaches of the rivers was a prime objective of the Phase I investigation. It was possible to select projects on the Rio Grande de Matagalpa which fully satisfy this objective although it was necessary to use saddle dikes at two projects to do so.

3.2 PRELIMINARY DESIGN CONSIDERATIONS

3.2.1 GENERAL

The design considerations used during this phase of investigation are similar to those adopted for Phase I and are in accordance with normal standards used for prefeasibility studies. The Phase II investigations required, or permitted some changes of the earlier consideration. Therefore, this section includes the pertinent portions of the previous considerations and the revisions made to others.

3.2.2 DAM

This phase of the work will retain rockfill dam as the primary type of structure; however, geologic field investigations indicated that foundation and geological conditions may permit the use of concrete dams at some sites. However, the construction materials investigations did not locate a large quantity of concrete aggregate and it was concluded that they would have to be manufactured from quarry rock which further justifies the use of rockfill dams. Sufficient quantities of impervious material were not located to justify further consideration of earthfill dams; however, adequate quantities for the impervious core of rockfill dams were located at each site. Sufficient quantities of rock for rockfill dams were located within reasonable distances of each damsite. The relative economy of the dam type is a subject for the feasibility study when more data is available regarding foundation conditions and the physical properties and location of the various types of materials.

The dam crest will be 10 meters wide and the cross section will consist of a central impervious core, upstream and downstream filter zones adjacent to the core, upstream and downstream rockfill material and riprap on the upstream face. The embankment slopes will be 2.1 horizontal to 1.0 vertical upstream and 1.9 horizontal to 1.0 vertical downstream. These dam details are the same as used in Phase I. However, the rockfill will be divided into two different rock types designated as Type A and Type B on the project drawings rather than one classification. The rock near the dams are classified as being weaker than similar material farther away. Type A rock is the weaker of the two and will be placed adjacent to the filters where it will be subject to less weathering effects and Type B rock will be placed in the remaining portion of the dam section to withstand wave action and the effect of the wetting and drying cycles. This zoning of the rockfill will permit using the nearby weaker rock; thereby, resulting in lower costs than if all material is obtained from greater distances, yet it will still permit retaining the structural stability of the dam. The two types of rock illustrate a concept that must be considered in greater detail during the feasibility study. It may be necessary, or possible, to use more than two types of rockfill at that time.

A vertical impervious core will be retained for this study although an inclined core should be considered in later design. The use of an inclined or vertical core must be coordinated with the geology of the site and the properties of the embankment materials. An inclined core may permit using all Type B rock in the upstream portion and all Type A rock in the downstream portion, thereby affecting a considerable reduction in costs. The physical properties of the materials must be determined during the feasibility study and the dam designed accordingly.

The freeboard above normal maximum reservoir level will be determined from flood routing studies and in accordance with the fetch, wind velocity and storage capacity of each reservoir. Selection of the freeboard will recognize that it is more economical to construct a low parapet wall on the upstream side of the dam crest to provide for setup, seiches and wave ride up than it will be to construct the same additional height of dam.

Geologic investigations indicated that cutoff grouting will be required at each damsite. However, this conclusion was reached from surface geological conditions and subsurface explorations are necessary to determine the extent of grouting required. Since surface condition indicate the need for a grout curtain and subsurface conditions are unknown at present, a grouting gallery will be provided on the dam axis below the impervious core for the entire length of the dam foundation and a reasonable distance into each abutment. Grouting will be done from this gallery either during construction or after completion of the dam. A grouting gallery usually permits the lowest possible grouting costs and has the added advantage that it can be used later if leakage occurs during project operation. The grout curtain will be assumed to average 30 meters of depth.

3.2.3 SPILLWAY

The spillway type adopted for the Phase I study will be retained. All spillways will consist of an inlet channel, an ogee crest control structure with radial gates, inclined chute and a flip bucket and plunge pool energy dissipator. They will be located in one of the dam abutments with the axis of the crest approximately in line with the axis of the dam. The orientation of the spillway will be controlled by the topography and the location of other project features. Flip bucket and plunge pool energy dissipators will be used because they normally are more economical than stilling basin energy dissipators where conditions permit their use. The flip bucket will throw the water into the plunge pool in the river at a sufficient distance from the structures to prevent retrogression from endangering them. The number and size of the radial gates will be determined in connection with the flood routing studies that will establish the dam heights.

3.2.4 DIVERSION FACILITIES

Diversion tunnels will be provided at all sites for diverting the river during construction. The facilities will consist of an inlet channel, upstream portal, concrete lined tunnel,downstream portal, outlet channel and cofferdams. The upstream cofferdam will be incorporated into the body of the main dam, but separate downstream cofferdams will be provided. Tunnel diversion will be used because the valley at most damsites is very narrow and the abutments are very steep, thereby making it difficult to use diversion channels, diversion conduits or passing the construction flood through a gap in the dam. However, the construction schedules prepared for all projects during this phase of the investigation indicate that the diversion period for some projects may be as short one wet season. This places greater importance on attempting to find more economical solutions for river diversion than can be obtained by using diversion tunnels. Alternative diversion facilities must coordinate the diversion period and time required to construct the dam in greater detail than is possible during a prefeasibility study. The recurrence interval of the construction design flood and the risk involved if a smaller facility is provided must be evaluated in greater detail during later studies.

Construction of the dam will begin at the start of a dry season. The upstream cofferdam will be constructed at that time only to the height required to divert the first dry season discharge. The main dam embankment will be constructed to a sufficiently high elevation to serve in place of the upstream cofferdam during the following wet season or seasons.

The tunnels will have a horseshoe cross section and will be assumed to be concrete lined throughout their entire length for this investigation. However, it may be possible to leave some portions unlined when the tunnels are under construction and the rock quality can be firmly established. This possibility is especially important because of the possible cost savings for the short diversion and construction periods discussed above. Heavy tunnel supports will be provided near the portals and light support elsewhere. The tunnels will be closed by a concrete plug and the downstream cofferdam removed upon completion of construction. Parts of the diversion tunnels will be used as power tunnels at some sites, thereby saving some of the costs of separate power tunnels. The tunnels for this investigation will be designed to pass a flood with a 15-year recurrence interval at a velocity of approximately 20 meters per second. This velocity is approaching that which could erode the concrete lining, unless care is excercised in placement; especially if the flood contains large amounts of erosive sediments. The allowable velocity was adopted after considering the time that the diversion tunnel will be used and the severity of the recurrence interval.

3.2.5 POWER FACILITIES

Power facilities will consist of an inlet channel, intake structure, power tunnel, penstock, manifold and powerhouse. They are similar to the corresponding facilities of the Phase I investigation for the same projects, but minor changes will be made for this stage of investigation. The inlet channel will be excavated to a level that limits the entrance velocity to approximately one meter per second at minimum reservoir level. The inlet channel invert elevation will be established from the minimum reservoir levels obtained from the reservoir operation studies even though those levels may occur for only a very small percentage of time. Later studies should consider higher invert elevations based on a study of the length of time when the reservoir is abnormally low. This type study is outside the normal scope of prefeasibility level investigations.

The intake structure will form the entrance to tunnel which will convey water from the reservoir to the powerhouse. It will contain trashracks, control gates, hoists and appurtenant facilities. The entrance will be bell-mouthed to minimize hydraulic losses. The minimum reservoir level used for establishing the inlet channel invert elevation will be used in setting the elevation of the entrance. The gates will be operated from a hoist structure which will have the same floor elevation as the crest of the dam.

The power tunnel will be located at the highest elevation possible consistent with minimum reservoir water level. This will result in the lowest possible tunnel pressures and the shortest length of tunnel. Some sites will have an entirely separate power tunnel, but others will combine the power tunnel with the diversion tunnel. The tunnels will be concrete lined from the intake structure to the cutoff grout curtain and concrete and steel line downstream of that point. The thickness of the steel lining in the tunnel will be adequate for full internal pressure

or minimum handling thickness. The tunnel will be excavated to a horseshoe cross section, but the concrete or steel lining will be circular. The tunnel will be sized for the highest discharge required to operate all units during an average year at a velocity of approximately 4.5 meters per second. The tunnels will be sloped so that negative internal pressures do not arise.

Steel penstocks will extend from the downstream tunnel portal to the manifold upstream of the powerhouse. The penstocks will be installed in a trench that will be excavated in the hillside. They will be placed on a concrete pad for the entire length and the trench will be back filled, wherever possible, to reduce the effects of temperature variations. The plate thickness will be determined for maximum internal pressure, including pressure surges or minimum handling thickness. No expansion joints will be necessary because of the installation method to be used and the relatively short length of penstock. Concrete anchor blocks will be provided at all horizontal and vertical penstock bends.

The combined length of the power tunnel and penstock are relatively short and the operating heads are relative low; therefore no surge tanks or pressure regulators will be provided. However, pressure surges must be more throughly checked during the feasibility study using operating data of the equipment selected at that time.

The powerhouse will be located in one of the abutments downstream of the dam. Their location and orientation will avoid interference of spillway discharge on unit operation. They will be conventional reinforced concrete structures of adequate size for the turbines, generators, governors, valves and all auxiliary equipment. Each generating unit will be in separate unit bays and a service and control bay will be provided at one end of the unit bays. An overhead bridge crane will be provided for initial installation of equipment and subsequent maintenance of units. The units will be erected in the service and control bay which will also contain the control room and project offices. The tranformers will be located upstream of the powerhouse superstructure walls in conformity with the location of switchyard and the outgoing transmission line. The switchyards will also be located nearby on the nearest acceptable terrain. The tailrace will be excavated from the powerhouse to the natural river channel.

3.2.6 RESERVOIRS

The normal maximum reservoir elevations established during the Phase I investigations will be retained for this phase of the investigation. These levels are elevation 271 for Paso Real, elevation 205 for El Carmen and elevation 155 for Copalar for the three dam solution. The corresponding levels for the two dam solution are elevation 271 for Paso Real and elevation 205 for Copalar. The minimum reservoir elevations were established in Phase I as the levels required for the volume of 50 years of sedimentation plus the volume required to regulate the average annual discharge. This criteria will not be used during Phase II and the minimum reservoir levels will be established from the critical 54-month period of the reservoir operation studies which assumes that the reservoirs will be at the normal maximum level at the beginning of the operation study. Minimum reservoir will be the absolute minimum obtained during the reservoir operation studies regardless of the duration that they occur and will vary in accordance with the construction status of the respective projects.

3.2.7 ACCESS ROADS

The project sites are in remote areas and presently have no nearby road network of adequate quality for construction and operation and maintenance. It will, therefore, be necessary to improve long distances of existing roads and to construct many kilometers of new access roads. The main access roads will be double lane all weather roads with gravel surfacing and will have suitable drainage facilities and structures. Secondary access roads to saddle dikes and some project features will be single lane with gravel surfacing and passing zones at critical locations. The maximum grade normally will be limited to 10 percent, but may be increased to 12 percent for short distances. The minimum radius of curve normally will be 50 meters. Hairpin curves with shorter radii will be used only where they cannot be avoided.

3.2.8 CONSTRUCTION MATERIALS

Construction materials will make maximum use of required excavations. The construction schedule may require that materials be temporarily stockpiled for later use. The stockpiles will be located downstream of the dam as much as possible in order to prevent damage or loss during period of high water upstream of the partially completed dam. The remaining construction materials will be obtained from the nearest acceptable source.

3.2.9 CAMPS AND CONSTRUCTION PLANT SITE

Camps will be provided for the personnel engaged in construction activities and project operation. The topographical configuration in the vicinity of the damsites may require that these facilities be located short distances from the site or on nearby hilltops that have been levelled or terraced for the purpose. There are no nearby towns or villages and all personnel will have to be provided with living, eating, recreation, religious and similar facilites and activities.

The construction plant and offices will be located as near the dam as possible. However, the topographic configuration of the site will make the location as difficult to find as sites for the camps. Preference will be given to locating the construction plant and offices nearer the damsite than the camps to permit higher construction efficiency.

3.2.10 LAGUNA DE APOYO

This facility will be essentially the same as adopted for the Phase I study. Special consideration will be given to this project because of the importance of the Laguna as a tourist attraction.

3.3 PROJECT DESCRIPTION

3.3.1 GENERAL

The location of all hydroelectric projects investigated during both phases of this investigation are shown on Annex III-1. That annex shows nine sites on Rio Grande de Matagalpa, three sites on Rio Coco and two sites on Rio Viejo that were considered during Phase I. A tenth site designated as Copalar Upstream Site on Rio Grande de Matagalpa was considered during Phase I, but it is not shown on this annex. It also shows the seven sites

selected from the 15 considered that merited further consideration during the Phase I investigation. Finally it shows the three sites on the Rio Grande de Matagalpa that were selected for further study during the present stage of investigation. The location of the Laguna de Apoyo Project is also shown on Annex III-1.

The reservoirs and damsites for Paso Real, El Carmen and Copalar are shown on Annex III-2. The Copalar low dam reservoir is shown cross-hatched on this annex and the high dam reservoir is shown by a dotted line outside of the cross-hatched area.

A profile of the Rio Grande de Matagálpa is shown on Annex III-3. The profile schematically shows the dams considered during Phase II for both the two and three dam alternatives. It also shows that the full available head has been exploited.

3.3.2 PASO REAL PROJECT

A. GENERAL

This project is located about two kilometers downsteam of the confluence of the Rio Olama with the Rio Grande de Matagalpa. The general project layout is shown on Annex III-4. Access to the site is by means of a short length of road from the Copalar Project access road which will have been constructed several years prior to the construction of this project. This project will be the same for the two dam solution as it is for the three dam solution.

The site is well suited for a storage dam of medium height. The dam creates a large reservoir in which the natural flow of the Rio Grande de Matagalpa can be regulated and sediments can be accommodated. The drainage area at the damsite is almost 3,900 square kilometers and the average annual runoff is estimated to be in excess of 1,500 million cubic meters. The average discharge is 48.2 cubic meters per second.

B. DAM

The dam is located in the upstream part of a narrow canyon at the beginning of a series of rapids in the river. The normal maximum reservoir level is elevation 271 and the surcharged flood level is elevation 272.0. The dam crest is at elevation 275 which provides a freeboard of 3.0 meters above maximum flood level and 4.0 meters at the normal maximum reservoir level. The reservoir capacity is approximately 3,050 million cubic meters at the normal maximum level and 3,500 million cubic meters at the maximum flood level. The minimum reservoir water surface is elevation 240 during the critical 54-month period of the reservoir operation study. The dam contains a total of slightly more than 1.5 million cubic meters of all types of embankment material.

The upstream cofferdam is a portion of the main dam and will be constructed to an initial height of elevation 230. This height is adequate to provide diversion for the first dry season during which time the main dam will be constructed to elevation 243 and will serve as the cofferdam after the first dry season. The downstream cofferdam is a separate structure with crest elevation 214 and will be removed when construction is completed.

C. SPILLWAY

The spillway is located in the right abutment because the topography is too steep to locate it in the left abutment. It is designed for a maximum discharge of 1,300 cubic meters per second resulting from a peak inflow to the reservoir of 6,200 cubic meters per second.

The inlet channel is curved as required by topography and has the invert at elevation 254. The maximum inlet channel velocity is about three meters per second immediately upstream of the crest. The ogee control section contains two radial gates; each eight meters high by twelve meters wide, operated by hoists located on a deck at elevation 275. The spillway crest is at elevation 263. The chute is inclined and about 130 meters long between the crest section and the flip bucket. The flip bucket is located at the end of chute and the discharge lip is at elevation 220 approximately. Water is discharged from the lip of the bucket into the river downstream of the powerhouse. A channel is excavated to elevation 205 downstream of the bucket to permit lower spillway discharges to return to the river.

D. DIVERSION FACILITIES

The diversion tunnel is located in the left abutment and is designed for a maximum discharge of 1,625 cubic meters per second. The internal tunnel diameter is 9.9 meters using the velocity criteria previously specified. The tunnel has one long radius curve and is about 450 meters long between inlet and outlet portals. The inlet channel is excavated to elevation 205 and the outlet channel to elevation 204. The portion of this tunnel upstream of the dam axis is used later as the power tunnel and a penstock is installed within the tunnel downstream of the axis. Power facilities are discussed in the folowing paragraph.

E. POWER FACILITIES

The power facilities are located in the left abutment and include the inlet channel, intake structure, power tunnel, penstock and manifold. These facilities are designed for a normal maximum discharge of 107 cubic meters per second. The inlet channel is not to be excavated until after the diversion tunnel is no longer required so that there is adequate cover until diversion is complete. The inlet channel will be excavated at that time to elevation 235. The intake structure is circular and free standing. Trashracks are provided all around the entire structure. Closure gates are provided at this location only for use during periods of minimum reservoir level. The intake structure is located above the diversion tunnel so that the portion upstream of the dam axis can be used as a power tunnel. This part of the power tunnel is designed for full internal pressure. However, it may be possible to design the lining for only partial pressure when the properties of the surrounding rock are known. A concrete elbow at the base of the intake tower turns the water from the vertical to horizontal direction and also serves as a diversion tunnel closure plug. The power tunnel upstream of the axis is 9.9 meters horseshoe diameter and is about 140 meters long.

A valve chamber is provided on the dam axis and contains two 3.6 meter diameter butterfly valves for penstock closure. Access to the valve chamber is from the downstream end of the diversion tunnel. A steel penstock 5.5 meters in diameter

is installed from the valve chamber to the penstock manifold. The first 200 meters of the penstock is installed on pedestals in the diversion tunnel. A separate power tunnel, 30 meters long, is provided for the last portion of the penstock. The penstock thickness is controlled by internal pressure.

The penstock manifold is located immediately upstream of the powerhouse and provides separate branch penstocks for each of the two units in the powerhouse. It is partially encased in concrete and covered with backfill to form a parking and service area at elevation 215 upstream of the powerhouse.

F. POWERHOUSE

The powerhouse is located on the left bank of the river a short distance downstream of the dam. It contains two 25 MW generators directly coupled to reaction type (Francis) turbines. Each unit bay contains a turbine, governor, generator, turbine inlet valve and all required auxiliary electrical and mechanical equipment. A service and control bay is provided at the right end of the powerhouse. It contains the control room, offices and other facilities required in the plant.

The area upstream of the powerhouse is backfilled to elevation 215 to form a parking and service area for the plant. One transformer for the two unit is located in this area immediately upstream of the superstructure wall. High voltage lines extend from it to the switchyard which is located about 200 meters away on top of the hill behind the powerhouse. The transformer and switchyard are discussed in Section 7.1.

G. ACCESS ROADS

The access roads for Paso Real are very short because they branch from the Copalar Project access road which passes near this site and will have been constructed several years before this project is required. Two branch roads are provided from the Copalar Project road; one for access to the powerhouse and the other for access to the dam crest. Both roads have two lanes although later study may show that only one lane is required for the road to the dam crest. The powerhouse access road crosses the outlet channel of the diversion tunnel. This crossing is made on an embankment placed in the diversion tunnel outlet channel although subsequent investigation may show that a bridge is preferable. A single lane service road is provided for access to the switchyard on top of the hill behind the powerhouse. All roads require a sustained grade of 10 percent in order to keep the lengths to a minimum. All curves have a relatively long radius. Most of the length of the roads is in side-hill cuts although there are short distances on fill. Drainage culverts and auxiliary structures are provided where required.

3.3.3 EL CARMEN PROJECT

A. GENERAL

This project is required only for the three dam alternative and is located about two kilometers downstream of the confluence of the Rio Quisara with the Rio Grande de Matagalpa. The general project layout is shown on Annex III-5. Access to the site is by an access road which branches from the Copalar access road near the area designated as Comarca de Paiwas. The Copalar Project access road is required several years prior to the construction of this project.

This is the best site topographically and geologically of all considered during

both phases of this investigation. The site is suitable for either a rockfill or concrete dam; however, this investigation uses a rockfill dam for the reasons given in Section 3.2.2. The dam creates a relatively small reservoir which cannot appreciably improve regulation of natural river discharge until Paso Real is constructed. The drainage area at the damsite is slightly more than 5,900 square kilometers and the average annual runoff is estimated to be more than 3,300 million cubic meters. The average discharge is 104.5 cubic meters per second.

B. DAM AND DIKE

The dam is located in a narrow canyon where the river completely fills the channel section. The normal maximum reservoir level is elevation 205 which backs water up to the Paso Real Project. The maximum surcharged flood water level is at elevation 210.4. The dam crest is at elevation 212 which provides 7.0 meters of freeboard for the normal maximum level and 1.6 meter above the maximum flood level. The small freeboard for the flood level was used because Paso Real will be constructed shortly after this project and will reduce flood inflows to this reservoir thereby ultimately providing additional freeboard. The reservoir capacity is approximately 815 million cubic meters at the normal maximum reservoir level and about 1,000 million cubic meters at maximum flood level. The minimum reservoir level is elevation 182 during the critical 54-month period of the reservoir operation study before Paso Real is constructed. The dam contains a total of approximately 1.2 million cubic meters of all types of embankment material.

The upstream cofferdam is part of the main dam and is initially constructed to elevation 175 for the first dry season diversion. The main dam will be constructed to elevation 195 during this period and subsequently serve as the cofferdam. It is possible to construct the entire dam in one dry season except for the time required for mobilization and for embankment placement to reach peak efficiency. The downstream cofferdam is a separate structure with its crest at elevation 163 and will be removed when construction is completed.

A low saddle dike is required and is located about 300 meters east of the main dam. This dike is about 15 meters high and about 170 meters long. It has the same cross section as the main dam and contains approximately 50,000 cubic meters of all types of embankment material.

C. SPILLWAY

The spillway is located in the right abutment near the main dam. It is designed for a maximum discharge of 4,760 cubic meters per second resulting from a peak inflow to the reservoir of 10,250 cubic meters per second. No curves are required for any portion of the spillway alignment.

The inlet channel is excavated to elevation 188. The maximum inlet channel velocity is slightly more than three meters per second immediately upstream of the ogee control section when the spillway is discharging its maximum capacity. The ogee crest control section contains four radial gates; eight meters high by twelve meters wide, operated by hoists located on a deck at elevation 212. The spillway crest is at elevation 197. The chute is inclined and is about 150 meters long between the crest section and the flip bucket. The flip bucket is

located at the end of the chute and the discharge lip is at elevation 165 approximately. Water is discharged from the flip bucket into the river more than 300 meters downstream of the dam and powerhouse, therefore there is no danger of retrogression damaging those structures. A channel is excavated to elevation 155 downstream of the flip bucket to permit lower spillway discharges to return to the river.

The low saddle about 300 meters east of the main dam could be used as an emergency spillway for the larger floods of infrequent recurrence, thereby reducing the size of the main spillway. This possibility was recognized during this investigation, but was not used because of the small storage capacity of the reservoir. Further consideration should be given to the use of an emergency spillway when more reliable data and topography maps are available.

D. DIVERSION FACILITIES

The diversion tunnel is located in the right abutment between the dam and spillway. The tunnel and the downstream discharge channel have a straight alignment, but a curve is required near the upstream end of the inlet channel. The tunnel is designed for a maximum discharge of 3,125 cubic meters per second and has an internal diameter of 13.5 meters using the velocity criteria previously specified. The tunnel is approximately 360 meters long between inlet and outlet portals. The inlet channel is excavated to elevation 156 and the outlet channel to elevation 155.

E. POWER FACILITIES

The power facilities are located in the left abutment and include the inlet channel, intake structure, power tunnel, penstock and manifold. These facilities are designed for a normal maximum discharge of 208 cubic meters per second. The inlet channel is excavated to elevation 167 as required by minimum reservoir water level.

The intake structure is constructed at the upstream portal of the power tunnel. It consists of a concrete portal structure, trashracks and tunnel closure gates. The gates are operated by hoists located in a hoist structure with the floor at elevation 212, the same as the dam crest elevation. Access to the intake structure is by means of a short service road from the dam crest and a small embankment; however, it may be necessary to provide a small bridge instead of the embankment in subsequent investigations.

The power tunnel is 7.5 meters in diameter and is approximately 180 meters long from portal to portal. The portion of the tunnel upstream of the dam axis is designed for total internal pressure, but it may be possible to transmit some of the pressure to the surrounding rock when their strength and physical properties are known. The steel lined portion of the tunnel, downstream of the axis, is 90 meters long. The thickness of the steel lining is controlled by minimum handling thickness and therefore no internal pressure can be transmitted to the surrounding concrete or rock.

The penstock is 7.5 meters in diameter, the same as the power tunnel although it may be possible to reduce the diameter during subsequent studies by allowing for

the differences in the coefficients of roughness of concrete and steel. It is approximately 130 meters long between the downstream tunnel portal and the penstock manifold. The penstock is installed on a concrete pad in a trench which is later backfilled to reduce the effects of temperature variations. The penstock thickness is controlled by minimum handling thickness criteria throughout its entire length between the tunnel portal and the penstock manifold. Two anchor blocks are provided; one 70 meters downstream of the tunnel portal and the other upstream of the powerhouse at the elevation of the centerline of the turbine.

The penstock manifold is located immediately upstream of the powerhouse and provides separate branch penstocks for each of the two units in the powerhouse. The branches are partially encased in concrete and later covered with backfill to provide a parking and service area at elevation 163 upstream of the powerhouse.

F. POWERHOUSE

The powerhouse is located on the left bank of the river downstream of the heel of the main dam. It contains two 35 MW generators directly coupled to reaction type (Francis) turbines. Each unit bay contains a turbine, governor, generator, turbine inlet valve and all required auxiliary electrical and mechanical equipment. A service and control bay is located at the left end of the powerhouse. It contains the control room, office and all supporting facilities required in the plant.

The area upstream of the powerhouse will be backfill to elevation 163 to form a parking and service area for the plant. One transformer for the two generators is located in this area immediately upstream of the powerhouse. High voltage lines extend from it to the switchyard which is located at elevation 220 on the hillside behind the powerhouse. The transformer and switchyard are described in Section 7.1 .

G. ACCESS ROADS

The access road for this project consists of approximately three kilometers of improvement of existing roads and 23 kilomters of new road. The new road extends from a point on the Copalar Project access road about three kilometers northwest of the village of Paiwas to the project site. The access road has two branches near the project site. One leads to the service area at elevation 163 behind the powerhouse and the other leads to the crest of the main dam. Access to the intake structure was previously discussed with the power facilities. Access to the spillway and saddle dike is across the dam crest and spillway operating deck. Access to the switchyard is from the road leading to the crest of the dam. All roads near the dam require a sustained grade of 10 percent in order to keep the length to a minimum. All curves are of relatively long radii. The roads are mostly in side-hill cut although short length of embankment will be used to keep roadway lengths to a minimum. Drainage culverts, auxiliary structures and facilities are provided where required.

3.3.4 COPALAR PROJECT - LOW DAM

A. GENERAL

This is the first dam that is to be constructed in the three dam alternative and

is called Copalar Project Low Dam in contrast to the Copalar Project High Dam of the two dam alternative which is described in Section 3.3.5. This is the largest and most important project included in the three dam solution and represents the key to maximum exploitation of the hydroelectric resources of the Rio Grande de Matagalpa. Since this is to be the first project constructed, many of the facilities required for it will lower the cost of El Carmen and Paso Real. It is located approximately 300 meters downstream of the confluence of the Cano de Agua with the Rio Grande de Matagalpa. The general project layout is shown on Annex III-6. Access to the site is provided by improving existing roads and constructing a new road. The improvement and construction of these roads will provide easier access to the other dams of the three dam solution. The axis of this dam is slightly upstream of the axis of the high dam because of the dam size, topography and geologic conditions.

This site is suitable for a rockfill dam, although a concrete dam may be feasible when more information is available on foundation and subsurface conditions; however, this investigation considered only a rockfill dam. The dam creates a reservoir that has a reasonably large storage volume. The drainage area at the damsite is slightly more than 7,100 square kilometers and the average annual runoff is estimated to be in excess of 5,000 million cubic meters, or 159.0 cubic meters per second.

B. DAM

The dam is located as far upstream in the canyon as possible in order to take maximum advantage of topographic configuration and geologic conditions. The selected axis provides the smallest sized dam and best location of related project features. The normal maximum reservoir level is elevation 155 and the maximum surcharged level is elevation 160.3. The dam crest is at elevation 162 which provides 1.7 meters of freeboard above maximum flood level and 7.0 meters of freeboard above normal maximum level. The small freeboard above maximum flood level applies only before the regulating effects of El Carmen and Paso Real are included The freeboard will increase when those projects are constructed. The reservoir capacity is approximately 2,500 million cubic meters at the normal maximum reservoir level and about 3,400 million cubic meters at the maximum flood level. The minimum reservoir level during the critical 54-month period of the reservoir operation study is elevation 122 when operating alone; elevation 126 upon completion of El Carmen and elevation 134 upon completion of Paso Real. The dam contains a total volume of almost 3.7 million cubic meters of all types of embankment materials.

The upstream cofferdam is part of the main dam and is constructed to elevation 103 for diversion of the river discharge during the first dry season of construction. The dam is constructed to elevation 110 during that period and serves as the cofferdam during following construction periods. The downstream cofferdam is a separate structure with the crest at elevation 82. It must be removed for project operation after construction is completed. No saddle dikes are required at this site for a dam constructed to elevation 162.

C. SPILLWAY

The spillway is located in the left abutment and the centerline is inclined at about 30 degrees from the axis of the main dam. It is designed for a maximum

discharge of 3,530 cubic feet per second which results from a peak inflow to the reservoir of 15,300 cubic meters per second. No curves are required for any portion of the spillway alignment.

The inlet channel is excavated to elevation 138. The maximum inlet channel velocity will be slightly more than three meters per second immediately upstream of the ogee control section when the spillway is discharging its maximum capacity. The ogee crest control section contains three radial gates; each eight meters high by twelve meters wide, operated by hoists located on a deck at elevation 162. The chute is inclined and is about 170 meters long between the control section and flip bucket. The flip bucket is located at the end of the chute and the discharge lip is at elevation 105 approximately. Water is discharged from the flip bucket into the river about 300 meters downstream of the dam and powerhouse, therefore, those structures are not endangered by retrogression. A channel is excavated to elevation 70 downstream of the flip bucket to permit lower discharges to return to the river.

D. DIVERSION FACILITIES

The diversion tunnel is located in the right abutment. One curve is required in the alignment near the downstream end. The tunnel is 670 meters long and is designed for a maximum discharge of 4,700 cubic meters per second. The internal diameter is 17.0 meters as required by the velocity criteria previously specified. This is a very large size and may be difficult to construct. Therefore a cost comparison was made between this tunnel and two tunnels of equivalent discharge capacity. The diameter of each of the two tunnel solution is 12 meters. The cost comparison indicated that the two tunnels would cost almost 50 percent more than one tunnel. The use of one tunnel for this study was influenced by the duration of the diversion and the severity of the construction flood recurrence interval. The tunnel size needs further study in subsequent stages of investigation.

E. POWER FACILITIES

The power facilities include the inlet channel, intake structure, power tunnel, penstock and manifold and are located in the left abutment between the dam and the spillway. These facilities are designed for a normal maximum discharge of 454 cubic meters per second. The inlet channel is excavated to elevation 104 as required by minimum reservoir level and a limiting channel velocity during all stages of constructing the three dams.

The intake structure is constructed at the upstream tunnel portal. It consists of a concrete portal structure, trashracks and tunnel closure gates. The gates are operated by hoists located in a hoist structure which has the floor at elevation 162, the same as the crest of the dam. The left dam abutment is levelled to elevation 162 and access to the hoist structure is directly from this level area.

The power tunnel is 11.4 meters in diameter and is approximately 170 meters long from portal to portal. One curve is required in the alignment, although it may be possible to eliminate it during later investigations. A concrete lining is provided from the intake structure to the dam axis and a concrete and steel lining is provided from that location to the downstream portal. The concrete lined portion

is about 70 meters long and the steel lined portion 100 meters long. The concrete lined portion of the tunnel upstream of the axis is designed for full internal pressure, but it may be possible to transmit some of the pressure to the surrounding rock when their strength and physical properties are known. The thickness of the steel lining in the tunnel downstream of the axis is controlled by minimum handling thickness criteria and therefore no pressure can be transmitted to the surrounding concrete or rock.

The penstock is 11.4 meters in diameter; the same as the steel lining in the power tunnel. It may be possible to reduce the penstock diameter during subsequent investigations by allowing for the differences in the coefficients of roughness of concrete and steel. It is approximately 170 meters long between the downstream tunnel portal and the penstock manifold. The penstock is installed on a concrete pad in a trench which is later backfilled to reduce the effects of temperature variations. The penstock thickness is controlled by minimum thickness criteria at the tunnel portal and internal pressure immediately upstream of the penstock manifold. Two anchor blocks are provided; one at the power tunnel portal and the other upstream of the powerhouse at the elevation of the centerline of the turbine.

The penstock manifold is located immediately upstream of the powerhouse and provides separate branch penstocks for each of the five units in the plant. The branches are partially encased in concrete and later covered with backfill to provide a parking and service area at elevation 83 upstream of the powerhouse.

F. POWERHOUSE

The powerhouse is located on the left bank of the river downstream of the dam. It contains five 55 MW generators directly coupled to reaction type (Francis) turbines. Each unit bay contains a turbine, governor, generator, turbine inlet valve and all required auxiliary mechanical and electrical equipment. A service and control bay is located at the right end of the unit bays. It contains the control room, office and all supporting facilities required in the plant.

The area upstream of the powerhouse is backfilled to elevation 83 to form a parking and service area for the plant. The transformers are located in this area immediately upstream of the powerhouse. High voltage lines extend from the unit transformers to the switchyard which is located at elevation 180, about 300 meters away on the hillside behind the powerhouse. The transformers and switchyard are described in Section 7.1.

G. ACCESS ROADS

The access roads for this project consist of the improvement of 27 kilometers of existing road and the construction of 66 kilometers of new road, or a total of 93 kilometers of access road. This represents the distance from Boaco to the project site. The access road reaches the project site on the left abutment and follows an alignment across the spillway bridge, dam crest and down the right side of the valley to the powerhouse. Access to the powerhouse directly from the left side is not feasible because of the spillway location. Access to the switchyard is directly from this road. The road near the damsite requires sustained grades of 10 percent, but flatter grades can be used further

away from the dam. One hairpin curve is required near the powerhouse, but might be eliminated by lengthening the access road. The curve off the dam crest at the right abutment is quite sharp and may have to be changed during later studies. Otherwise, all curves have a minimum radius of 50 meters. The roads near the damsite are mostly side hill cuts; but roads further away may be in cut, fill or a combination of both. Drainage culverts, bridges and auxiliary structures are provided where required.

3.3.5 COPALAR PROJECT - HIGH DAM

A. GENERAL

This project is similar in many respects to the Copalar Project Low Dam. It is by far the most important and has the largest power and energy potential of all projects investigated on the Rio Grande de Matagalpa. It can make significant contributions to satisfying the power and energy requirements for Nicaragua for many years. Although this is the most economical of all projects considered; it, unfortunately, cannot be adopted until the uncertainty regarding topography discussed in Section 3.1.1 is resolved.

This project is located at the same general location as the Copalar Project Low Dam except that the axis is slightly further downstream because of the larger size of dam required. This project is part of the two dam solution which require only it and the Paso Real Project to completely develop the entire available head. The general proyect layout is shown on Annex III-7 and Annex III-8. Access to the site is generally the same as that for the low dam except for one short length where the alignment must be changed slightly.

This site is suitable for a rockfill dam, although a concrete dam may also be feasible when more data is available regarding foundation and subsurface condition. This is a relatively high dam and only a rockfill structure has been considered during this investigation. The dam creates a large reservoir for storage of the runoff. The drainage area at the damsite is slightly more than 7,100 square kilometers and the average annual runoff is estimated to be in excess of 5,000 million cubic meters, or 159.0 cubic meters per second. These last three values are the same as the corresponding values for the Copalar Low Dam.

B. DAM AND DIKES

The dam is located as far upstream as possible in the canyon consistent with the size required. The normal maximum reservoir level is elevation 205 which backs water up to the heel of the Paso Real Dam. The maximum surcharged flood level is elevation 207.4. The dam crest is at elevation 210 and provides 2.6 meters of freeboard above maximum flood level and 5.0 meters above normal maximum reservoir level. The flood level freeboard applies only until Paso Real is constructed at which time it will increase as a result of the reservoir storage capacity at the upstream project. The reservoir capacity is approximately 15,500 million cubic meters at normal maximum reservoir level and in excess of 16,500 million at the flood surcharged level. The minimum reservoir level is at elevation 173 during the critical 54-month period of the reservoir operation study when this project is operating alone and elevation 175 after Paso Real is constructed. The dam contains a total volume of almost 11 million

cubic meters of all types of embankment material.

The upstream cofferdam is part of the main dam and will be constructed to elevation 111 which is high enough for diversion until the dam can be constructed to a higher level. The downstream cofferdam is a separate structure with the crest at elevation 82 and will be removed for project operation after construction is completed.

Four saddle dikes are required for a reservoir water level of elevation 205. According to the 20-meter contour maps, there is one area below elevation 180, one below 200 and two below elevation 220 that require dikes. The saddle area below elevation 180 is located about 29 kilometers generally south of the main dam near La Olosica and Cano La Vaca. Access to this saddle dike is by a new single lane road between it and the main dam. The saddle area below elevation 200 is located on the left bank of the reservoir near Cerro El Trompillo and the headwaters of Rio Malacaguas, approximately 18 kilometers generally west of the main dam. Access to this saddle dike is by five kilometers of new single lane access road that branches from the main project access road near a location called El Toro. One of the saddle areas below elevation 220 is located on the left bank of the reservoir and adjoins the hill forming the left abutment of the main dam. No access road is required for this dike. The second area below elevation 220 that requires a saddle dike is located about four kilometers south of the main dam in a low ridge between Quebrada El Guarumo and Quebrada El Cacao. Access to this site is by the same road that connects the dam with the saddle area below elevation 180 near La Olosica.

C. SPILLWAY

The spillway is located in the left abutment and has the centerline rotated at about 35 degrees from the dam axis. It is designed for a maximum discharge of 2,440 cubic meters per second which results from a peak inflow to the reservoir of 15,300 cubic meters per second. No curves are required for any part of the spillway alignment.

The inlet channel is excavated to elevation 188 and the maximum inlet channel velocity is slightly less than two meters per second immediately upstream of the ogee control section when the spillway is discharging its maximum capacity. The ogee control section contains three radial gates; each eight meters high by twelve meters wide, operated by hoists located on a deck at elevation 210. The chute is inclined and is about 410 meters long between the control section and the flip bucket. The flip bucket is located at the end of the chute and the discharge lip is at elevation 85 approximately. Water is discharged from the flip bucket into the river about 300 meters downstream of the dam and powerhouse, therefore those structures are not endangered by retrogression. A channel is excavated to elevation 70 downstream of the flip bucket to permit lower discharges to return to the river.

An alternate location for a spillway in the right abutment was considered because it appears to be more economical than a location in the left abutment. The alternate location was not used because the area was not geologically investigated for this purpose. However, this location must be considered in subsequent investigations and a cost comparison made between the

two locations.

One of the four saddle dikes required for this project could be used as an emergency spillway thereby reducing the capacity of the main spillway. This possibility was recognized, but was not used due to the uncertainty of the topography in the area and geological requirements related to the use of such a facility. However, the use of an emergency spillway should be included in subsequent investigations.

D. DIVERSION FACILITIES

The diversion tunnel is located in the right abutment and has a straight alignment for its entire length. The tunnel is 750 meters long and is designed for a maximum discharge of 4,700 cubic meters per second which requires an internal tunnel diameter of 17.0 meters using the velocity criteria previously specified. The same size and construction conditions discussed in Section 3.3.4. D for the Copalar Project Low Dam apply to this tunnel.

E. POWER FACILITIES

The power facilities are located in the left abutment between the dam and the spillway and include the inlet channel, intake structure, power tunnel, penstock and manifold. These facilities are designed for a normal maximum discharge of 308 cubic meters per second. The inlet channel is excavated to elevation 188 as required by minimum reservoir level and a limiting channel velocity during all stages of constructing the two dams.

The intake structure is constructed at the upstream tunnel portal. It consists of a concrete portal structure, trashracks and tunnel closure gates. The gates are operated by hoists located in a hoist structure which has the floor at elevation 210, the same as the crest of the dam. The left dam abutment is levelled to elevation 210 and access to the hoist structure is directly from this level area.

The power tunnel is 9.5 meters in diameter and is approximately 220 meters long from portal to portal. One long radius curve is required in the power tunnel, although it may be possible to eliminate it during later investigations. A concrete lining is provided from the intake structure to the dam axis and a concrete and steel lining is provided from that location to the downstream portal. The concrete lined portion of the tunnel is about 30 meters long and the steel lined portion about 190 meters long. The concrete lined portion of the tunnel upstream of the axis is designed for full internal pressure, but it may be possible to transmit some of the pressure to the surrounding rock when their strength and physical properties are known. The thickness of the steel lining in the tunnel downstream of the axis is controlled by minimum handling thickness criteria and therefore no pressure can be transmitted to the surrounding concrete or rock.

The penstock is 9.5 meters in diameter; the same as the steel lining in the power tunnel. It may be possible to reduce the penstock diameter during subsequent investigations by allowing for the differences in the coefficients of roughness of concrete and steel. It is approximately 280 meters

long between the downstream tunnel portal and the penstock manifold. The penstock is installed on a concrete pad in a trench which is later backfilled to reduce the effects of temperature variations. The penstock thickness is controlled by minimum handling thickness criteria for the 60 meter horizontal portion between the tunnel portal and the first vertical bend and by internal pressure from that point to the penstock manifold. Three anchor blocks are provided; one about 60 meters downstream of the power tunnel portal, a second about half-way down the slope and a third upstream of the powerhouse at the elevation of the centerline of the turbine.

The penstock manifold is located immediately upstream of the powerhouse and provides separate branch penstocks for each of the six units in the plant. The branches are partially encased in concrete and later covered with backfill to provide a parking and service area at elevation 83 upstream of the powerhouse.

F. POWERHOUSE

The powerhouse is located on the left bank of the river downstream of the main dam. It contains six 55 MW generators directly coupled to reaction type (Francis) turbines. Each unit bay contains a turbine, governor, generator, turbine inlet valve and all required auxiliary mechanical and electrical equipment. A service and control bay is located at the right end of the unit bays. It contains the control room, office and all supporting facilities required in the plant.

The area upstream of the powerhouse is backfilled to elevation 83 to form a parking and service area for the plant. The transformers are located in this area immediately upstream of the powerhouse. High voltage lines extend from the transformers to the switchyard which is located at elevation 182, about 300 meters away on the hillside behind the powerhouse. The transformers and switchyard are described in Section 7.1.

G. ACCESS ROADS

The access roads for this project consist of the improvement of 23 kilometers of existing road and the construction of 113 kilometers of new road. This is the distance from Boaco to the project site plus the access roads required for three saddle dikes. The access road reaches the project site on the left abutment and follows an alignment across the spillway bridge, dam crest and down the right side of the valley to the powerhouse. Access to the powerhouse directly from the left side is not feasible because of the spillway location. Access to the switchyard is directly from this road. The road near the damsite requires sustained grades of 10 percent, but flatter grades can be used further away from the dam. The curve off the dam crest at the right abutment is quite sharp and may have to be changed during later studies. Otherwise, all curves have a minimum radius of 50 meters. The roads near the damsite are mostly side hill cuts; but roads further away may be in cut, fill or a combination of both. Drainage culverts, bridges and auxiliary structures are provided where required.

Access to the saddle dikes located four and 29 kilometers south of the main dam is provided by a single lane gravelled road. Its alignment is in a south direction and crosses the crest of the first saddle dike located near Quebrada El Guarumo and Quebrada El Cacao. It continues south from that location around the backwater of the reservoir in Rio La Toboba near a location called San Antonio. The road turns at that location and follows a general west alignment to the saddle dike near La Olosica and Cano La Vaca. Although this dike is only 29 kilometers from the main dam; the access road to it is approximately 37 kilometer long because of the backwaters of the reservoir.

Access to the saddle dike located 18 kilometers east of the main dam near Cerro El Trompillo is provided by a single lane gravelled surface road. This road branches from the Copalar Project access road near a location called El Toro and follows a south alignment for about five kilometers to the dike location. This saddle dike is not otherwise connected to the main dam.

3.3.6 LAGUNA DE APOYO PUMPED-STORAGE PROJECT

A. GENERAL

This project was only slightly revised during Phase II and much of the following text is the same as contained in the Phase I Report. It is located approximately 35 kilometers southeast of Managua. The purpose of this project is to provide peaking capacity and energy by pumping water from an existing volcanic lake and storing it in an upper level reservoir during the low demand hours and generating power by dropping the water back into the lake during the peak demand hours.

The lower reservoir for the project is Laguna de Apoyo. This area is one of scenic beauty around Managua and is a tourist attraction. The region has high seismic activity and the temperature of the water in the lake has sometimes been observed to fluctuate which could be an indication of dormant volcanic activity. The water level in the lake varies by as much as 1.5 meters. The inside crater wall is covered with talus and has lush vegetation.

The project is located on the west side of the lake where the rim is the highest in order to provide the maximum possible head for power generation, The surface and underground alternatives for the pumping-generating plant used during Phase I have been only slightly revised for this phase of the investigation. The general project layouts for these alternatives are shown on Annex III-9 and Annex III-10 respectively.

B. UPPER RESERVOIR

Two possible upper reservoir locations were considered. One is about 500 meters north of the village of Catarina and the other is about 500 meters further north. The site nearer to Catarina was selected for further study because it requires less embankment than the site further away for all levels of energy storage. However, it must be recognized that the other storage reservoir could be combined with the site selected to gain more energy storage capacity if a low cost source of pumping energy becomes

available. The relationship between energy required for pumping and that available for power generation is shown on the project layout drawings. The following discussion applies to the selected reservoir site.

The upper reservoir is the same for the surface pumping-generating station as it is for the underground installation. A small dike with a crest at elevation 553 is built across the valley utilizing materials obtained from within the reservoir. The dike will have an inside slope of 1.8:1 (horizontal to vertical) and the outside slope of 3:1 (horizontal to vertical). The drainage area of the basin is very small; therefore, neither sediment storage volume nor spillway is required. Preliminary investigations indicate that the reservoir is underlain by tuff below which there is a pervious layer of pumice which could be very thick. The geologic formation requires that a lining be provided for the reservoir. The maximum water level in this reservoir is elevation 550 and the minimum level is elevation 530.

C. SURFACE PLANT

A gated intake tower with trashracks is provided at the lowest elevation of the upper reservoir. A bridge provides access from the top of the dike to the intake tower. A concrete lined tunnel, approximately 650 meters long, connects the intake tower to a steel penstock, approximately 900 meters long, which slopes down the inside of the crater to the pumping and generating station located at the side of the lake. The penstock is placed in a trench, which will be excavated to sound rock. It will be anchored to the rock and the trench will subsequently be backfilled with excavated material to reduce the effects of temperature variations.

This station is planned for a maximum generating capacity of 200 MW and will ultimately contain four 50 MW units and an erection bay. Provisions will be made for a staged development of the project, starting with one unit. One penstock will serve two units and a bifurcation of the penstock will be provided upstream of the station. The average gross head developed at this site is about 460 meters. A reversible pump turbine for this head requires deep submergence and will increase construction costs of the powerhouse. Therefore, an impulse type turbine (Pelton) and a multistage pump will be provided. Each unit will have a motor-generator and a three phase transformer. The switchyard is located near the station from which high voltage transmission lines extend to the load center.

D. UNDERGROUND PLANT

This station will also be planned for a maximum generating capacity of 200 MW, with four 50 MW unit bays and an erection bay. The layout will be arranged so that the station can be developed in stages with an initial installation of one unit.

The intake structure is the same for the underground plant as it is for the surface plant. A concrete lined tunnel extends horizontally from the intake structure for about 300 meters where a 45 degree slope begins and extends to the elevation of the centerline of the turbine. A construction adit, about 270 meters long, extends horizontally from the elbow to the natural ground surface. The inclined portion of the tunnel is approximately 650

meters long. The tunnel bends to the horizontal direction about 250 meters upstream of the sphere valve chamber which is about 50 meters upstream of the plant.

An access tunnel, approximately 450 meters long, is provided from the service and control bay to the natural ground surface near the shore of the lake. This tunnel is sized to provide space for the required ventilation facilities and sulphur hexafluoride (SF_6) bus between the transformers in the plant and the switchyard near the tunnel portal.

A concrete lined turbine discharge tunnel extends for approximately 500 meters from the plant to the lake. A surge chamber is provided downstream of the plant to prevent undesireable pressure rise. Flap gates are provided at the end of this tunnel to prevent accidental flooding of the plant during periods when the plant is not in operation. A reversible pump-turbine will be used for this installation because adequate submergence can easily be obtained and the costs are lower than for a separate pump and turbine.

E. CONCLUSIONS REGARDING PROJECT

The Laguna de Apoyo Project offers good prospects as a source of peak power generation, however, construction presents many problems that require study. These include the geology of the site, seismic and volcanic activity in the area, environmental considerations and recreational aspects of the lake. In addition, it is not needed to satisfy energy requirements during the study decade. The first two reasons are the most serious and must be thoroughly investigated before construction is started. A search should be made for a more suitable site. Therefore, the project was eliminated from any further consideration during this investigation.

3.4 RIVER BASIN DEVELOPMENTS

The individual projects on the Rio Grande de Matagalpa were combined into two river basin developments for use in the evaluation of the total electrical system. These developments include the two dam alternative and the three dam alternative previously mentioned in this report. These two alternatives were studied in more depth during this phase of the investigation than in the earlier phase.

The two dam alternative produces more energy than the three dam alternative; however it requires a larger immediate and total capital investment than the three dam alternative. It was recognized that the smaller and lower investment schedule for the three dam alternative could make it more economical than the two dam alternative. The results of the economic analyses of these alternatives was made by including them as a part of the total system required to satisfy future power and energy requirements and are discussed in other portions of this report.

3.5 ACCESS ROADS

The access roads for projects on the Rio Grande de Matagalpa recognized that the Copalar Project would be constructed first for either river basin development alternative and that project construction would proceed from downstream to upstream. This requires that most of the project roads be constructed at the same time as the Copalar Project. The road alignment was coordinated with the transmission line route to permit the best and lowest combined cost of the two facilities. Transmission line routing is discussed in Section 7.1. The access road alignment and transmission route is shown on Annex III-11 and Annex III-12 respectively for the two and three dam alternatives.

The existing roads near the project area beyond Boaco are in very poor condition. Therefore, it was assumed that access roads would have to be constructed from there to each of the project sites. The existing road network beyond Boaco was used as much as possible in order to improve the transportation facilities in the most heavily populated areas in the vicinity.

Two general alignments were considered for access to the Copalar Project; both originating at Boaco. One followed the existing road network on the south side of the reservoirs and continued around the reservoirs to the Copalar Project. The second started at Boaco and went to the Paso Real damsite and around the north side of the reservoirs. The route around the north side of the reservoirs resulted in the shortest total length and was also more suitable for the transmission lines. The adopted alignments are almost the same for the two dam and three dam alternatives. The transmission line routes are included on the annexes to show their locations with respect to the roads. Locating the transmission line and access roads close together should materially reduce the operation and maintenance costs of the transmission lines.

The access road from Boaco to the Copalar site for the two dam and three dam alternatives pass through the same controlling location. Therefore, the following description is applicable to both alternatives. The Copalar Project access road originates at Boaco and follows a northeast alignment through, or near, El Paraiso, Las Pampas, Santa Rosa and Santa Rita before reaching the Paso Real site where a permanent bridge is provided downstream of the Paso Real Dam. The road continues in a general northeast direction after it crosses the Paso Real Bridge and passes through, or near, La Concepcion, El Delirio, La Salvadorita, El Palomar and Rio Blanco. The alignment turns and follows a general east direction from Rio Blanco through, or near, El Aparejo, La Esperanza and beyond Cano de Agua where it turns south for a few kilometers to finally arrive at the Copalar site.

The only difference in the alignment for the Copalar access road for the two dam and three dam alternatives is where the road crosses Rio Paiwas between El Delirio and La Salvadorita. The road for the two dam alternative must go around the backwater of the Copalar High Dam in Rio Paiwas; whereas, this is not necessary for the three dam solution.

Access to Paso Real damsite is from the Paso Real Bridge on the Copalar

Project access road. This access is the same for the two and three dam alternatives. Only a very minor amount of access road is required for the Paso Real Project.

An access road for the El Carmen Project is needed only for the three dam alternative. This road branches from the Copalar Project access road near a location known as Holanda between El Delirio and La Salvadorita and near Rio Paiwas. This general area is where the difference occurs in the alignment of the Copalar Project access road for the two dam and three dam alternatives.

The roads for access to the saddle dikes required for the Copalar High Dam are discussed in Section 3.3.5.G.

3.6 RESERVOIR OPERATION STUDIES

3.6.1 GENERAL

Reservoir operation studies were performed for the Phase II investigation using revised, additional and updated data. The procedures used are generally the same as those for Phase I and are discussed in the following paragraphs which are the same in many respects as those in the earlier report. The reservoir operation studies were conducted on a monthly basis for individual project sites and the two river basin development alternatives. The computer program, HEC-3, Reservoir System Analysis developed by the U.S. Army Corps of Engineers was used. This program requires the assumption of the installed capacity at each plant as part of the input data and computes the average monthly power using the available discharge and the resulting head for the month.

3.6.2. OPERATION PERIOD AND INFLOW DATA

A 50-year period was used for all reservoir operation studies. A representative stream gaging station was selected for each project site and a critical set of 50-year flows at that station was used. The selection of the critical set of flows was based on 20 generated sequences of 50 years; each containing the most critical 54-month average. Data related to the critical flow sequence are contained in Chapter I, Hydrology and Meteorology.

3.6.3 RESERVOIR INFLOW

The reservoir inflow was represented by the flows at a gaging station located at or near the project site for the reservoir operation studies of a single reservoir. For operation studies of multiple reservoirs, the inflow to the downstream reservoir was computed as the regulated discharge of the upstream reservoir plus the local inflow between the two reservoirs. Local inflow was the difference between the flow at the downstream and upstream sites.

3.6.4 RESERVOIR EVAPORATION

The net monthly evaporation rates at reservoir sites shown in Table I.14 of Chapter I, Hydrology and Meteorology, were used in reservoir operation

runs. The procedure used in computing net evaporation is contained in Section 1.4.5 of Chapter I of this report.

3.6.5 RESERVOIR AREA-CAPACITY CURVES

Area-Capacity curves were required as input for the reservoir operation studies. A table of reservoir water surface elevations, corresponding surface areas and storage capacities were entered for each reservoir. The reservoir area-capacity curves for each site are shown on the project layout drawings.

3.6.6 NORMAL RESERVOIR WATER SURFACE ELEVATIONS

The normal maximum and normal minimum reservoir water surface elevations were entered on each operation run and the allowable drawdown and live storage volumes were computed. The reservoir was assumed to be at normal maximum reservoir water surface elevation at the first of the month for all operation studies. No surcharge was allowed and reservoir spills occurred when the water surface was above the normal maximum level.

3.6.7 TAILWATER ELEVATION AND HEAD LOSSES

Constant tailwater elevations were assumed at the project sites and the average tailwater condition was used. Head losses were estimated for average conditions as a percentage of the total gross head and the same losses were used for all discharges.

3.6.8 POWER PLANT

The selected installed capacity was entered into the program. An overload of the unit up to 15 percent of rated capacity was allowed for computing peak capacity during the month. Net head was computed as reservoir water surface elevations minus tailwater elevation and head losses. An average overall power plant efficiency of 0.83 was assumed. The power generated was computed as a function of discharge, net head and efficiency. Firm capacity was computed by the program as the capacity derived from the combination of minimum reservoir water surface elevation and discharge. The program computed the average monthly power generation for each month of the 50-year period.

3.6.9 INSTALLED CAPACITY

The installed capacity for the computer analyses were assumed large enough that the peak output of the plant was unrestricted. They were 1,000 MW for Copalar High Dam, 600 MW for Copalar Low Dam and 200 MW for El Carmen and Paso Real. These capacities were not proposed as those that should be installed; but, rather represented the upper limit that could be considered in making the computer run. These capacities for input data to the computer runs are much higher than those ultimately adopted. The output of the computer analyses are shown in Table III.1.

TABLE III.1

RESERVOIR OPERATION STUDIES
SUMMARY OF RESULTS OF COMPUTER ANALYSES

ALTERNATIVE AND PROJECT	INSTALLED CAPACITY MW	INFLOW		POWER GENERATED 100% CAPACITY FACTOR		RESERVOIR DATA				TAILWATER ELEVATION m
		STATION NUMBER	50-YEAR MONTHLY m^3/sec.	FIRM MW	50-YEAR AVERAGE MW	MAXIMUM ELEVATION m	MAXIMUM VOLUME $m^3 \times 10^6$	MINIMUM ELEVATION m	MINIMUM VOLUME $m^3 \times 10^6$	
TWO DAM ALTERNATIVE										
Copalar	1,000	18	159.0	158.0	165.1	205.0	15,500	173.2	5,470	70
Copalar + Paso Real										
Copalar	1,000	18	159.0	159.8	163.9	205.0	15,500	175.2	5,910	70
Paso Real	200	13	48.2	21.0	23.9	271.0	3,050	240.4	230	205
TOTAL	1,200			180.8	187.8					
THREE DAM ALTERNATIVE										
Copalar	600	18	159.0	69.6	104.2	155.0	2,500	121.8	420	70
Copalar + El Carmen										
Copalar	600	18	159.0	72.0	104.8	155.0	2,500	126.4	528	70
El Carmen	200	9	104.5	16.8	40.6	205.0	820	181.9	150	155
TOTAL	800			88.8	145.4					
Copalar + El Carmen + Paso Real										
Copalar	600	18	159.0	82.4	104.4	155.0	2,500	133.6	760	70
El Carmen	200	9	104.5	28.2	39.3	205.0	820	184.8	190	155
Paso Real	200	13	48.2	21.0	23.9	271.0	3,050	240.4	230	205
TOTAL	1,000			131.6	167.6					

3.7 POWER GENERATION

The average monthly power generation was calculated from the results of the computer output of the reservoir operation studies. The average monthly power generated for each month of the 50-year period was computed, but limited the capacity to 330 MW for Copalar High Dam, 184 MW for Copalar Low Dam, 70 MW for El Carmen and 50 MW for Paso Real. The monthly averages are shown in Table III.2 for the two and three dam alternatives. These values were converted from 12-one month intervals to 13-four week periods for the use in system planning. The converted values are shown in Table D. 6 and Table D. 7 for the two dam and three dam alternatives respectively and are discussed in Section 8.1.1.B. A river profile is schematically shown on Annex III-13 which includes the installed capacity, firm capacity and annual energy generation for an average year after the projects are in full operation.

The Copalar High Dam requires three years for construction and also three years of average annual runoff to fill the reservoir. In order to reduce the time between completion of the dam and the first power generation, reservoir filling will commence at the beginning of a wet season before the dam is entirely completed in the following dry season. This procedure can be used in this case because the reservoir volume is so large that there is no danger of overtopping the partially completed dam even if runoff during the year is abnormally high. Reservoir filling will continue through the wet season following completion of dam construction and the reservoir will be approximately two-thirds full at that time and power generation can begin, but at reduced output. Therefore, a study was made to determine the reduced average capacity at which the plant could be operated and still permit the reservoir to reach its normal maximum level within a reasonable period of time. This study was made by testing the effects on the reservoir if a constant average capacity were generated throughout the year. The study used the average monthly discharges estimated for the Phase I investigation and assumed tailwater elevations. The corresponding discharges for the Phase II study were received later, but did not vary enough from those used in studying reduced capacities to warrant revision of the previously completed work. The difference in discharges occurs mostly in the distribution throughout the months of the year and the annual average discharge varies by less than one percent. The effects on reservoir filling was examined for 60, 75, 90, 100 and 140 megawatts constant power generation. The study resulted in the selection of 60 MW capacity for the first year of operation and 90 MW capacity for the second year, at which time the reservoir will reach its normal maximum level and full power generation can begin. This study used a constant power generation throughout the year, but it could have been varied for each month of the year and not affect the final outcome of the study. However, variations of the average capacities during this period were made for production costing and system planning as shown in Table D.6 and Table D.7.

The reservoir of the Copalar Low Dam will fill in one wet season and can produce full capacity as soon as it is placed in operation. However, a period of decreased power generation will occur at the downstream sites during the reservoir filling periods at El Carmen and Paso Real. This is not so critical for these dams as it is for Copalar High Dam. The El Carmen

TABLE III.2

AVERAGE MONTHLY POWER GENERATION*

	POWER GENERATION 100% CAPACITY FACTOR - MW												
TWO DAM ALTERNATIVE	J	F	M	A	M	J	J	A	S	O	N	D	AVERAGE ** FOR YEAR
Copalar - 330 MW	158.1	158.1	158.1	158.1	158.1	158.1	158.1	160.5	172.9	187.7	162.1	158.1	162.3
Copalar + Paso Real													
Copalar - 330 MW	158.9	158.9	158.9	158.9	158.9	158.9	158.9	160.1	169.4	177.0	163.2	158.9	161.7
Paso Real - 50 MW	21.0	21.0	21.0	21.0	21.0	21.0	21.0	22.9	26.2	30.7	21.9	21.0	22.5
TOTAL 380 MW	179.9	179.9	179.9	179.9	179.9	179.9	179.9	183.0	195.6	207.7	185.1	179.9	184.2
THREE DAM ALTERNATIVE													
Copalar - 275 MW	71.7	69.6	69.6	69.6	69.6	69.6	72.2	115.3	149.0	158.1	101.0	70.5	90.5
Copalar + El Carmen													
Copalar - 275 MW	73.7	72.0	72.0	72.0	72.0	72.0	73.6	111 7	148.1	156.9	100.8	72.6	91.4
El Carmen - 70 MW	20.2	16.8	16.8	16.8	16.8	16.8	41.9	62.4	63.7	64.9	38.7	20.9	33.1
TOTAL 345 MW	93.9	88.8	88.8	88.8	88.8	88.8	115.5	174.1	211.8	221.8	139.5	93.5	124.5
Copalar + El Carmen + Paso Real													
Copalar - 275 MW	84.3	82.4	82.4	82.4	82.4	82.4	84.9	105.9	141.1	153.8	102.2	82.5	97.2
El Carmen 70 MW	30.3	28.2	28.2	28.2	28.2	29.0	35.0	47.2	57.5	58.0	39.4	29.3	36.5
Paso Real 50 MW	21.0	21.0	21.0	21.0	21.0	21.0	21.0	22.9	26.2	30.7	21.9	21.1	22.5
TOTAL 395 MW	135.6	131.6	131.6	131.6	131.6	132.4	140.9	176.0	224.8	242.5	163.5	132.9	156.2

** Lower than 50-year average values in Table III.1 because of lower installed capacities.

* Power generation for average year after reaching full development.

reservoir will fill in only a few months of average runoff during one wet season and the Paso Real reservoir will fill in two wet seasons. Consideration can be given to partially filling the Paso Real reservoir during the wet season before it is completed similar to the procedure used for the Copalar High Dam. Additional studies of the effects of reservoir filling at upstream sites on power generation at downstream sites should be made during the feasibility study of each project.

3.8 FLOOD ROUTING STUDIES

Flood routing studies were performed using inflows to the reservoir contained in Table I.15 of Chapter I, Hydrology and Meteorology. The studies were made assuming that the reservoir was at its normal maximum level when the flood occurred. The proposed construction begins with the Copalar Project and proceeds upstream to the Paso Real Project. Each dam, therefore, is subjected to the full natural inflow until the next upstream dam is constructed. The flood routing studies were made in conformity with this construction sequence. A summary of the flood routing study is contained in Table III.3. The maximum surcharged reservoir water surface elevations shown in that table will be reduced for Copalar and El Carmen when all projects are completed, but the Paso Real level will not change. The studies did not utilize fuse plug spillways to reduce the size of the service spillway, but this possibility must be investigated in future studies.

3.9 PRELIMINARY COST ESTIMATES

3.9.1. GENERAL

This section contains the results of preliminary cost estimates for the projects investigated on the Rio Grande de Matagalpa during this phase of the study. The factors affecting these costs; such as accessibility of the damsites, terrain, duration of the dry seaon, availability of local skilled and unskilled labor, local materials and the import of foreign technical personnel, material, equipment and supplies have been given full considerations in determining these costs. No estimate was prepared for the Laguna de Apoyo Project because it was eliminated from consideration for the reasons given in Section 3.3.6.E. The cost estimate for that project contained in the Phase I Report is sufficiently accurate that it can be used until the additional technical investigations for it have been made on which to base a more accurate estimate.

3.9.2 QUANTITY ESTIMATES

Quantity estimates were prepared for the principal features of each of the four projects investigated. These estimates were prepared from the revised project layout drawings which differ from the earlier layouts in many cases. The layouts are contained in the annexes at the end of this chapter. They are prefeasibility standard and were made from topography prepared by the Instituto Geografico Nacional (IGN) at a scale of 1:50,000. All major quantities were estimated in detail and were subsequently subdivided into component parts using standard and accepted methods. This subdivision utilized curves, ratios and percentages derived from recently completed

TABLA III.3

ESTUDIOS DE RASTREO DE CRECIDA
DATOS DE CAUDAL DE CRECIDA

PROYECTO	AFLUENTE MAXIMO				CAUDAL MAXIMO			
	HORA	AFLUENTE AL EMBALSE	CAUDAL DEL VERTEDERO	ELEVACION DEL EMBALSE	NUMERO DEL INTERVALO DE TIEMPO	AFLUENTE AL EMBALSE	CAUDAL DEL VERTEDERO	ELEVACION DEL EMBALSE
		m^3/s	m^3/s	m			m^3/s	m
COPALAR-ALTA	24	15,300	2,000	206.3	17	2,490	2,440	207.4
COPALAR-BAJA	24	15,300	2,570	158.2	16	3,900	3,530	160.3
EL CARMEN	16.5	10,250	4,250	209.5	8	5,270	4,760	210.4
PASO REAL	11	6,200	1,210	271.6	12	1,450	1,300	272.0

* Al comienzo del número del Invertalo de Tiempo

TABLE III.3

FLOOD ROUTING STUDIES
FLOOD DISCHARGE DATA

PROJECT	MAXIMUM INFLOW				MAXIMUM DISCHARGE			
	HOUR	RESERVOIR INFLOW	SPILLWAY DISCHARGE	RESERVOIR ELEVATION	TIME INTERVAL	RESERVOIR INFLOW	SPILLWAY DISCHARGE	RESERVOIR ELEVATION
		m^3/s	m^3/s	m			m^3/s	m
COPALAR-HIGH	24	15,300	2,000	206.3	17	2,490	2,440	207.4
COPALAR-LOW	24	15,300	2,570	158.2	16	3,900	3,530	160.3
EL CARMEN	16.5	10,250	4,250	209.5	8	5,270	4,760	210.4
PASO REAL	11	6,200	1,210	271.6	12	1,450	1,300	272.0

* At beginning of Time Interval

estimates for other projects in Central America of a similar nature, working conditions and magnitude.

3.9.3 UNIT PRICES

Unit prices were estimated for all major civil work cost items. The unit price estimates were obtained by up-dating the estimate prepared in November 1974 for the Phase I investigation, other estimates prepared in late 1973 and early 1974 for two similar hydroelectric projects in Central America and more recent estimates for projects located elsewhere. The earlier estimates were adjusted to include the differences in costs in those countries and Nicaragua for salaries, explosives, fuel, construction equipment, spare parts, materials and supplies. Fuel costs have increased by 250 percent and the costs of explosives, equipment and spare parts have increased by 50 percent since the earlier estimates were made. Investigation in Managua showed that construction equipment costs increased by 37 percent between January 1974 and July 1974 and further increases are anticipated in the near future. Labor rates have also risen rapidly in the recent past. Labor rates higher than those prevaling in populated areas of Nicaragua are anticipated at the remote project sites. All of these cost increases were included in estimating and updating the unit prices.

Unit prices for this phase of investigation were estimated in April 1975 and no escalation has been applied for cost increases since that date. Future costs will largely depend on the same items listed above and the costs of these items are continuing to increase.

The unit prices of major electrical equipment were obtained from manufacturer's catalogs and were verified with the manufacturers, wherever possible. Minor electrical equipment costs were obtained from similar catalogs and verifications. The prices include the cost of freight and installation at the project site. These costs were obtained during May and June 1975.

The unit prices for mechanical equipment were estimated for the major items using recent quotations from manufacturers and from estimating data available from recent project estimates for work of a similar nature and magnitude. They are based on May and June 1975 cost data.

Unit prices include all labor, equipment, materials and supplies required to construct the projects plus the contractor's general expense and profit.

3.9.4 COST ESTIMATE

A. TOTAL CONSTRUCTION COST

The cost estimates contained in this section have been made in accordance with standards and techniques normally used for prefeasibility studies. They reflect as accurate an evaluation of project costs as is possible for the present investigation.

The unit prices discussed above were applied to the estimated quantities to obtain the total costs for most items. A lump sum allowance was used for a few items and was based on recent experience on similar projects.

Access road costs were based on similar work for other projects and was coordinated with costs of roads presently under construction in Nicaragua. Only the costs of principal features are tabulated in the cost table, however, all related costs are included in each feature. A contingency of 10 percent is included in the cost to provide for minor work items which were not estimated and to allow for items that may have been underestimated.

Preliminary cost estimates for the projects investigated during this phase of the study are shown in Table III.4 which is arranged to show the cost of each individual project and the corresponding river basin development alternative. It shows the estimated foreign and domestic currency components and total costs. These costs include all direct costs of construction, contractor's general expense and profit and contingency. The costs of the switchyard at the powerhouse is included with the transmission line and substation in the table. The costs shown in Table III.4 are referred to as total construction costs and do not include interest during construction, land acquisition, resettlement, engineering and ENALUF management.

B. TOTAL CAPITAL COST

The cost items not included in the total construction costs must be added to obtain the total capital costs, or the total investment required to place the project in operation. The total interest during construction was computed on a simplified basis using an eight percent interest rate. Major expenditures are incurred in six years for Copalar High Dam, four years for Copalar Low Dam and three years for El Carmen and Paso Real. Each of the foregoing periods were increased by one-half year to allow for minor expenditures outside of the period of major expenditure. It was assumed that expenditures were made on a straight line basis and therefore average interest can be used to approximate the total interest. This assumption resulted in a total interest equivalent to 26 percent of the total construction costs for Copalar High Dam, 18 percent for Copalar Low Dam and 14 percent for El Carmen and Paso Real.

Many other methods for computing interest could be used; including using the actual expenditures contained in the production costing analysis. However, such an analysis would require many assumptions and detailed consideration of the many different loans for equally as many different purposes and consequently it would be almost as approximate as the method used.

Engineering and administration has been considered as one item and assumed to be 10 percent of total construction costs. This percentage is based on experience for this type of work and data from other project investigations.

TABLA III.4

ESTIMACION DE COSTO PRELIMINAR
COSTO TOTAL DE CONSTRUCCION
$ x 10³

TABLE III.4

PRELIMINARY COST ESTIMATE
TOTAL CONSTRUCTION COST
$ x 10³

PROYECTO / Project	ELEVACION DEL EMBALSE / Reservoir Elevation m		CAMINO DE ACCESO Y OBRAS PRELIMINARES / Access Road and Preliminary Work	OBRAS DE DESVIO / Diversion Work	PRESA Y DIQUES / Dam and Dikes	VERTEDERO / Spillway	TOMA, TUNEL Y TUBERIA DE PRESION / Intake, Tunnel and Penstock	CENTRAL Y TRANSFORMADORES / Powerhouse and Transformers	SUBESTACIONES Y LINEAS DE TRANSMISION / Substations and Transmission Lines	SUBTOTAL	IMPREVISTO / Contingency	TOTAL
			ALTERNATIVA DE DOS PRESAS						TWO DAM ALTERNATIVE			
Copalar	205	L	9,577	5,070	18,458	5,389	3,992	10,102	4,933	57,521	5,752	63,273
		F	4,422	8,278	45,551	13,040	12,276	24,305	19,500	127,372	12,737	140.109
		T	13,999	13,348	64,009	18,429	15,268	34,407	24,433	184,393	18,489	203.382
Paso Real	271	L	2,505	2,062	2,966	2,481	1,136	2,502	154	13,806	1,380	15,186
		F	-	3,320	7,163	5,657	3,103	5,780	844	25,867	2,587	28,454
		T	2,505	5,382	10,129	8,138	4,239	8,282	998	36,673	3,968	43,640
GRAN TOTAL / GRAND TOTAL			16,504	18,730	74,138	26,567	20,507	42,639	25,431	224,516	22,451	247,022
			ALTERNATIVA DE TRES PRESAS						THREE DAM ALTERNATIVE			
Copalar	155	L	5,861	4,283	6,623	4,146	3,018	10,008	4,745	38,684	3,868	42,552
		F	6,336	7,002	16,004	10,045	8,965	24,354	18,748	91,454	9,146	100,600
		T	12,197	11,285	22,627	14,191	11,983	34,362	23,493	130,138	13,014	143,152
El Carmen	205	L	2,414	1,996	1,464	3,883	1,516	3,632	376	15,281	1,528	16,809
		F	1,566	3,172	3,357	9,001	3,832	8,872	1,680	31,480	3,148	34,628
		T	3,980	5,168	4,821	12,884	5,348	12,504	2,056	46,761	4,676	51,437
Paso Real	271	L	2,505	2,062	2,966	2,481	1,136	2,502	154	13,806	1,380	15,186
		F	-	3,320	7,163	5,657	3,103	5,780	844	25,867	2,587	28,454
		T	2,505	5,382	10,129	8,138	4,239	8,282	998	39,673	3,968	43,640
GRAN TOTAL / GRAND TOTAL			18,682	21,835	37,705	35,213	21,570	55,098	26,547	216,522	21,652	238,229

F = Moneda Extranjera
Foreign Currency
L = Moneda Local
Local Currency
T = Total

Land acquisition and resettlement is a relatively minor item in this case because of the remotness and low population density of the project areas. No towns or villages will be inundated by the reservoirs and a limited number of people, houses and temporary buildings are involved. Most of the reservoir areas are ranchland and the ownership and value is uncertain. An average value of C$700 per hectare was assumed. A small allowance is included for resettlement because there are very few permanent residents in the project areas. These assumptions will have to be verified during the feasibility studies of each project.

Total capital costs are shown in Table III.5. It also shows the cost per installed kilowatt and the cost per kilowatt hour based on total construction costs and total capital costs for the time when the projects and alternative developments are in full production. The table is arranged so that it can be easily revised if the use of other values are desired. However, the assumptions made are reasonable and serve to show the importance of these items in considering project costs.

3.10 PROJECT CONSTRUCTION

Construction schedules have been prepared for each project of the two and three dam alternatives without power purchases over interconnection and for the two dam alternative including purchases of power from Honduras and Costa Rica. The three schedules are shown on Annex III-14, Annex III-15 and Annex III-16 respectively. The schedules are preliminary and are subject to revision when additional studies are made. They are intended only to show the general concept of how the work must be performed in order to meet the required power production dates.

The schedules for the two and three dam alternatives without the purchase of power were prepared by beginning with the dates when the power is required on the line and working backwards to the latest dates that the preceeding activities can begin. The time available and allotted for both of these schedules is reasonable, but is very short and allows virtually no time for delays between the feasibility study, contract documents, construction financing and the start and completion of construction. The start and completion of all activities has been related to the wet and dry seasons which are very important considerations in this case. A year's delay in project completion can easily result unless the seasons are considered in the schedule of all work.

The schedule for the two dam alternative with power purchases from Honduras and Costa Rica permits more time for the feasibility study and contract documents, but is otherwise similar to the corresponding schedule without the purchases of power. The Copalar Project is the only generation facilities required for this alternative during the study decade. Although more time is available for the preliminary work than for the other two schedules, it should be started soon to assure completion as required. The longer schedule for the feasibility study and contract documents will result in higher costs for these parts of the work than the other two schedules because of the adverse effects of the rainy season.

TABLE III.5

VALUE OF POWER AND ENERGY
A N D
TOTAL CAPITAL COST *

TWO DAM ALTERNATIVE

ITEM	COPALAR	COPALAR + PASO REAL
CAPACITY AND ENERGY		
Installed Capacity - MW	330	380
Energy per Year - GWH	1,418	1,610
TOTAL CONSTRUCTION COST	203.382	247.022
Cost per KW	616	650
Cost per KWh	14.3	15.3
Interest During Construction	44.744	50.828
Engineering and Administration	20.338	24.702
Land Acquisition and Resettlement	5.208	7.254
TOTAL CAPITAL COST	273.672	329.806
Cost per KW	829	868
Cost per KWh	19.3	20.5

THREE DAM ALTERNATIVE

ITEM	COPALAR	COPALAR + EL CARMEN	COPALAR + EL CARMEN + PASO REAL
CAPACITY AND ENERGY			
Installed Capacity - MW	275	345	395
Energy per Year - GWH	850	1167	1366
TOTAL CONSTRUCTION COST	143.152	194.589	238.229
Cost per KW	521	564	603
Cost per KWh **	16.8	16.7	17.4
Interest During Construction	25.767	32.968	39.052
Engineering and Administration	14.315	19.459	23.823
Land Acquisition and Resettlement	1.954	2.679	4.725
TOTAL CAPITAL COST	185.188	249.695	305.829
Cost per KW	673	724	774
Cost per KWh	21.8	21.4	22.4

* Total Construction Cost and Total Capital in million U.S. Dollars; Cost per KW in U.S. Dollars; Cost per KWh in U.S. Mills.

** Assumes Total Annual Cost equals 10 percent of Total Construction Cost.

3.11 PROJECT ECOLOGY

A thorough environmental impact reconnaissance was performed at the pre-feasibility level by two highly qualified specialists in the ecological and environmental fields. Their report is contained in Appendix B. Their analyses and investigations included Human Ecology, Fauna, Vegetation and Flora, Protection of the Water Supply and Related Environmental Topics. The findings and conclusions are summarized in the following paragraphs.

Human Ecology included assessments of the population affected, public health, archaeology and esthetics. Specific recommendations are contained in the ecological report for each of these topics. Health campaigns are recommended including disease vector control, especially malaria, combined with frequent medical inspection and free prophylaxis. Relocation programs starting with a comprehensive cadastral inventory are recommended. Community development and watershed management should be an integral component of project development. Archaeological patrimony is likely to be located and should be conserved.

The analyses of the Fauna considered mammals, avifauna, reptiles and fish. Species in danger of extinction and destructive practices are given thorough consideration. The practice of cutting trees and vegetation, indiscriminate hunting of animals and the use of dynamite and poisons in fishing should be discontinued. The existing laws regarding these items should be strengthened and rigidly enforced. Habitats for the fauna should be provided in connection with project developments.

The Vegetation and Flora of the project areas were examined. These analyses included the deciduous forests, flora of Nicaragua, species changes, waterweeds, reservoir clearing and watershed preservation and community development. Deciduous forests exist in the project areas. They are susceptible to fires and are being cut and burned; although these conditions are not directly related to project construction. No especially valuable types of vegetation are likely to be threatened as a result of the projects. Very little up-to-date data is available regarding the flora of Nicaragua. It appears unlikely that the projects will threaten any species of plants since none contain a special community or type of vegetation that is not also present in nearby areas or elsewhere. No species changes are anticipated as a result of project construction. However, the possibility of large increases in waterweed should be carefully monitored and proper precautions taken to prevent their increase. The entire reservoir area should be cleared and the marketable timber from this operation should be made available to the displaced people of the project area. No vegetation above the reservoir water levels should be destroyed or damaged in the entire watershed. A reforestation and watershed management program is an essential and worthwhile part of the project.

Protection of the Water Supply is an important aspect of project construction. Basically, this is obtained by an effective and sound watershed management program. Erosion control and the reduction in reservoir sedimentation is an especially valuable contribution of watershed management.

The Related Environmental Topics include transmission lines, substations, Laguna de Apoyo Project and two thermal plants; one in operation and the other under construction. The transmission lines should be located to reduce adverse visual impacts and screening by vegetation should be provided. High growing vegetation should be removed from the rights-of-way and low growing shrubs should be used. Substations should be screened by vegetation or topography or otherwise be made to harmonize with the natural surroundings.

The Laguna de Apoyo Project should receive special cooperation between engineer and landscape architect to preserve the scenic beauty and tourist attraction of the lake. Water quality should be further checked and the effects of lake drawdown further investigated. Transmission lines at this site should be located underground so as not to mar the natural scenery of the area.

The Lago de Managua Thermal Plant is not contaminating the air at the site because of the natural circulation in the area. This plant has very little impact on the lake. The Puerto Somoza Thermal Plant will not contaminate the air in the vicinity because of the natural sea breezes. There are adverse environmental impacts at Puerto Somoza from the cooling water supply and discharge and the oil supply method. The velocity in the cooling water intake channel is high enough that marine plankton, including fish larvae, could be sucked into the pump intakes. Cooling water discharges from the plant to a small estuary through a channel that is to be eroded by the discharge. This will result in large deposits of sediments in the estuary and also raise the temperature. The sediments and increase in temperature will have adverse effects on the estuary. These effects should be eliminated. Precautions must also be made at this site to prevent oil spills and to confine and clean up the oil if a spill occurs.

A more detailed environmental assessment is required during the feasibility study of each project. Careful compliance with the recommendations contained in the report of the Environmental Impact Reconnaissance will ensure that the worst effects can be completely avoided.

3.12 FUTURE INVESTIGATIONS

The analyses made of the hydroelectric projects in the specified study areas during both phases of this investigation are comprehensive and thorough for the amount and reliability of the data available. However, it is still not technically possible to firmly select the river basin development on the Rio Grande de Matagalpa because of the uncertainty regarding topography. This aspect of the projects studied need additional verification using new topography maps presently being prepared. The relationship of the projects studied to the overall hydroelectric development of the nation needs broader and more extensive analyses to firmly establish their role in the power and energy component of the national economy. This investigation has been limited to a small percentage of the total hydroelectric resources of the nation. The following future investigations are among those that should be started soon:

1. Verify the topography of the Rio Grande de Matagalpa and select the development program.

2. Prepare a feasibility study of the Copalar Project using new topography.

3. Perform a survey of all hydroelectric potential and prepare a master expansion plan for Nicaragua.

4. Investigate water resource project for multi-purpose use.

5. Perform an electrical load survey of future expansion plans of government agencies, industry and other consuming sectors.

6. Investigate hydroelectric sites for peak-power installations.

Point 1 and Point 2 above should be performed simultaneously. The results of this analysis shows that an economical project can be constructed at Copalar and that the dam should be constructed to its maximum possible height consistent with topography in order to achieve maximum energy output and economy. The height of dam would be established as the first step in optimizing the Copalar Project.

There are many potential hydroelectric projects in Nicaragua that are in varying stages of developments which range from operating plants to initial recognization of the potential. However, there is no long-range comprehensive plan for coordinating the planning and construction of these projects. The Puerto Somoza Thermal Plant is under construction and will be completed soon. The geothermal project is well advanced and should be completed as expeditiously as possible. The Copalar Project is in the most advanced stage of planning of all possible future projects and the project on the San Juan is next. These two projects should be given priority in conformity with the status of planning assuming that the San Juan Project is found to be technically and economically feasible. General approximations indicate that Rio Tuma may have a good hydroelectric potential. When the discharge of Rio Tuma is added to that of the Rio Grande de Matagalpa at the site known as Tumarin on the latter river the potential may be equal to that of the reach of the river studied during this investigation. Therefore, a prefeasibility study should be made of Rio Tuma and the Tumarin Project similar to that performed under this investigation for the Rio Grande de Matagalpa. The combined potential of the Rio Grande de Matagalpa, Rio San Juan and Rio Tuma should be adequate to supply the energy and power needs of Nicaragua until after the year 2000. However, this possibility needs to be combined into a total coordinated development rather than being studied as individual components. The potential of the downstream reaches of Rio Coco should receive more attention and possibly may be developed in conjunction with Honduras. Other rivers in Nicaragua should also be investigated. When this is all done and made into a comprehensive long-range plan, Nicaragua should be free of her dependence on oil-fired power generation for several decades.

The Tumarin Project, downstream of the confluence of Rio Tuma with Rio Grande de Matagalpa, appears to be an excellent possibility for multipurpose development for power generation and irrigation. That project is

located about as far downstream as possible for the construction of storage dams. The terrain becomes gently rolling downstream of the Tumarin site and appears to be good agricultural land from aerial observations. The discharge at Tumarin might irrigate as much as 200,000 hectares or more after generating 200 or 300 megawatts of power. A thorough investigation may locate other sites equally as attractive for multi-purpose development.

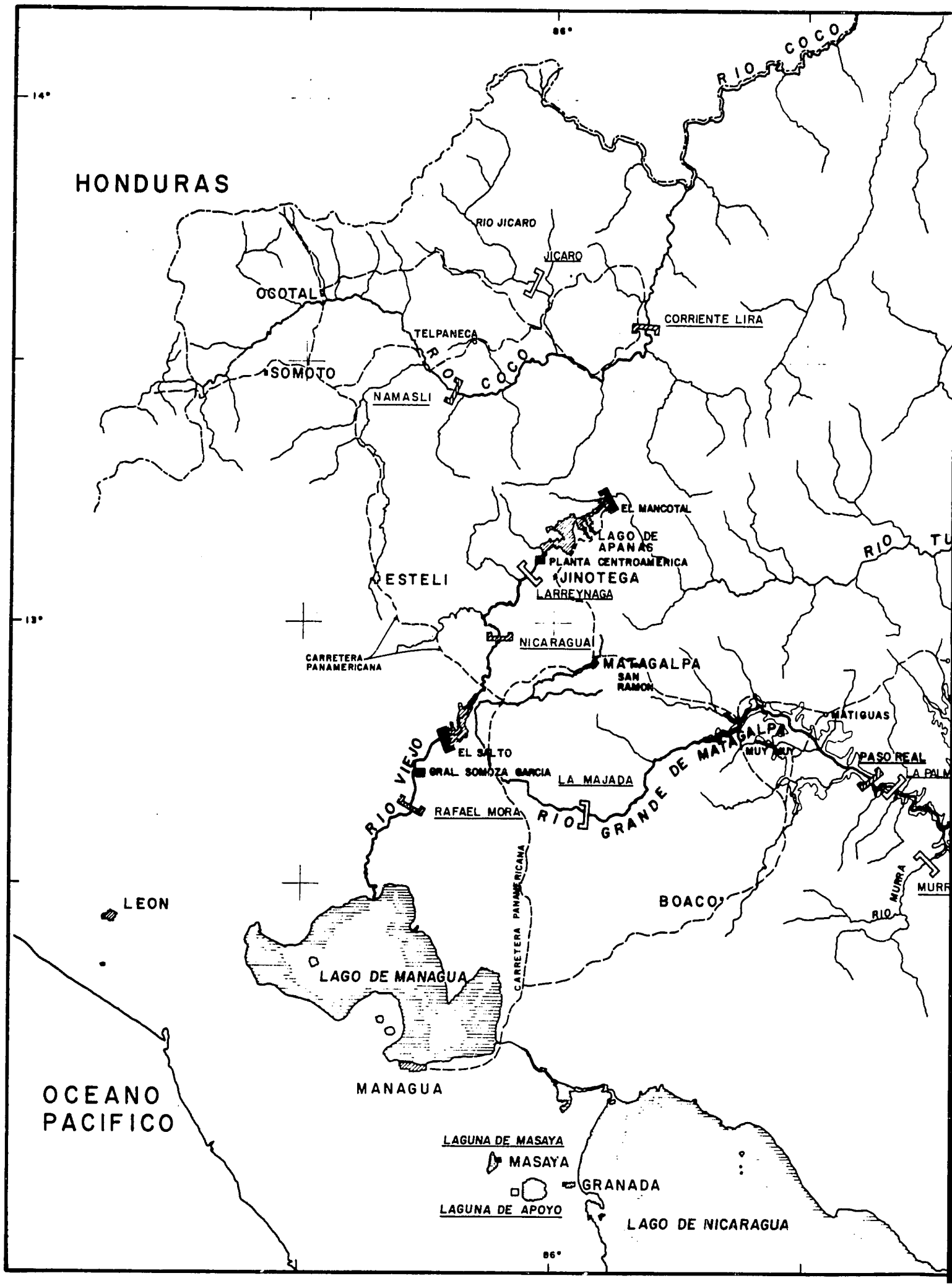
The load forecast performed as part of this investigation was based on economic parameters correlated with historical records and is considered to be reliable. However, this type of projections represents an average condition and follows standard procedures normally used for prefeasibility investigation. The forecast should be further improved by a load survey of future expansion plans of energy consumers. The load survey should be made by contacting industry, government and other planning agencies to ascertain their planned expansion programs. This type of a survey would reveal large future loads that may otherwise not be included.

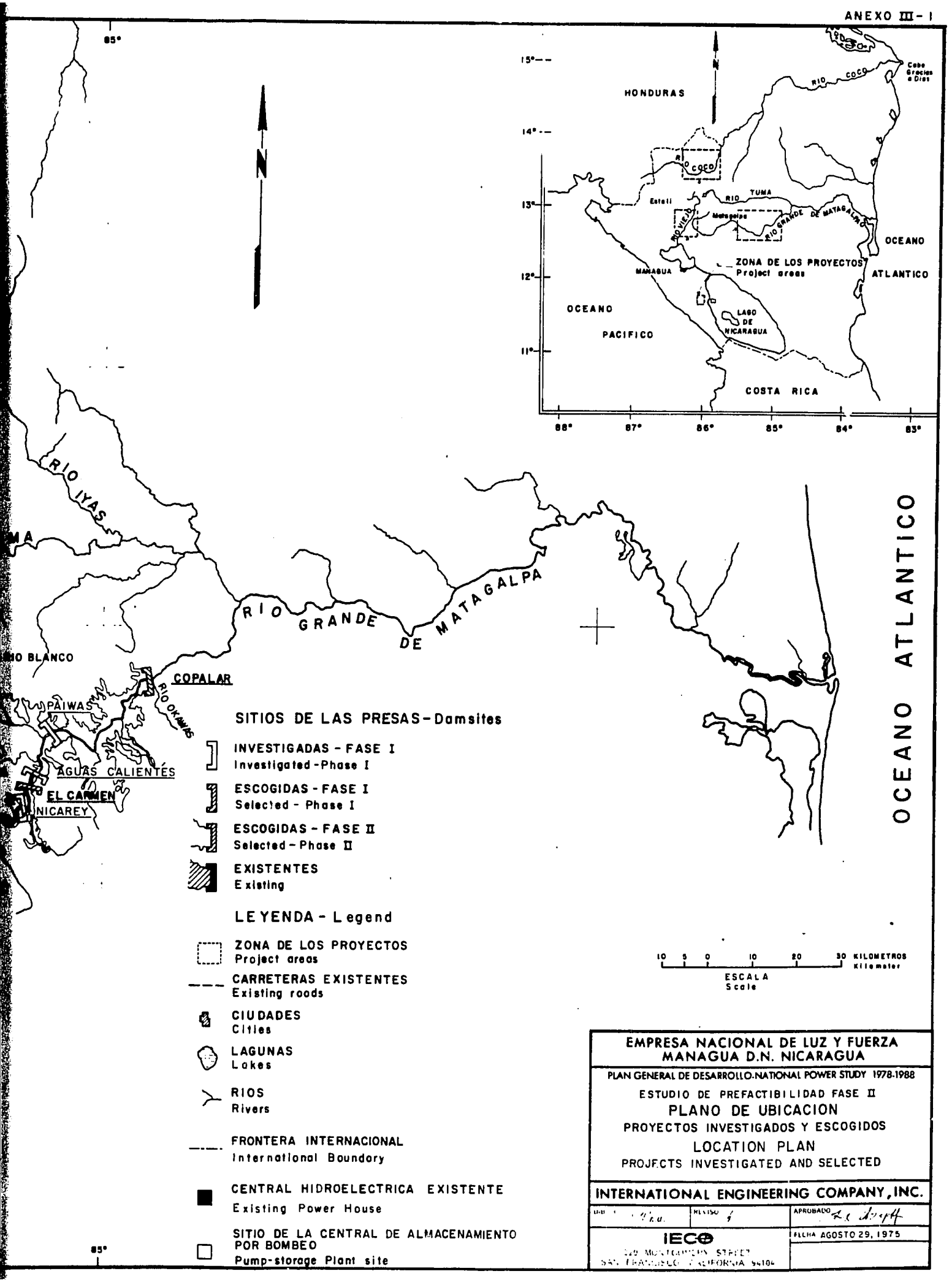
The shape of electrical load curves shows that peak load plants would be of value to Nicaragua; however, there are few peak load facilities in the Republic. The Laguna de Apoyo Project is one possible peak load site, but has several serious technical and environmental problems. Investigations should be made for more suitable sites.

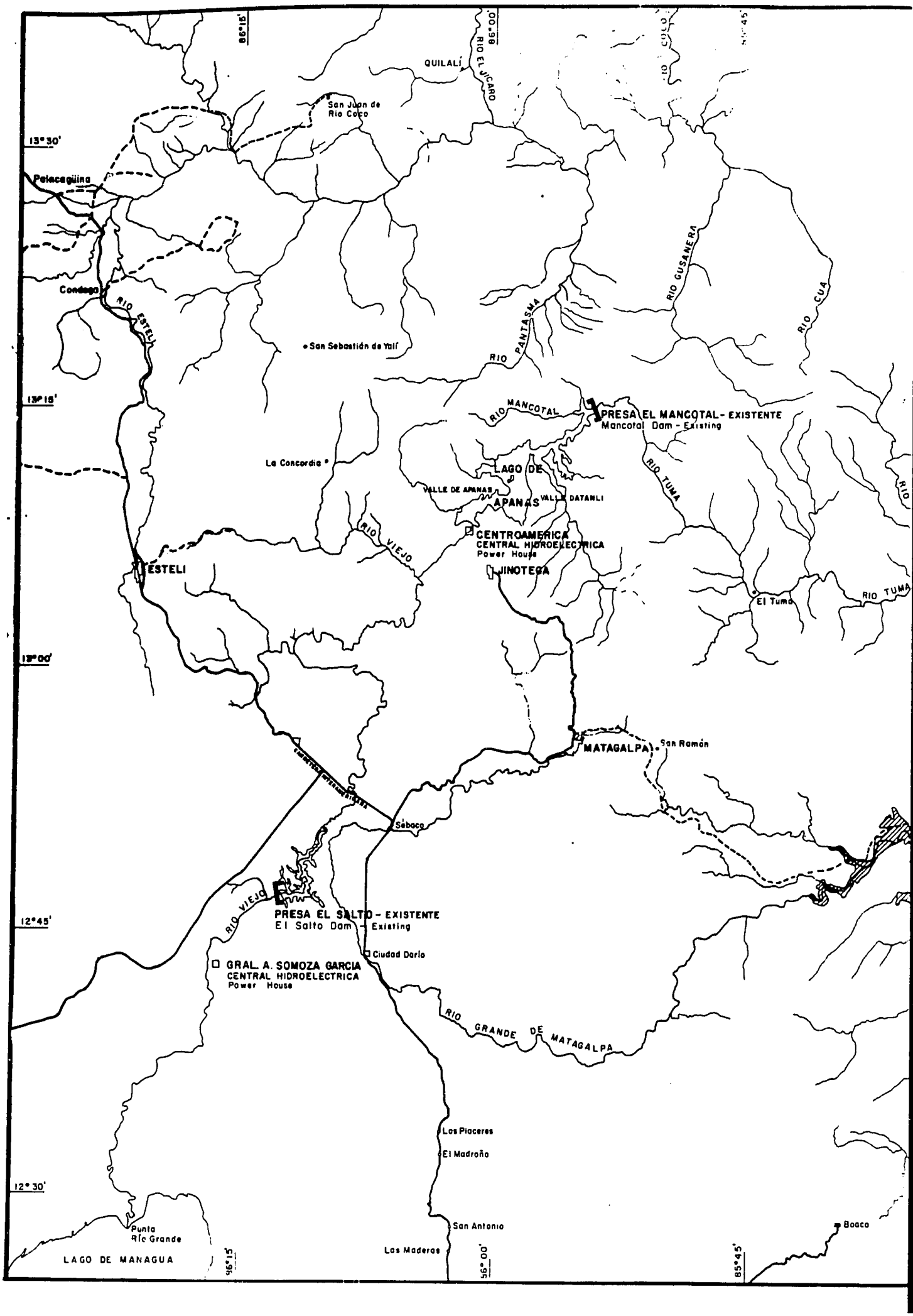
The performance of the studies mentioned above are only a partial list of those that should be given serious consideration. Many of the studies can be made as separate investigations, but it is very important that all of the parts be coordinated into a long-range program so that economical projects are available for construction at the time they are needed.

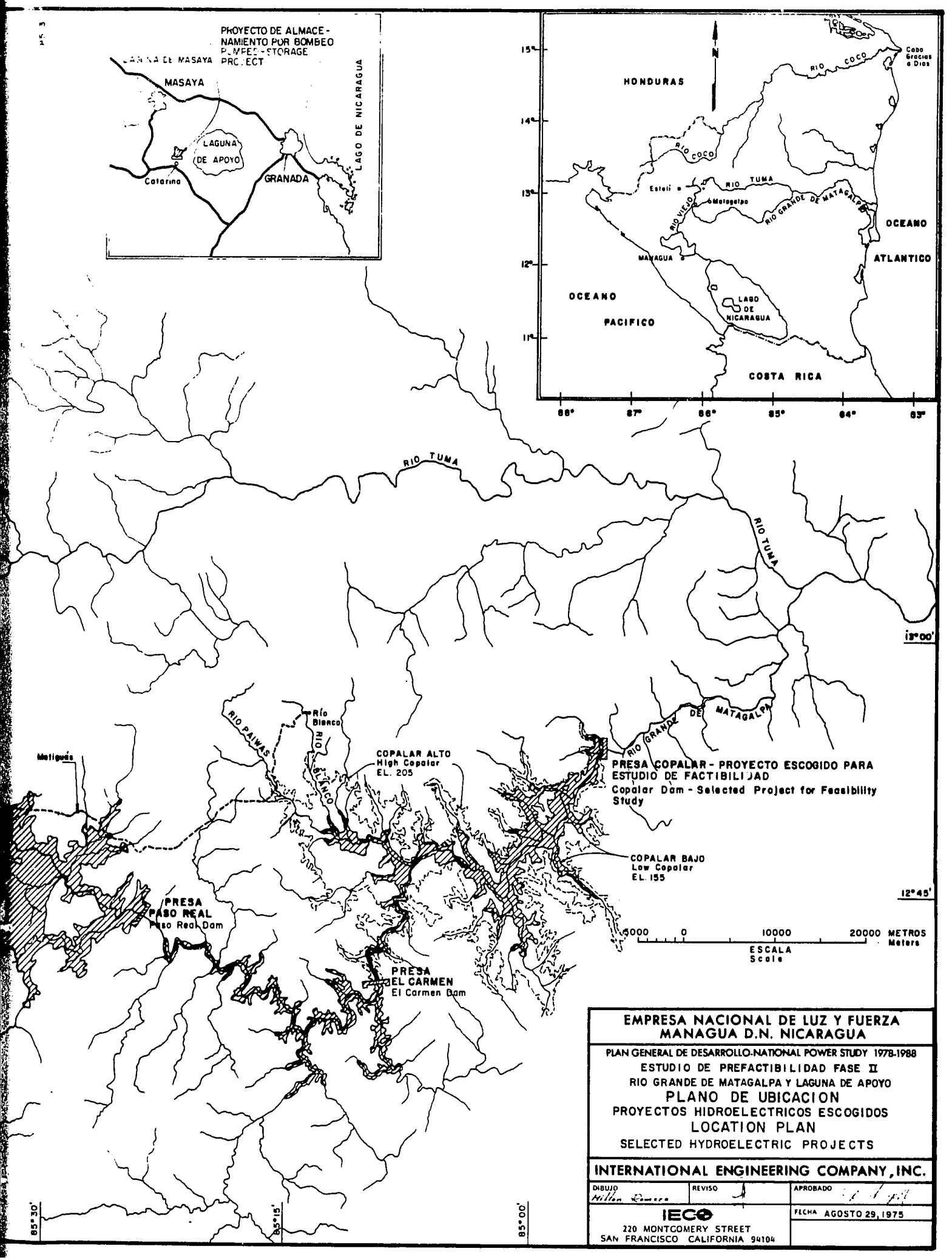
3.13 RECOMMENDATION FOR FEASIBLITY STUDY

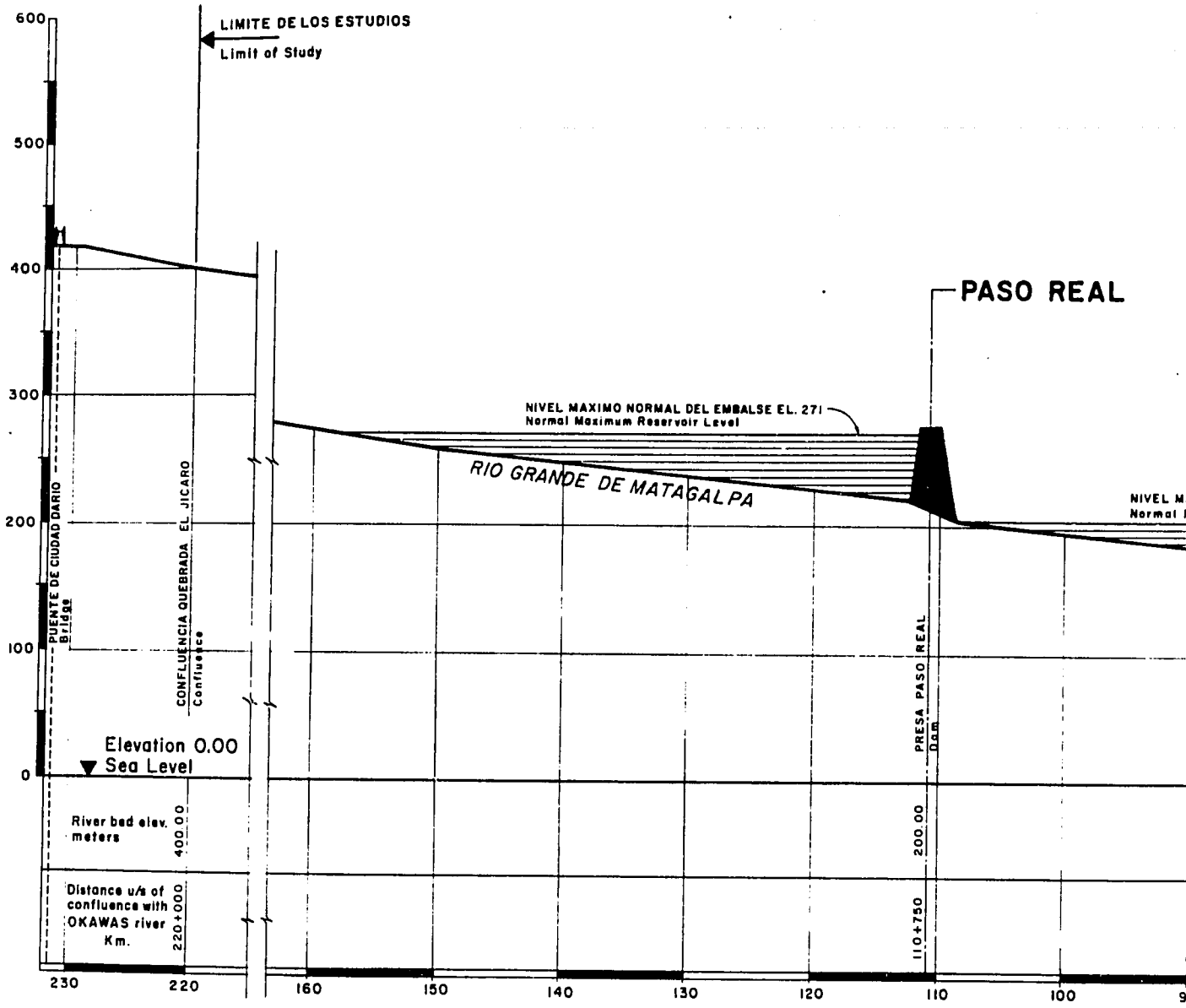
The Copalar Project is definitely the best and most economical of all projects studied. It can be economically constructed either as a high dam in the two dam alternative or as a low dam in the three dam alternative regardless of the results of topography maps under preparation. The time when additional power and energy is required make it imperative that the feasibility study be started at the beginning of the forthcoming dry season so that the required field work can be economically performed. There is a definite possibility of a delay of six months to one year in completing the feasibility study if the field work is not performed during the next dry season. This delay would result in a power and energy shortage in the near future or a needless investment in other types of generation facility. Therefore, the Copalar Project is recommended for study at the feasibility level and performance of the work should be made as expeditiously as possible.

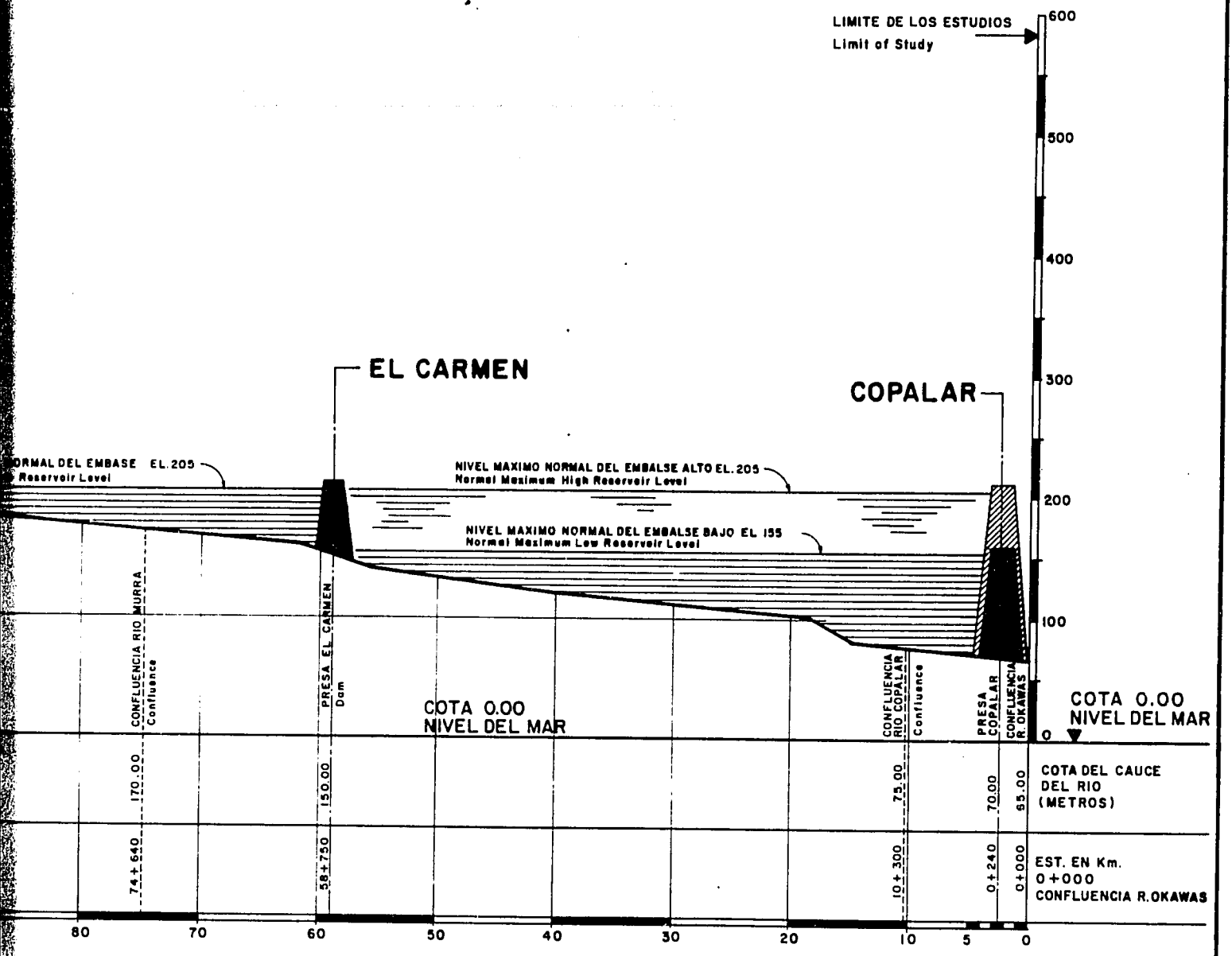

HONDURAS
RIO COCO
RIO JICARO
JICARO
OCOTAL
CORRIENTE LIRA
TELPANECA
SOMOTO
NAMASLI
EL MANCOTAL
LAGO DE APANAS
PLANTA CENTROAMERICA
JINOTEGA
ESTELI
LARREYNAGA
NICARAGUA
CARRETERA PANAMERICANA
MATAGALPA
SAN RAMON
MATIGUAS
EL SALTO
GRAL. SOMOZA GARCIA
LA MAJADA
PASO REAL
RAFAEL MORA
RIO VIEJO
RIO GRANDE DE MATAGALPA
LEON
BOACO
LAGO DE MANAGUA
CARRETERA PANAMERICANA
MANAGUA
OCEANO PACIFICO
LAGUNA DE MASAYA
MASAYA
GRANADA
LAGUNA DE APOYO
LAGO DE NICARAGUA


HONDURAS
RIO COCO
Cabo Gracias a Dios
RIO TUMA
Estelí
Matagalpa
RIO GRANDE DE MATAGALPA
OCEANO ATLANTICO
ZONA DE LOS PROYECTOS
Project areas
MANAGUA
LAGO DE NICARAGUA
OCEANO PACIFICO
COSTA RICA
15°
14°
13°
12°
11°
88°
87°
86°
85°
84°
83°
RIO IYAS
RIO GRANDE DE MATAGALPA
COPALAR
PAIWAS
RIO OKAWAS
AGUAS CALIENTES
EL CARMEN
NICAREY
OCEANO ATLANTICO
SITIOS DE LAS PRESAS - Damsites
INVESTIGADAS - FASE I
Investigated - Phase I
ESCOGIDAS - FASE I
Selected - Phase I
ESCOGIDAS - FASE II
Selected - Phase II
EXISTENTES
Existing
LEYENDA - Legend
ZONA DE LOS PROYECTOS
Project areas
CARRETERAS EXISTENTES
Existing roads
CIUDADES
Cities
LAGUNAS
Lakes
RIOS
Rivers
FRONTERA INTERNACIONAL
International Boundary
CENTRAL HIDROELECTRICA EXISTENTE
Existing Power House
SITIO DE LA CENTRAL DE ALMACENAMIENTO POR BOMBEO
Pump-storage Plant site
10 5 0 10 20 30 KILOMETROS
Kilometer
ESCALA
Scale
EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
PLANO DE UBICACION
PROYECTOS INVESTIGADOS Y ESCOGIDOS
LOCATION PLAN
PROJECTS INVESTIGATED AND SELECTED
INTERNATIONAL ENGINEERING COMPANY, INC.
REVISO
APROBADO
FECHA AGOSTO 29, 1975
IECO
SAN FRANCISCO, CALIFORNIA 94104


86°15'
86°00'
85°45'
13°30'
13°15'
13°00'
12°45'
12°30'
QUILALÍ
RIO EL JÍCARO
RIO COCO
San Juan de Río Coco
Palacagüina
Condega
RIO ESTELI
San Sebastián de Yalí
RIO PANTASMA
RIO GUSANERA
RIO CUA
RIO MANCOTAL
PRESA EL MANCOTAL - EXISTENTE
Mancotal Dam - Existing
La Concordia
LAGO DE APANAS
VALLE DE APANAS
VALLE DATANLI
RIO TUMA
RIO VIEJO
CENTROAMERICA
CENTRAL HIDROELECTRICA
Power House
JINOTEGA
ESTELI
El Tuma
RIO TUMA
MATAGALPA
San Ramón
Sébaco
PRESA EL SALTO - EXISTENTE
El Salto Dam - Existing
Ciudad Darío
GRAL. A. SOMOZA GARCIA
CENTRAL HIDROELECTRICA
Power House
RIO GRANDE DE MATAGALPA
Los Placeres
El Madroño
San Antonio
Boaco
Punta Río Grande
LAGO DE MANAGUA
Las Maderas


PROYECTO DE ALMACENAMIENTO POR BOMBEO
PUMPED-STORAGE PROJECT
LAGUNA DE MASAYA
MASAYA
LAGUNA DE APOYO
Catarina
GRANADA
LAGO DE NICARAGUA
HONDURAS
RIO COCO
Cabo Gracias a Dios
Estelí
RIO TUMA
Matagalpa
RIO VIEJO
RIO GRANDE DE MATAGALPA
OCEANO ATLANTICO
MANAGUA
LAGO DE NICARAGUA
OCEANO PACIFICO
COSTA RICA
86°
87°
86°
85°
84°
83°
15°
14°
13°
12°
11°
RIO TUMA
RIO TUMA
13°00'
RIO PAIWAS
Río Blanco
RIO BLANCO
COPALAR ALTO
High Copalar
EL. 205
RIO GRANDE DE MATAGALPA
PRESA COPALAR - PROYECTO ESCOGIDO PARA ESTUDIO DE FACTIBILIDAD
Copalar Dam - Selected Project for Feasibility Study
Matiguás
COPALAR BAJO
Low Copalar
EL. 155
12°45'
PRESA PASO REAL
Paso Real Dam
5000 0 10000 20000 METROS
Meters
ESCALA
Scale
PRESA EL CARMEN
El Carmen Dam
85°30'
85°15'
85°00'
EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA Y LAGUNA DE APOYO
PLANO DE UBICACION
PROYECTOS HIDROELECTRICOS ESCOGIDOS
LOCATION PLAN
SELECTED HYDROELECTRIC PROJECTS
INTERNATIONAL ENGINEERING COMPANY, INC.
DIBUJO
REVISO
APROBADO
IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104
FECHA AGOSTO 29, 1975


LIMITE DE LOS ESTUDIOS
Limit of Study
PASO REAL
NIVEL MAXIMO NORMAL DEL EMBALSE EL. 271
Normal Maximum Reservoir Level
RIO GRANDE DE MATAGALPA
PUENTE DE CIUDAD DARIO
Bridge
CONFLUENCIA QUEBRADA EL JICARO
Confluence
PRESA PASO REAL
Dam
Elevation 0.00
Sea Level
River bed elev. meters
400.00
200.00
Distance u/s of confluence with OKAWAS river Km.
220+000
110+750
600
500
400
300
200
100
0
230
220
160
150
140
130
120
110
100



EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

PERFIL LONGITUDINAL
LONGITUDINAL PROFILE

INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO	REVISO	APROBADO
MILTON ROMERO		
IEC 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975

SUBESTACION EN LA CIMA DE LA MONTAÑA
Switchyard on Top of Hill

CARRETERA DE ACCESO
Access Road

EJE DE LA PRESA
Dam Axis

TUNEL DE DESVIO
Y GENERACION
Diversion and Power Tunnel

OBRA DE TOMA
Intake

PORTAL
Portal

CENTRAL
Powerhouse

CORONA DE LA PRESA EL.275
Dam Crest

ATAGUIA
Cofferdam

TRAMPOLIN
Flip Bucket

CANAL DE DESCARGA-Chute

RIO GRANDE DE MATAGALPA

RIO GRANDE MATAGALPA

EL.235
EL.205
EL.218
EL.204
EL.214
EL.254

2.1:1
1.9:1

A
B
C
D
E

320
310
300
290
280
270
260
250
240
230
220
210

NIVEL MAXIMO DURANTE CRECIDA EL.272
CAUDAL MAXIMO = 1,300 m³/s
Maximum Flood Level El. 272
Maximum Discharge = 1,300 m³/s

VERTEDERO EL. 275
Spillway

EL.254

CORONA EL.263
Crest

TERRENO ORIGINAL
Original Ground

CANAL DE DESCARGA
Chute

EL. 220

TRAMPOLIN
Flip Bucket

SECCION C-C
SECTION C-C

OBRA DE TOMA EL.275
Intake

REJILLA
Trashrack

TERRENO ORIGINAL
Original Ground

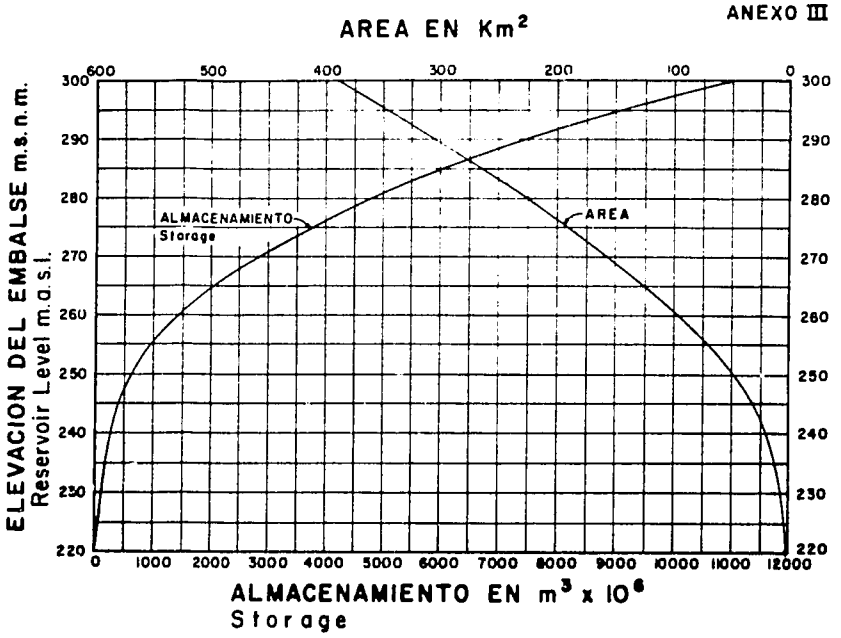
EL. 235

EL. 205

CAMA
Valve

TUN
Diver

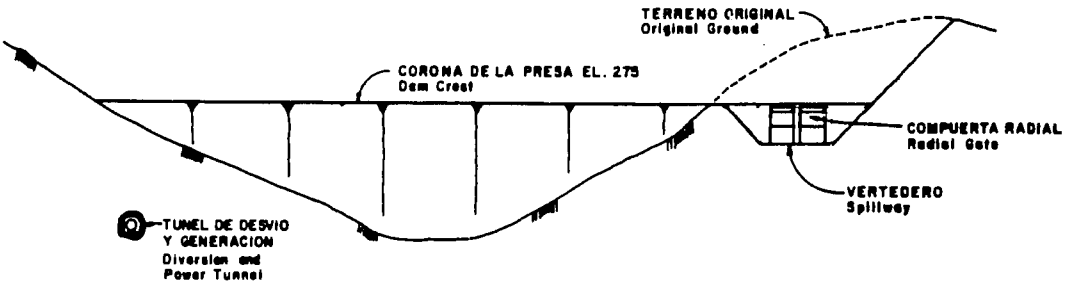
NIVEL MINIMO DEL EMBALSE Minimum Reservoir Level			
ALTERNATIVA DE DOS PRESAS-2 Dam Alternative			
PROYECTO - Project	EL. A		
	COPALAR	PASO REAL	
COPALAR	173	-	
COPALAR + PASO REAL	175	240	
ALTERNATIVA DE TRES PRESAS-3 Dam Alternative			
PROYECTO - Project	EL. A		
	COPALAR	EL CARMEN	PASO REAL
OPALAR	122	-	-
OPALAR + EL CARMEN	126	182	-
PALAR+EL CARMEN+PASO REAL	134	185	240



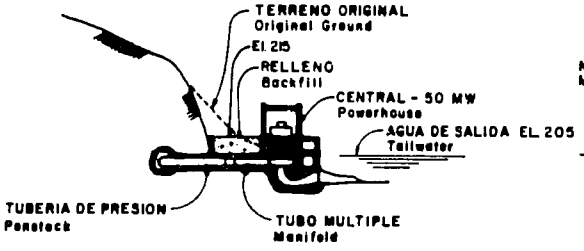
A COPALAR Y BOACO
To Copalar and Boaco

RETERA DE ACCESO
ess Road

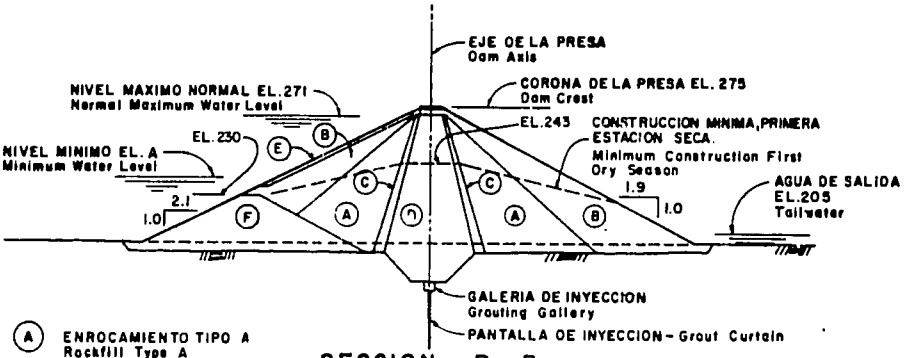
DE DE
PA



SECCION A-A
SECTION A-A



SECCION E-E
SECTION E-E



SECCION B-B
SECCION B-B

(A) ENROCAMIENTO TIPO A
Rockfill Type A

(B) ENROCAMIENTO TIPO B
Rockfill Type B

(C) FILTRO - Filter

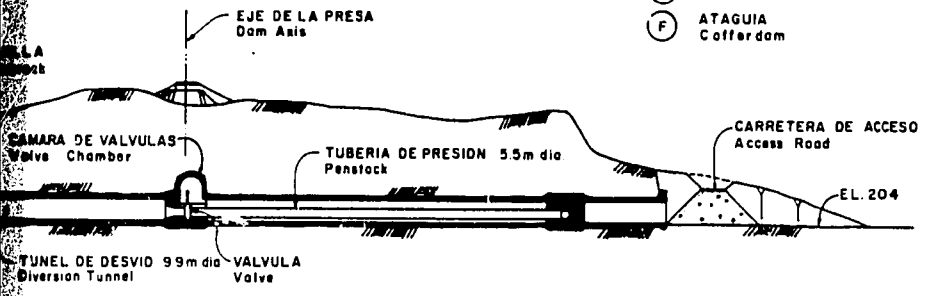
(D) NUCLEO - Core

(E) RIPRAP

(F) ATAGUIA
Cofferdam

NOTA:
EL PROYECTO PASO REAL ES IDENTICO PARA LAS ALTERNATIVAS DE DOS Y TRES PRESAS
Paso Real Project is identical for the two and tree dam alternatives

20 0 50 100 METROS
Meters
ESCALA
Scale



SECCION D-D
SECTION D-D

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

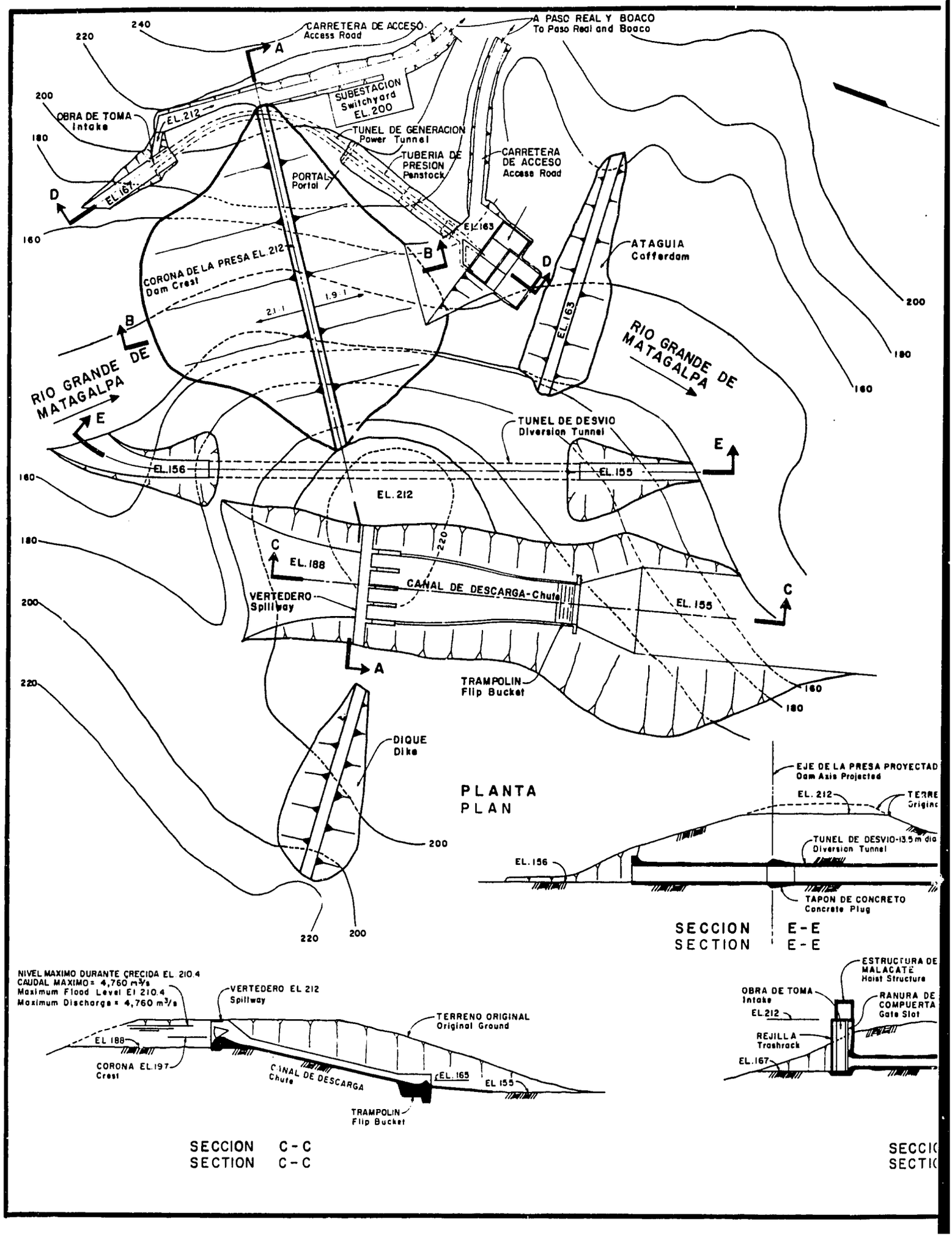
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

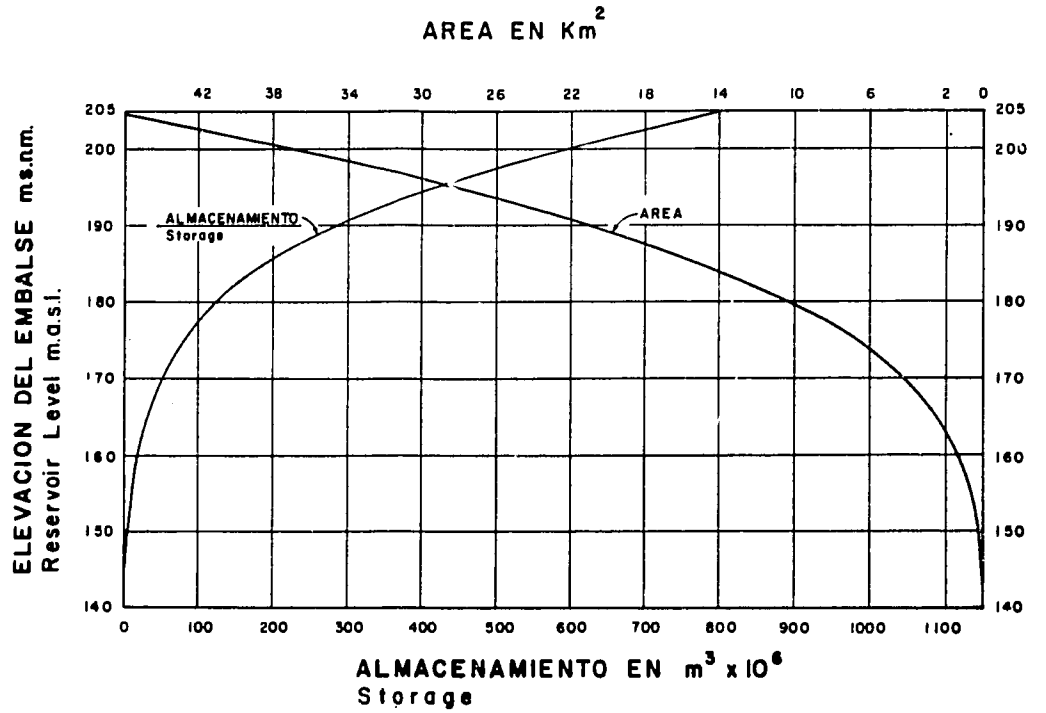
PROYECTO PASO REAL

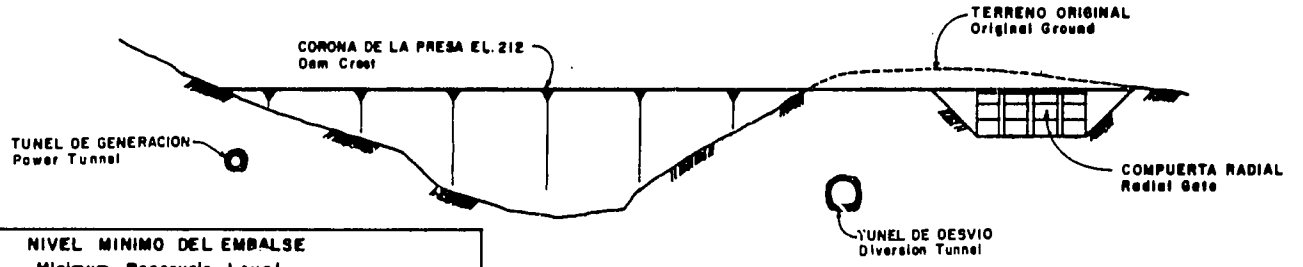
PLANO GENERAL
GENERAL PLAN

INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO	REVISO	APROBADO
MILTON ROMERO		
IEC 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975

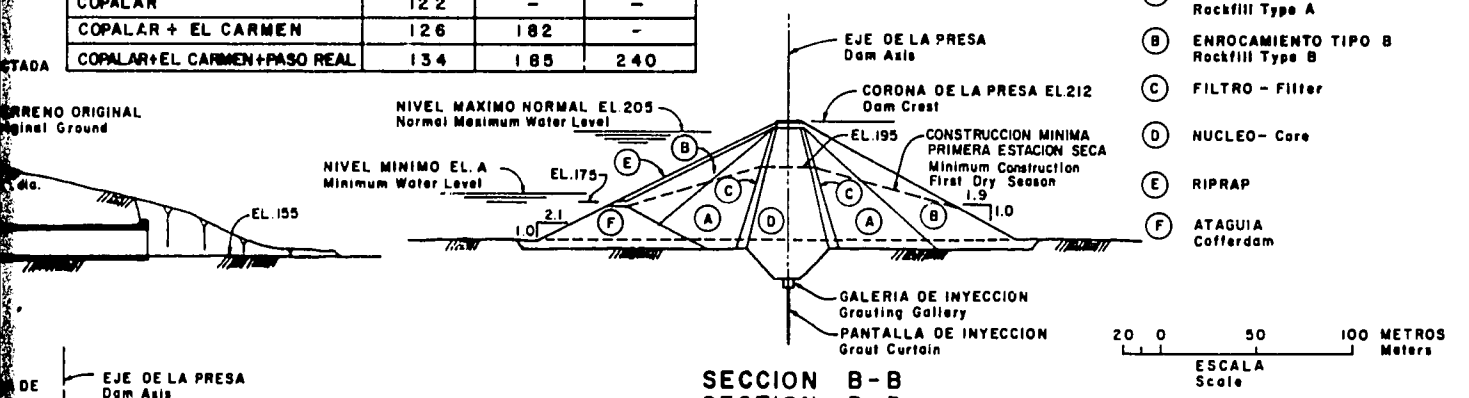

CARRETERA DE ACCESO
Access Road
A PASO REAL Y BOACO
To Paso Real and Boaco
SUBESTACION
Switchyard
EL. 200
OBRA DE TOMA
Intake
EL. 212
EL. 167
TUNEL DE GENERACION
Power Tunnel
TUBERIA DE PRESION
Penstock
PORTAL
Portal
CARRETERA DE ACCESO
Access Road
EL. 163
ATAGUIA
Cofferdam
CORONA DE LA PRESA EL. 212
Dam Crest
1.9 : 1
2.1 : 1
RIO GRANDE DE MATAGALPA
TUNEL DE DESVIO
Diversion Tunnel
EL. 156
EL. 155
EL. 212
EL. 188
CANAL DE DESCARGA-Chute
VERTEDERO
Spillway
TRAMPOLIN
Flip Bucket
DIQUE
Dike
PLANTA
PLAN
EJE DE LA PRESA PROYECTADA
Dam Axis Projected
EL. 212
TERRE
Originc
TUNEL DE DESVIO-13.5 m dia
Diversion Tunnel
EL. 156
TAPON DE CONCRETO
Concrete Plug
SECCION E-E
SECTION E-E
NIVEL MAXIMO DURANTE CRECIDA EL. 210.4
CAUDAL MAXIMO = 4,760 m³/s
Maximum Flood Level El 210.4
Maximum Discharge = 4,760 m³/s
VERTEDERO EL 212
Spillway
TERRENO ORIGINAL
Original Ground
EL 188
CORONA EL.197
Crest
CANAL DE DESCARGA
Chute
EL. 165
EL 155
TRAMPOLIN
Flip Bucket
SECCION C-C
SECTION C-C
ESTRUCTURA DE MALACATE
Hoist Structure
OBRA DE TOMA
Intake
EL.212
RANURA DE COMPUERTA
Gate Slot
REJILLA
Trashrack
EL.167
SECCIO
SECTIO



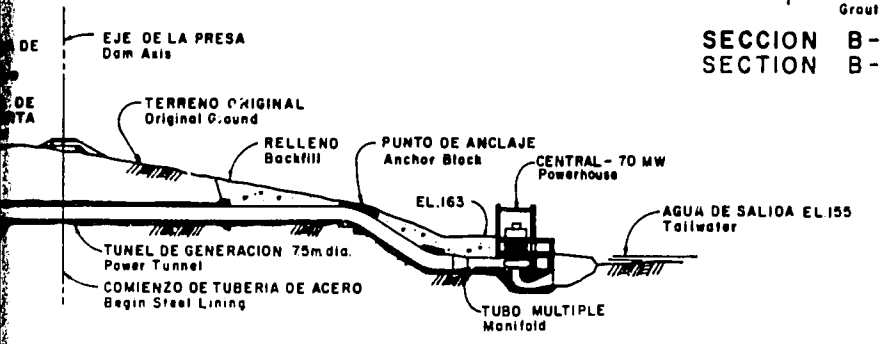


NIVEL MINIMO DEL EMBALSE Minimum Reservoir Level			
PROYECTO - Project	EL. A		
	COPALAR	EL CARMEN	PASO REAL
COPALAR	122	-	-
COPALAR + EL CARMEN	126	182	-
COPALAR+EL CARMEN+PASO REAL	134	185	240

SECCION A-A
SECTION A-A



SECCION B-B
SECTION B-B



CION D-D
TION D-D

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

PROYECTO EL CARMEN

PLANO GENERAL
GENERAL PLAN

INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO F. JAVIER E.M. MILTON R.G. | REVISO | APROBADO

IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104

FECHA AGOSTO 29, 1975

NIVEL M Minimum
PROYECTO - Project
COPALAR
COPALAR + EL CARMEN
COPALAR+EL CARMEN+PASO R

SUBESTACION Switchyard EL. 180

A PASO REAL Y BOACO To Paso Real and Boaco

CARRETERA DE ACCESO Access Road

VERTEDERO Spillway

TUNEL DE GENERACION Power Tunnel

CANAL DE DESCARGA Chute

TRAMPOLIN Flip Bucket

PORTAL Portal

OBRA DE TOMA Intake

EL. 138 · EL. 104 · EL. 162 · EL. 70 · EL. 83

TUBERIA DE PRESION Penstock

ATAGUIA Cofferdam

RIO GRANDE MATAGALPA

CORONA DE LA PRESA Dam Crest EL. 162

CENTRAL Powerhouse

CARRETERA DE ACCESO Access Road

TUNEL DE DESVIO Diversion Tunnel

RIO GRANDE DE MAGALPA

PLANTA
PLAN

TERRENO ORIGINAL Natural Ground

COMPUERTA RADIAL Radial Gate

VERTEDERO Spillway

TUNEL DE GENERACION Power Tunnel

NIVEL MAXIMO DURANTE CRECIDA EL 160.3
CAUDAL MAXIMO = 3,530 m³/s
Maximum Flood Level El. 160.3
Maximum Discharge = 3,530 m³/s

VERTEDERO EL. 162 Spillway

TERRENO ORIGINAL Original Ground

EL. 138

CANAL DE DESCARGA Chute

CORONA EL 147 Crest

EL. 105

TRAMPOLIN Flip Bucket

EL 70

SECCION C-C
SECTION C-C

ESTRUCTURA DE MALACATE Hoist Structure

EL. 162

OBRA DE TOMA Intake

RANURA DE COMPUERTA Gate Slot

EL. 104

REJILLA Trashrack

EJE DE LA PRE Dam Axis

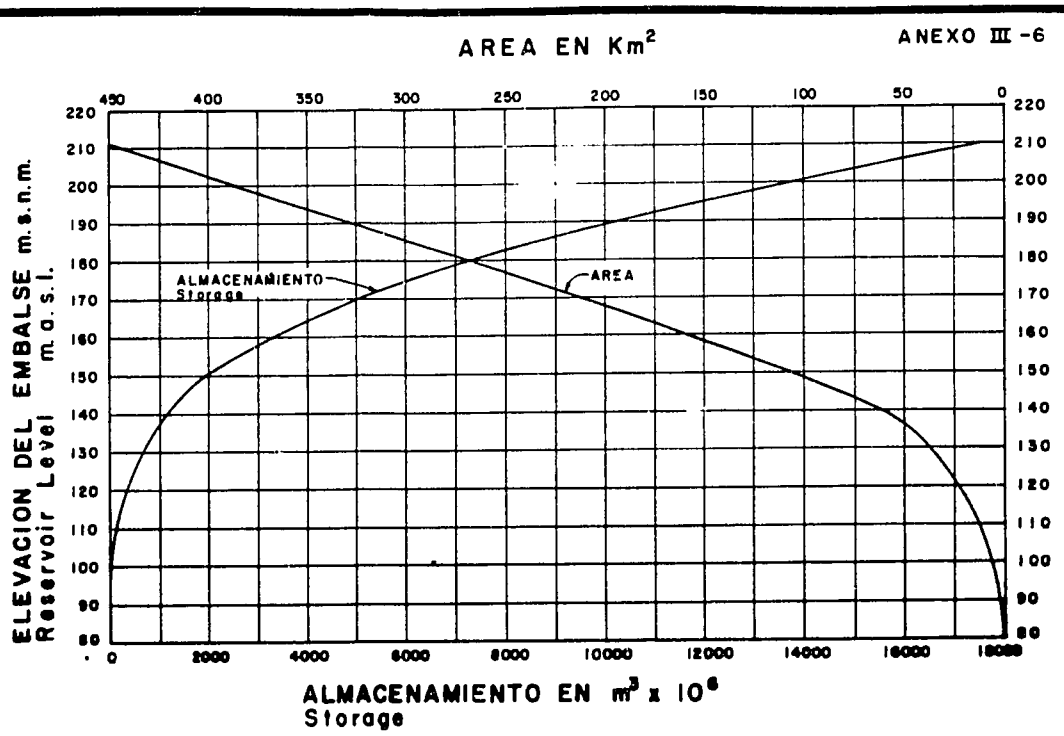
TUNEL DE GENERA Power Tunnel

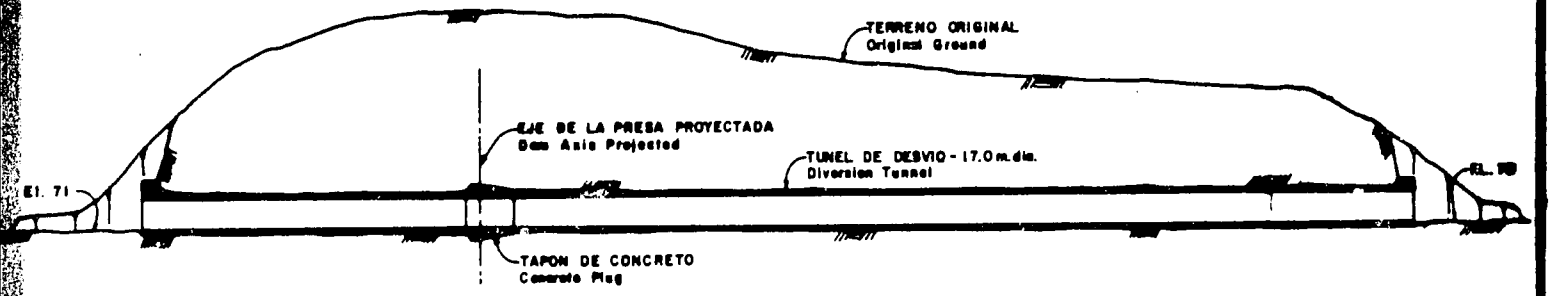
COMIENZO DE LA DE ACERO Begin Steel Lin

SECCION
SECTION

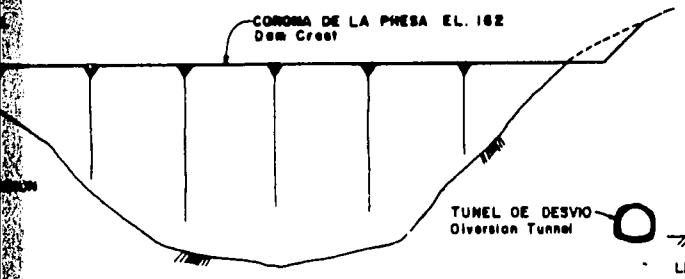
MINIMO DEL EMBALSE m Reservoir Level		
	EL. A	
	COPALAR	EL CARMEN	PASO REAL
	122	—	—
	126	182	—
REAL	134	185	240

ANEXO III -6

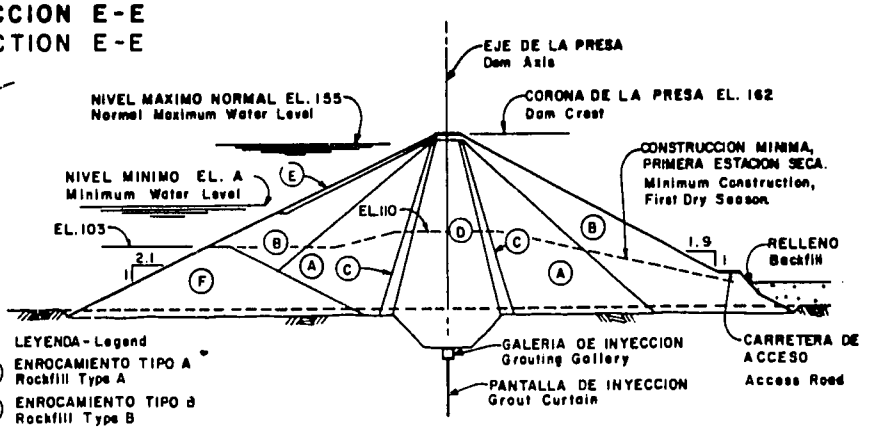




SECCION E-E
SECTION E-E



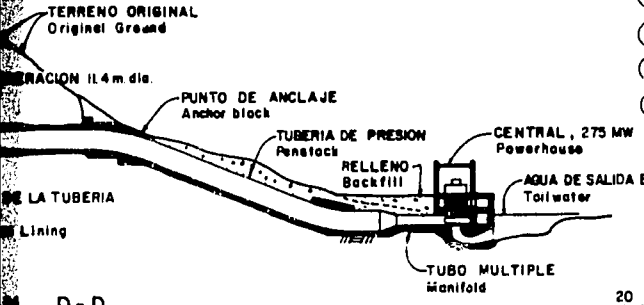
SECCION A-A
SECTION A-A



LEYENDA - Legend

- (A) ENROCAMIENTO TIPO A Rockfill Type A
- (B) ENROCAMIENTO TIPO B Rockfill Type B
- (C) FILTRO - Filter
- (D) NUCLEO - Core
- (E) RIPRAP
- (F) ATAGUIA Cofferdam

SECCION B-B
SECTION B-B



D-D
D-D

20 0 50 100 METROS
Meters
ESCALA
Scale

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988

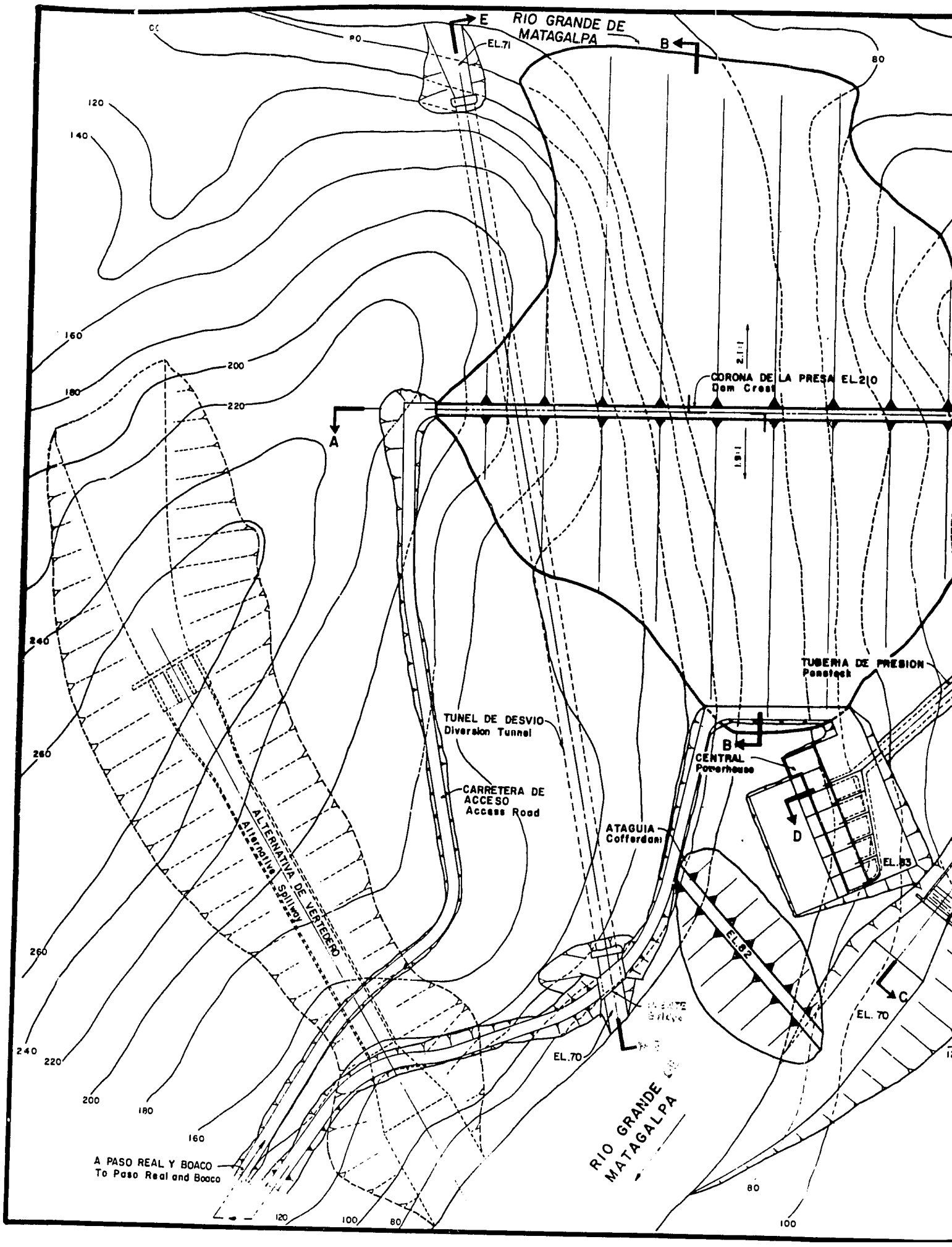
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

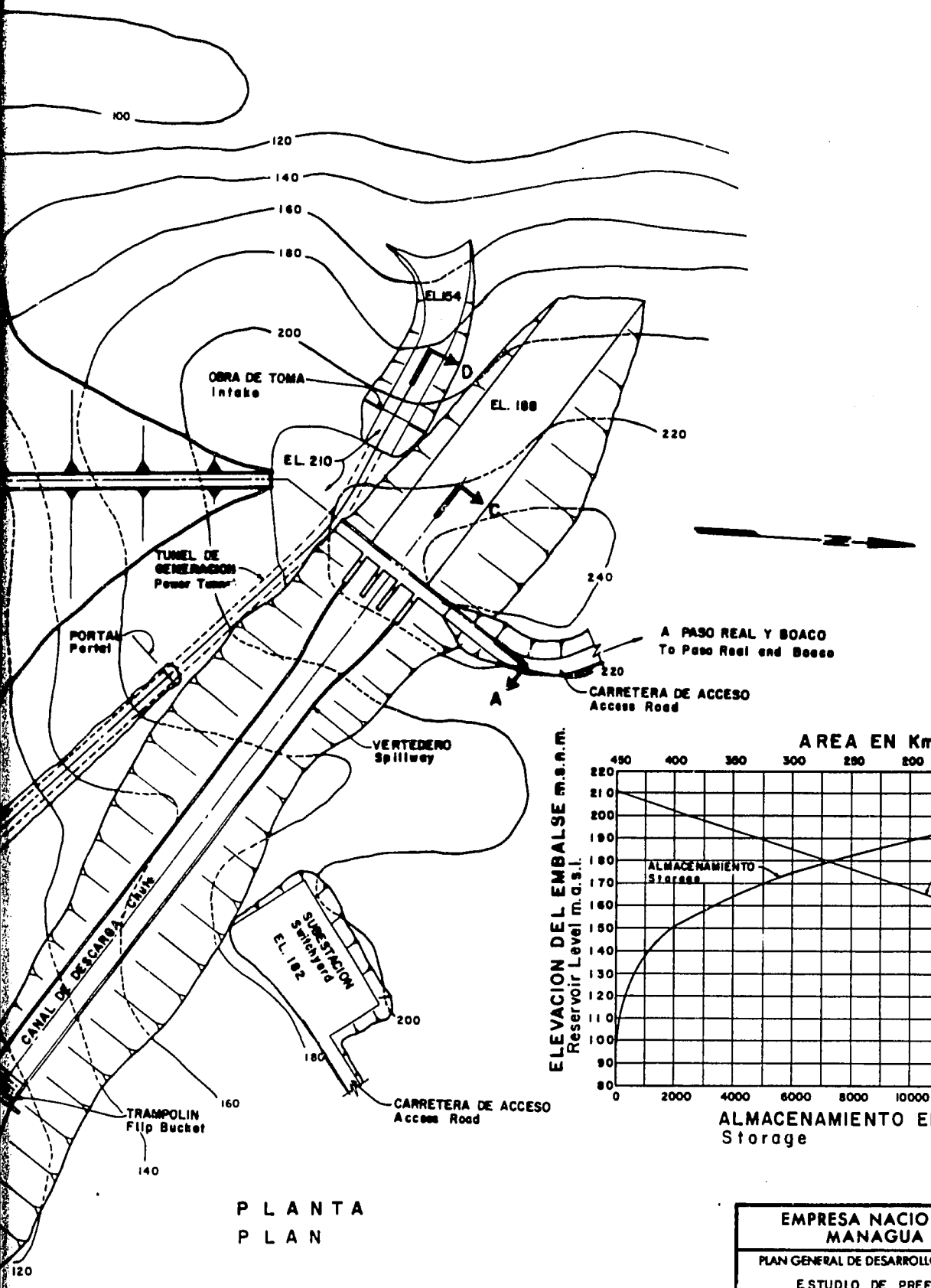
PROYECTO COPALAR

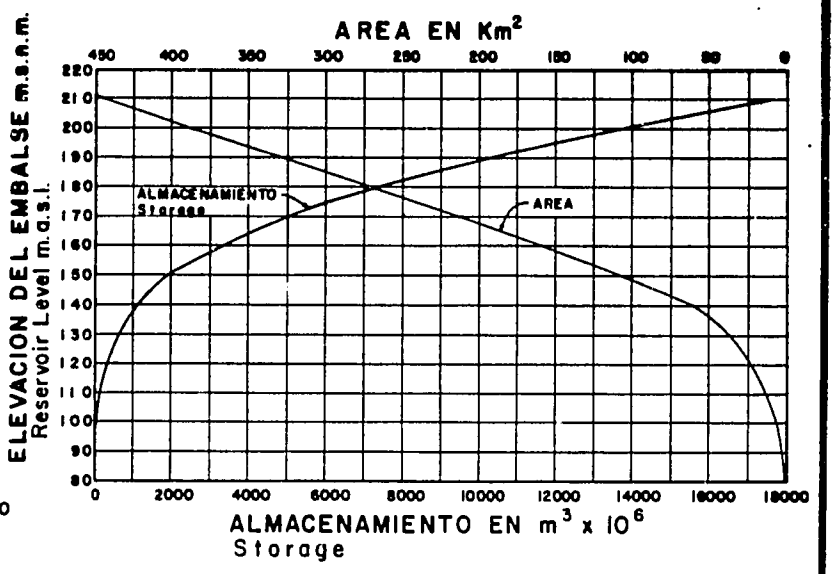
PLANO GENERAL, PRESA BAJA
GENERAL PLAN, LOW DAM

INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO F. JAVIER E.M.	REVISO	APROBADO
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975


RIO GRANDE DE MATAGALPA
E
B
EL.71
80
120
140
160
180
200
220
240
260
CORONA DE LA PRESA EL.210
Dam Crest
2:1:1
1.5:1
A
TUBERIA DE PRESION
Penstock
TUNEL DE DESVIO
Diversion Tunnel
CENTRAL
Powerhouse
D
CARRETERA DE ACCESO
Access Road
ATAGUIA
Cofferdam
ALTERNATIVA DE VERTEDERO
Alternative Spillway
EL.83
EL.82
C
EL. 70
EL.70
RIO GRANDE DE MATAGALPA
A PASO REAL Y BOACO
To Paso Real and Boaco
100
120





P L A N T A

P L A N

20 0 50 100 METROS
Meters

ESCALA
Scale

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988

ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

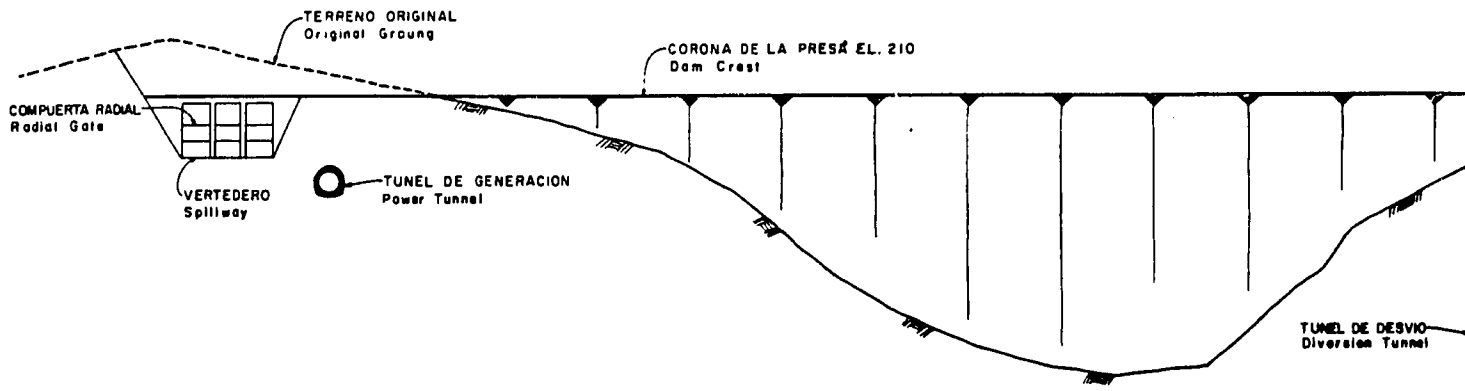
PROYECTO COPALAR

PLANO GENERAL, PRESA ALTA- PLANTA
GENERAL PLAN, HIGH DAM- PLAN

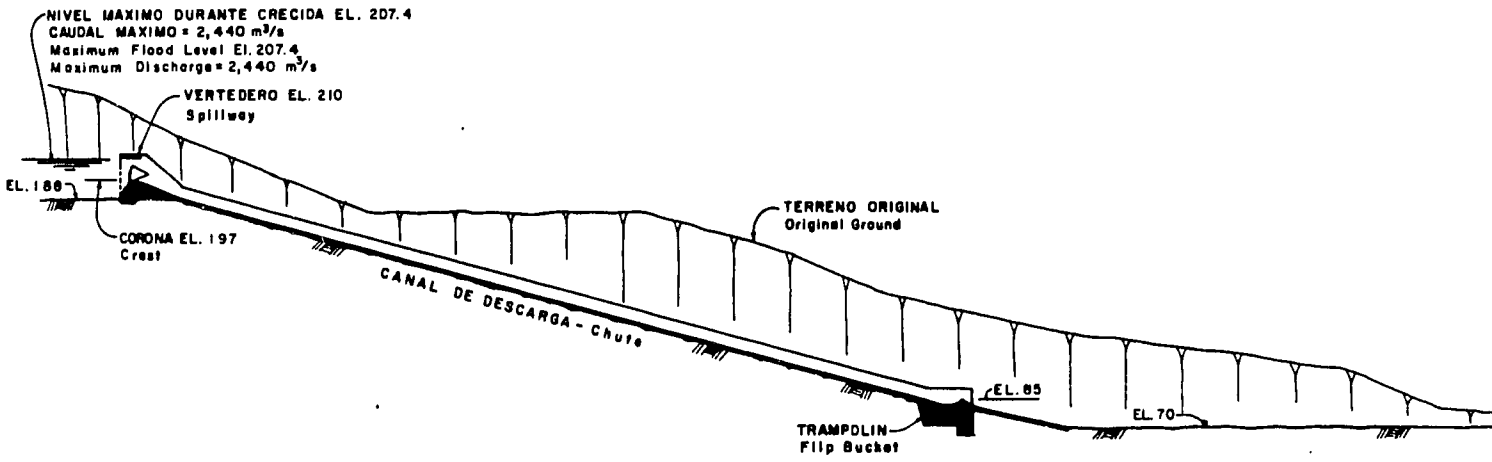
INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO	REVISO	APROBADO
		FECHA AGOSTO 29, 1975

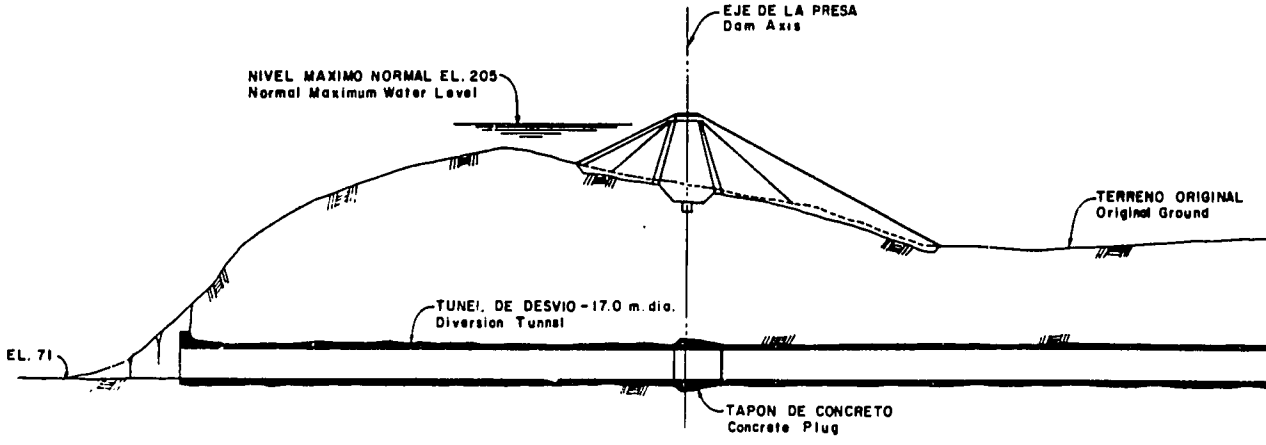
IEC
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104



SECCION A-A
SECTION A-A

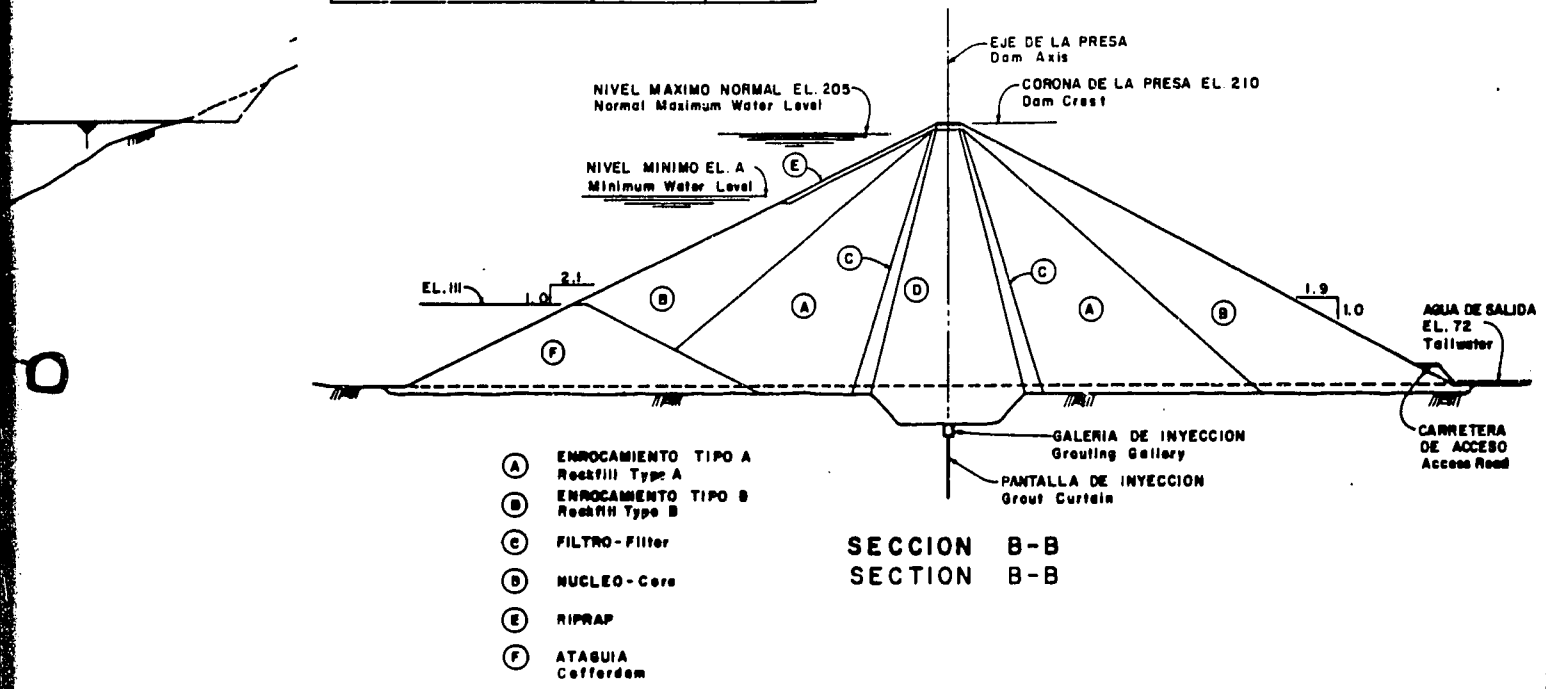


SECCION C-C
SECTION C-C

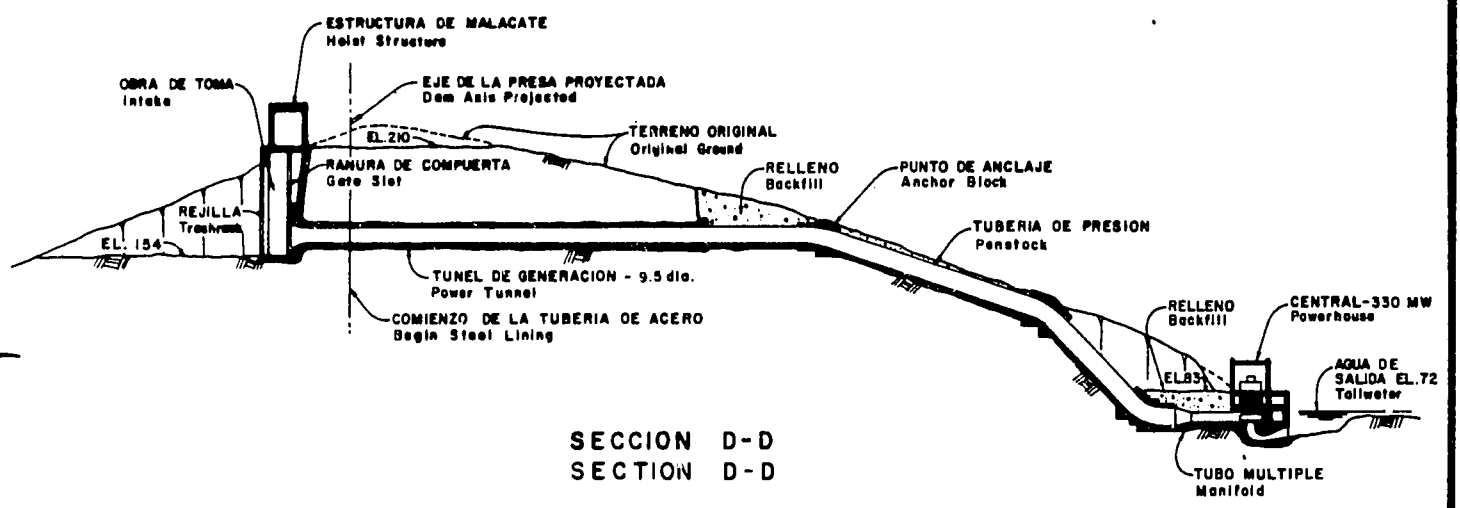


SECCION E-E
SECTION E-E

NIVEL MINIMO DEL EMBALSE Minimum Reservoir Level		
PROYECTO- Project	EL. A	
	COPALAR	PASO REAL
COPALAR	173	—
COPALAR+ PASO REAL	175	240

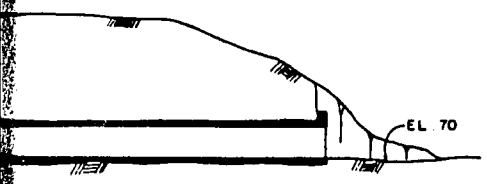


SECCION B-B
SECTION B-B



SECCION D-D
SECTION D-D

20 0 50 100 METROS
Meters
ESCALA
Scale



EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988

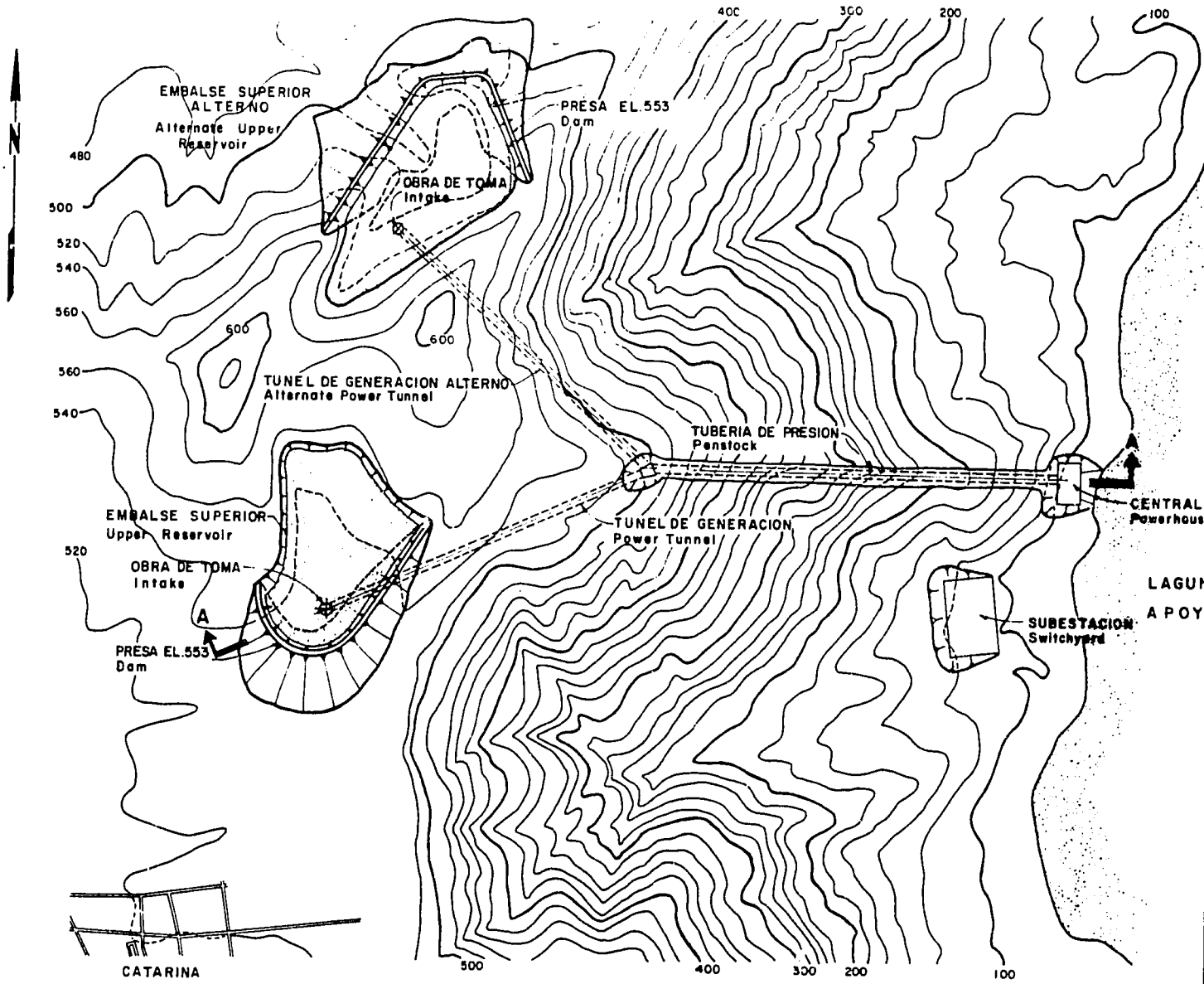
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA

PROYECTO COPALAR

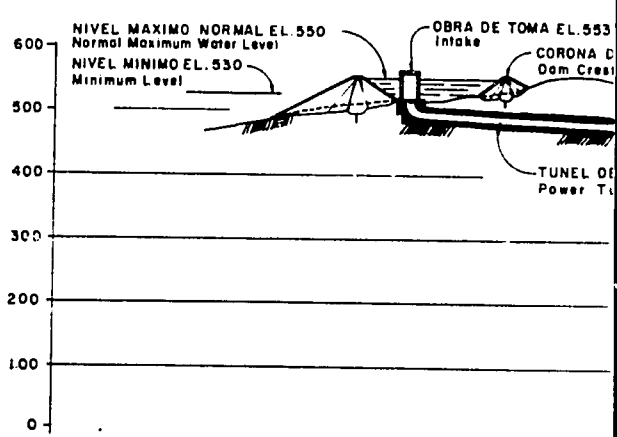
PLANO GENERAL, PRESA ALTA-SECCIONES
GENERAL PLAN, HIGH DAM-SECTIONS

INTERNATIONAL ENGINEERING COMPANY, INC.

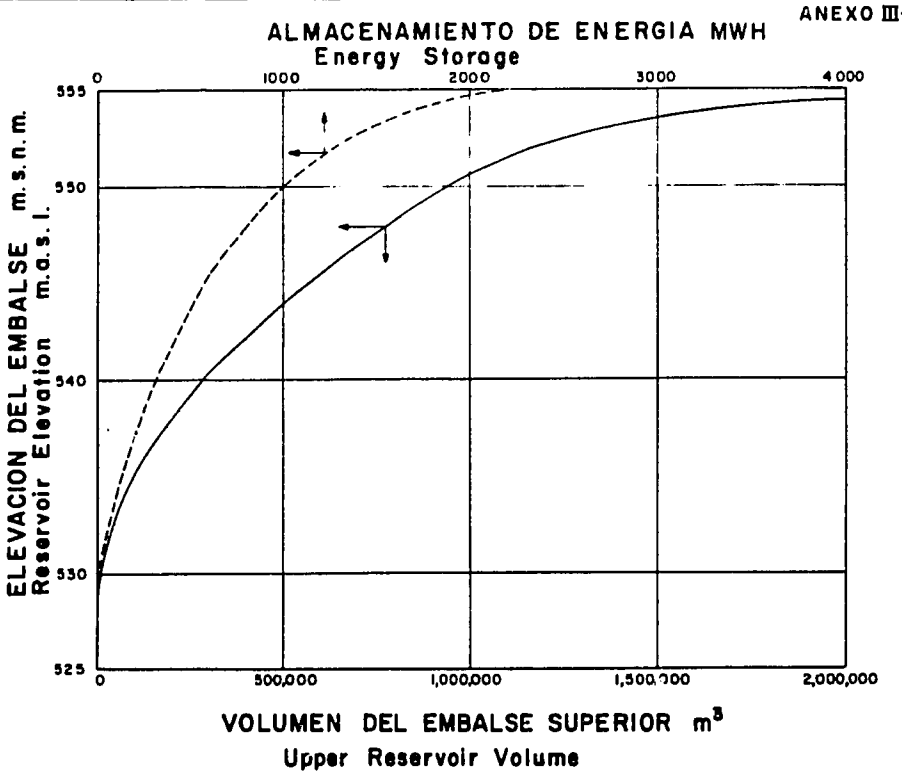
DIBUJO F. JAVIER E.M.	REVISO	APROBADO
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975

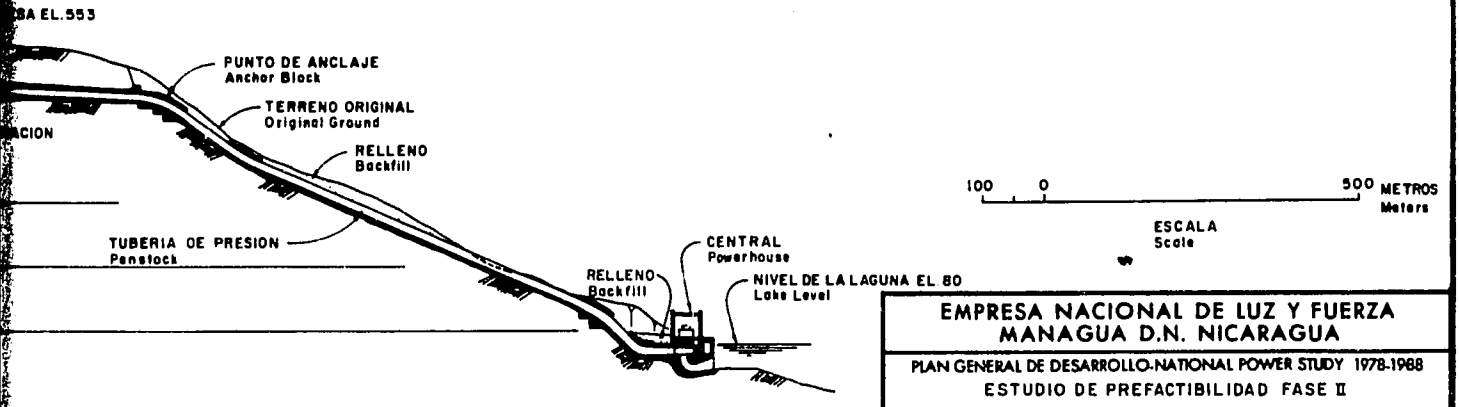


PLANTA
PLAN



SECCION
SECTION





EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

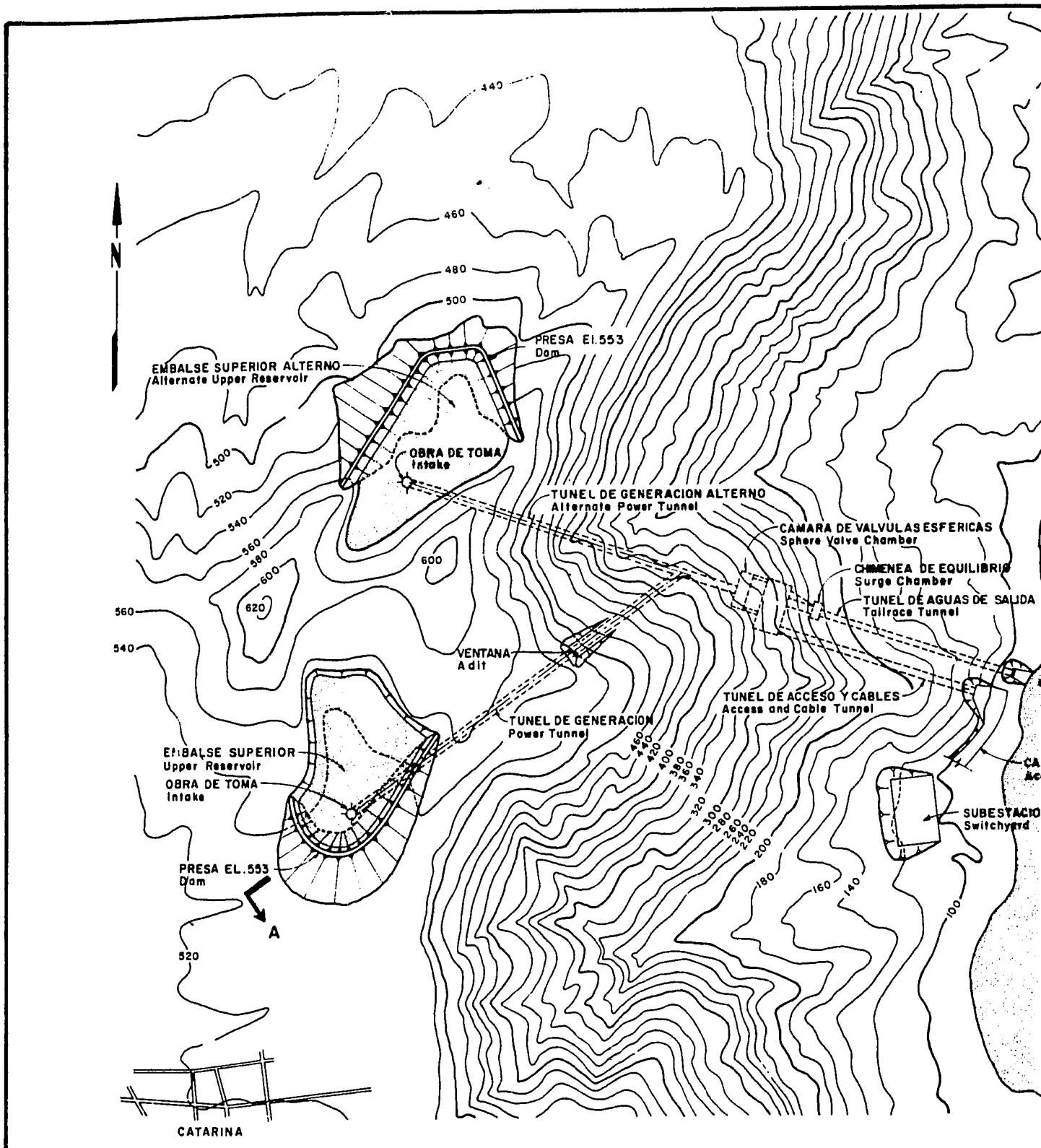
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II

LAGUNA DE APOYO

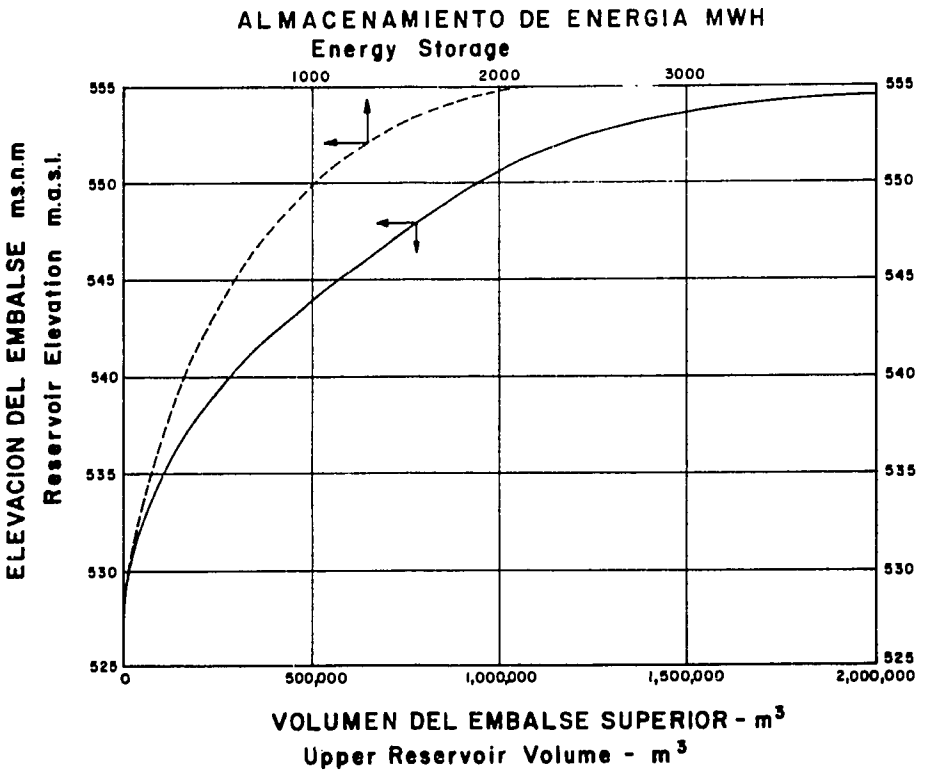
PROYECTO DE ALMACENAMIENTO POR BOMBEO
CENTRAL SUPERFICIAL - PLANO GENERAL
PUMPED - STORAGE PROJECT
SURFACE PLANT - GENERAL PLAN

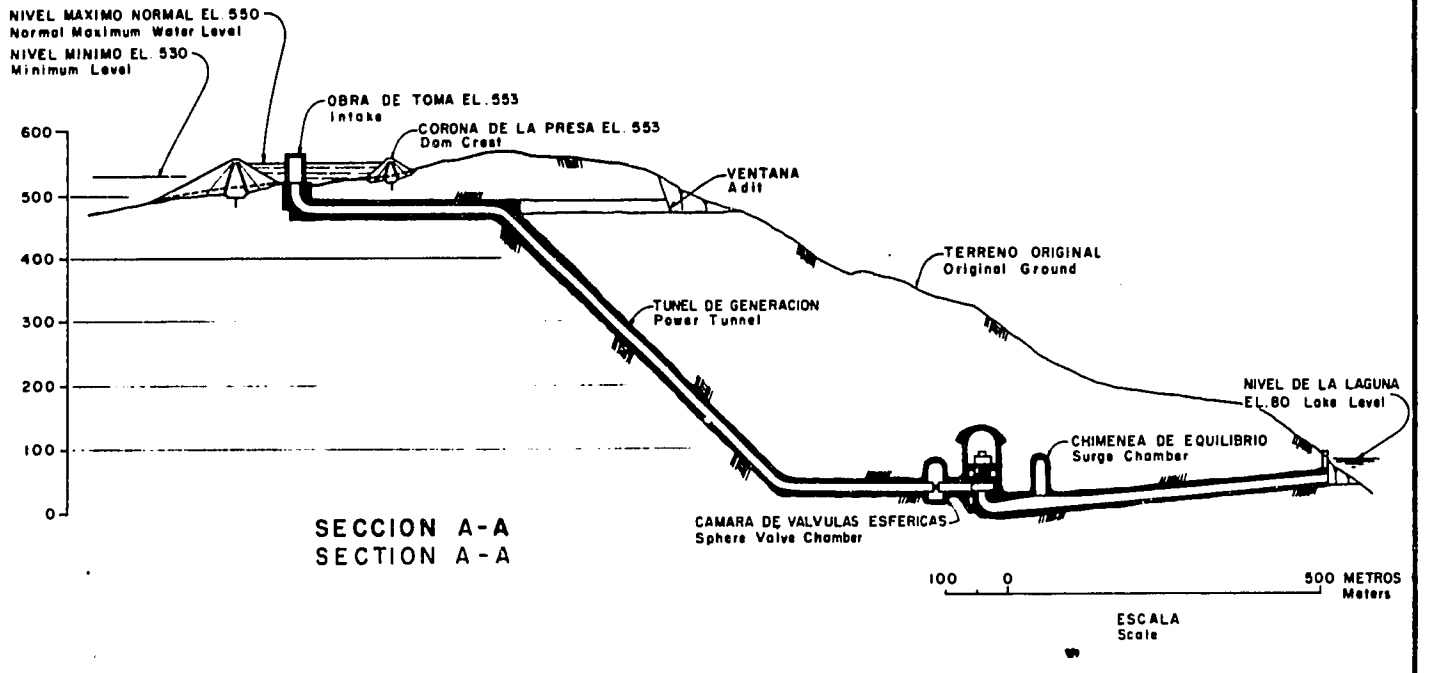
INTERNATIONAL ENGINEERING COMPANY, INC.

DIBUJO MILTON ROMERO F JAVIER E.M	REVISO	APROBADO
IEC 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975


N
EMBALSE SUPERIOR ALTERNO
Alternate Upper Reservoir
PRESA El.553
Dam
OBRA DE TOMA
Intake
TUNEL DE GENERACION ALTERNO
Alternate Power Tunnel
CAMARA DE VALVULAS ESFERICAS
Sphere Valve Chamber
CHIMENEA DE EQUILIBRIO
Surge Chamber
TUNEL DE AGUAS DE SALIDA
Tailrace Tunnel
VENTANA
Adit
TUNEL DE ACCESO Y CABLES
Access and Cable Tunnel
TUNEL DE GENERACION
Power Tunnel
EMBALSE SUPERIOR
Upper Reservoir
OBRA DE TOMA
Intake
PRESA EL.553
Dam
A
SUBESTACIO
Switchyard
CATARINA

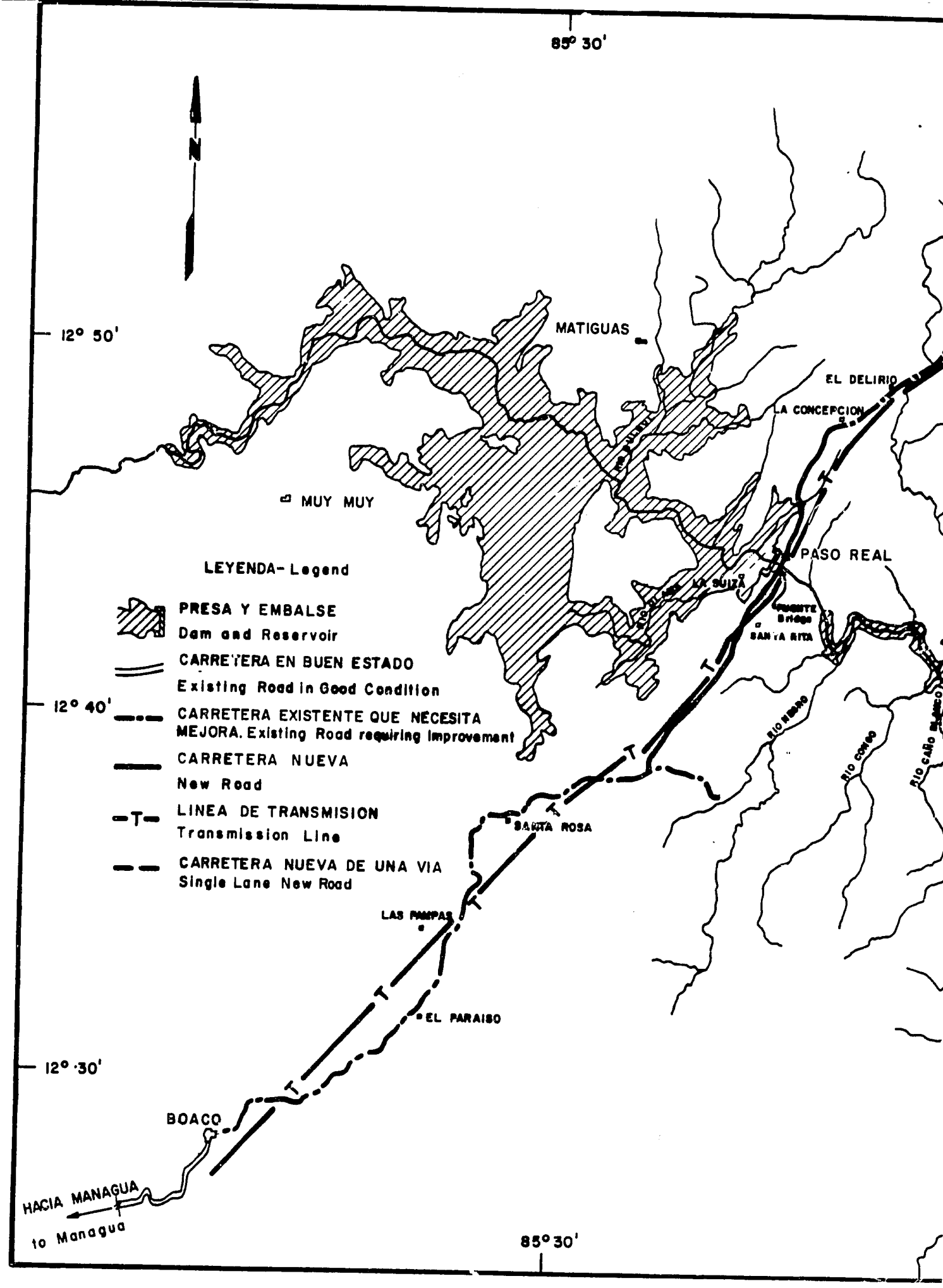
PLANTA
PLAN



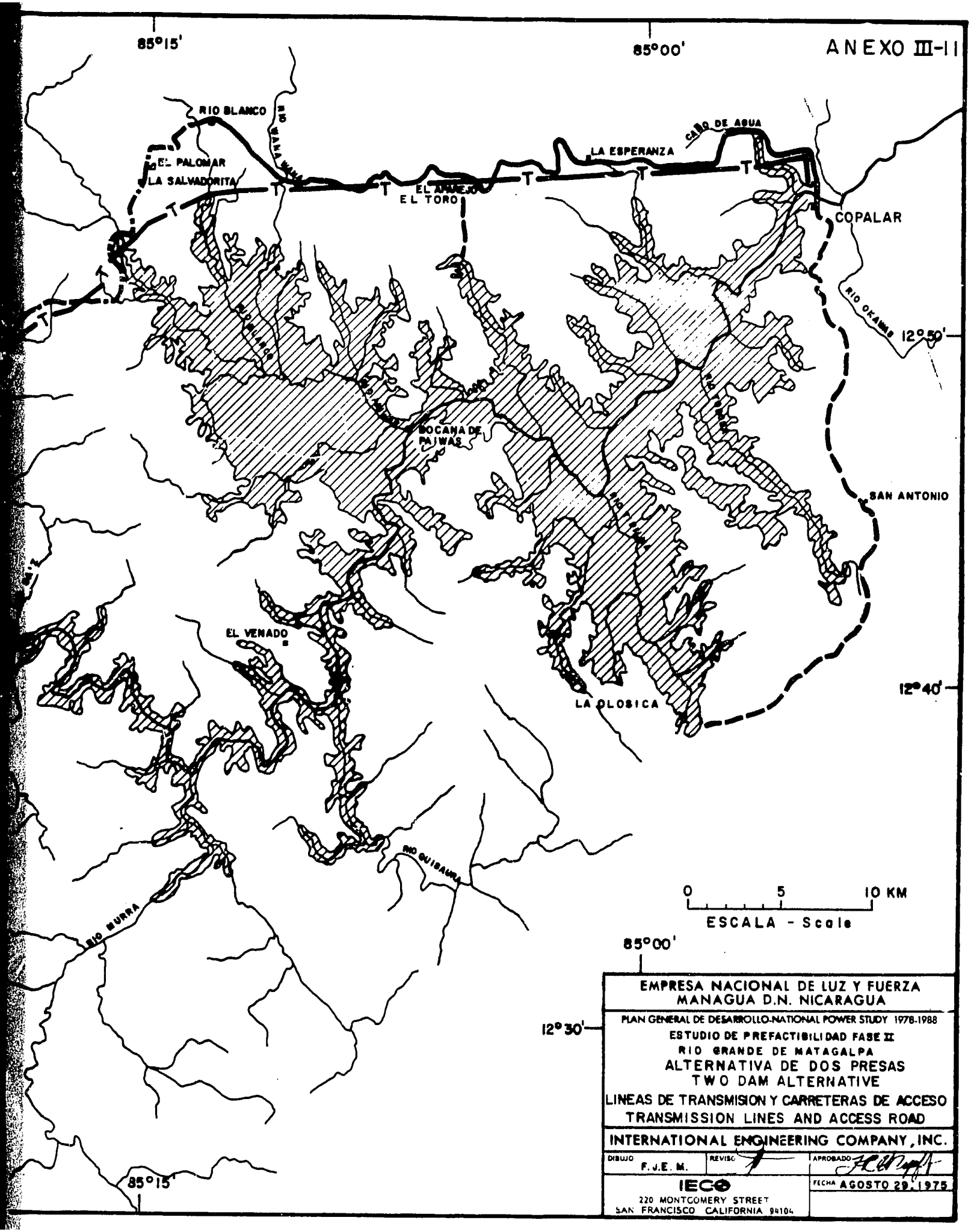


SECCION A-A
SECTION A-A

EMPRESA NACIONAL DE LUZ Y FUERZA MANAGUA D.N. NICARAGUA		
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988 ESTUDIO DE PREFACTIBILIDAD FASE II LAGUNA DE APOYO PROYECTO DE ALMACENAMIENTO POR BOMBEO CENTRAL SUBTERRANEA - PLANO GENERAL PUMPED - STORAGE PROJECT UNDERGROUND PLANT - GENERAL PLAN		
INTERNATIONAL ENGINEERING COMPANY, INC		
DIBUJO MRG-F J E M	REVISO 7	APROBADO
IEC 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		FECHA AGOSTO 29, 1975


85° 30'
N
12° 50'
MATIGUAS
EL DELIRIO
LA CONCEPCION
MUY MUY
PASO REAL
LA SUIZA
Bridge
SANTA RITA
12° 40'
RIO RIBAO
RIO CONIO
LEYENDA- Legend
PRESA Y EMBALSE
Dam and Reservoir
CARRETERA EN BUEN ESTADO
Existing Road in Good Condition
CARRETERA EXISTENTE QUE NECESITA MEJORA. Existing Road requiring improvement
CARRETERA NUEVA
New Road
LINEA DE TRANSMISION
Transmission Line
CARRETERA NUEVA DE UNA VIA
Single Lane New Road
SANTA ROSA
LAS PAMPAS
EL PARAISO
12° 30'
BOACO
HACIA MANAGUA
to Managua
85° 30'

ANEXO III-11



EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

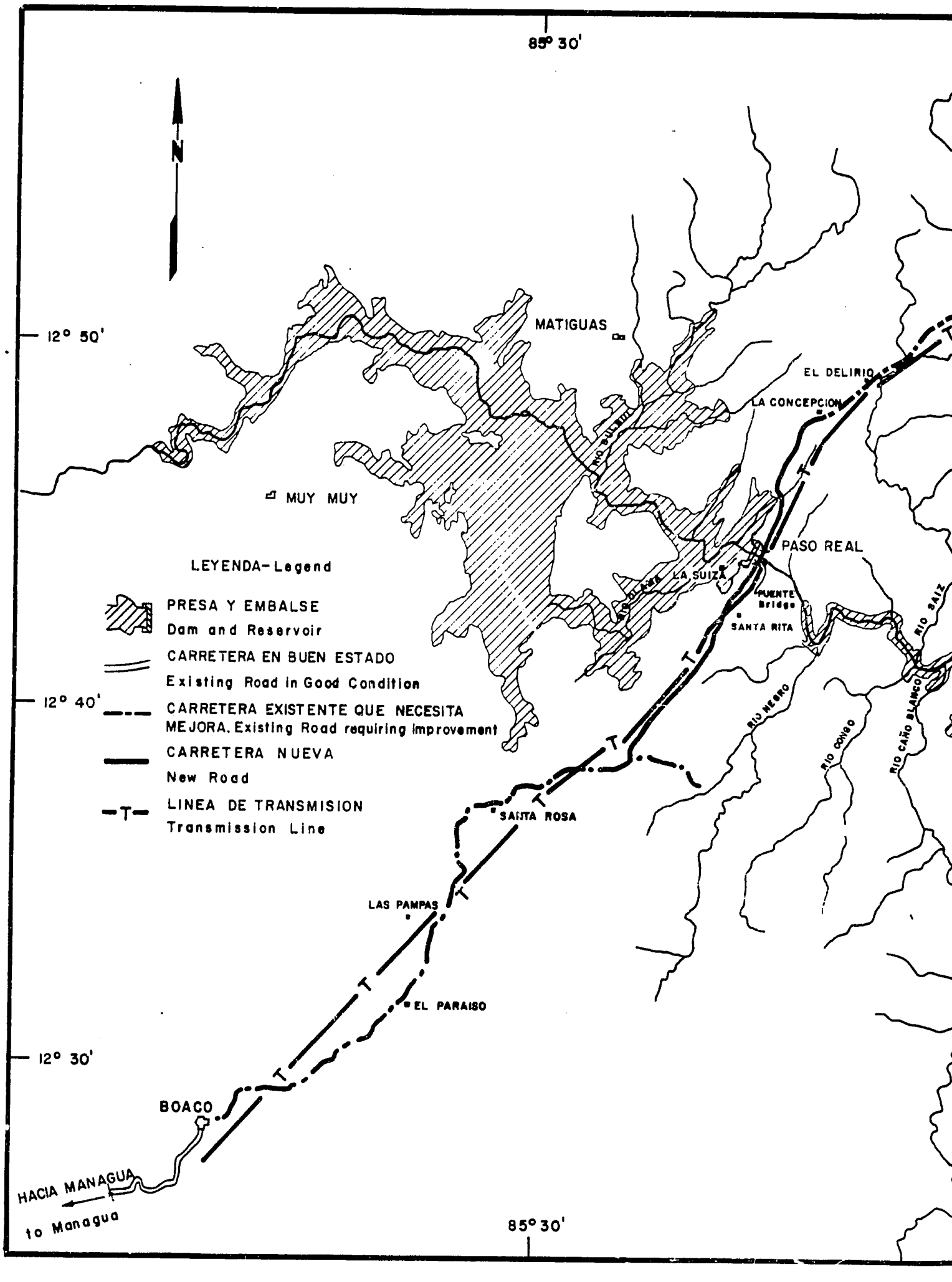
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
ALTERNATIVA DE DOS PRESAS
TWO DAM ALTERNATIVE
LINEAS DE TRANSMISION Y CARRETERAS DE ACCESO
TRANSMISSION LINES AND ACCESS ROAD

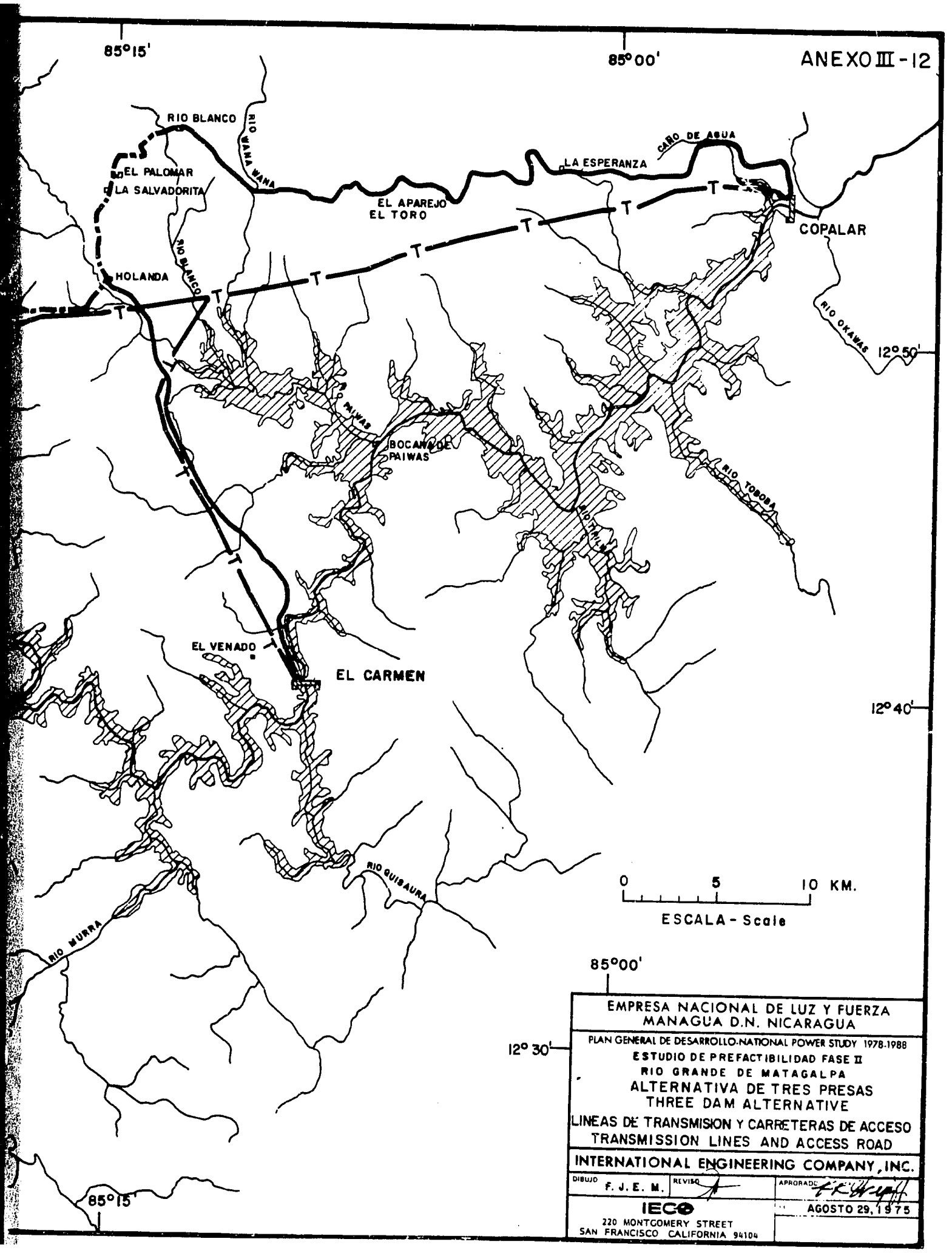
INTERNATIONAL ENGINEERING COMPANY, INC.

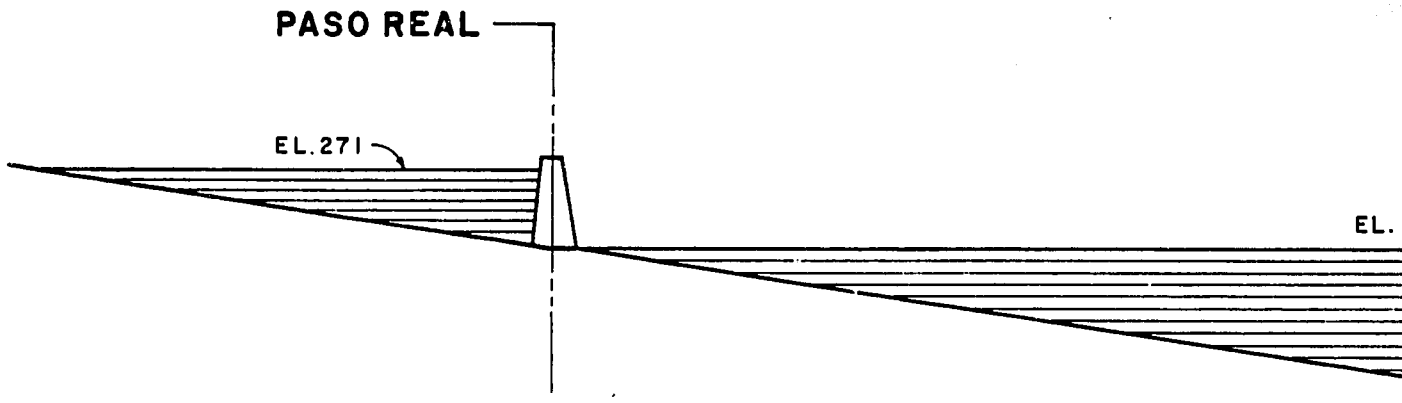
DIBUJO	REVISO	APROBADO
F. J. E. M.		

IEC
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104

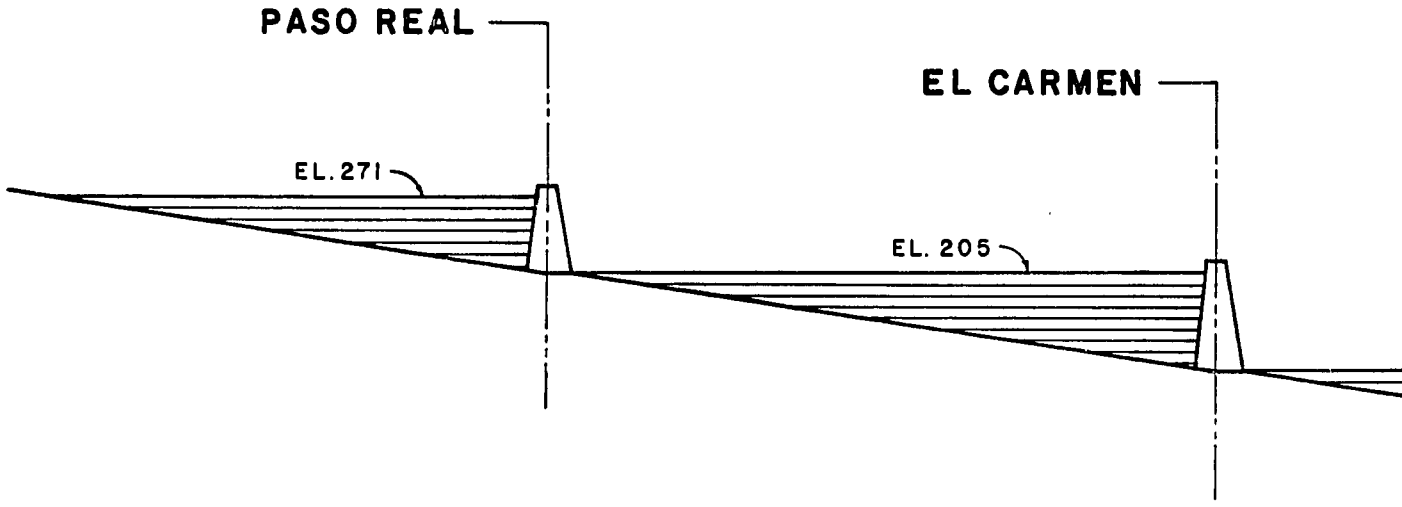
FECHA AGOSTO 29, 1975


85° 30'
N
12° 50'
12° 40'
12° 30'
MATIGUAS
MUY MUY
EL DELIRIO
LA CONCEPCION
PASO REAL
LA SUIZA
PUENTE
Bridge
SANTA RITA
RIO SAIZ
RIO NEGRO
RIO CONGO
RIO CAÑO BLANCO
SANTA ROSA
LAS PAMPAS
EL PARAISO
BOACO
HACIA MANAGUA
to Managua
LEYENDA-Legend
PRESA Y EMBALSE
Dam and Reservoir
CARRETERA EN BUEN ESTADO
Existing Road in Good Condition
CARRETERA EXISTENTE QUE NECESITA MEJORA. Existing Road requiring improvement
CARRETERA NUEVA
New Road
LINEA DE TRANSMISION
Transmission Line
T


ANEXO III-12
85°15'
85°00'
RIO BLANCO
RIO WANA WANA
EL PALOMAR
LA SALVADORITA
EL APAREJO
EL TORO
LA ESPERANZA
CAÑO DE AGUA
COPALAR
HOLANDA
RIO BLANCO
RIO OKAWAS
12°50'
PAIWAS
BOCANA DE PAIWAS
RIO TOBOBA
EL VENADO
EL CARMEN
12°40'
RIO QUISAURA
RIO MURRA
0 5 10 KM.
ESCALA - Scale
85°00'
12° 30'
85°15'
EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA
PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
ALTERNATIVA DE TRES PRESAS
THREE DAM ALTERNATIVE
LINEAS DE TRANSMISION Y CARRETERAS DE ACCESO
TRANSMISSION LINES AND ACCESS ROAD
INTERNATIONAL ENGINEERING COMPANY, INC.
DIBUJO F. J. E. M.
REVISO
APROBADO
IEC
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104
AGOSTO 29, 1975



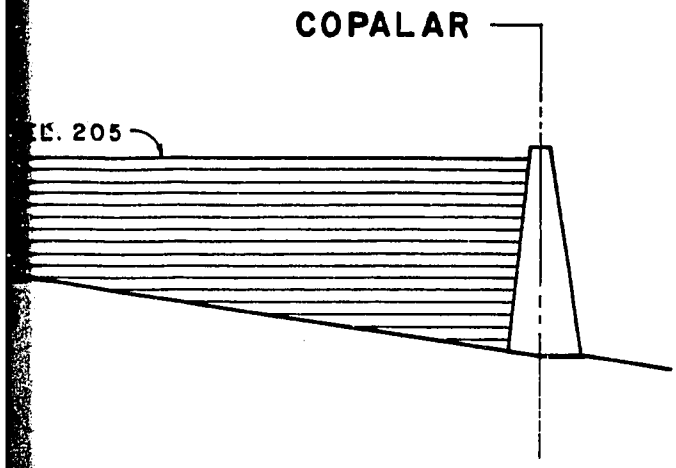
TWO DAM ALTERNATIVE



THREE DAM ALTERNATIVE

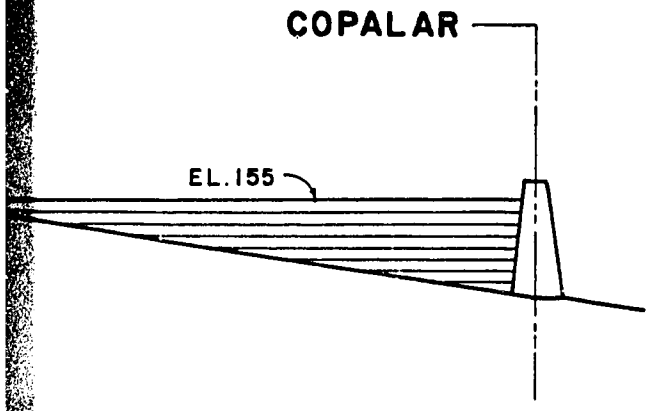
NOTA: LA CAPACIDAD FIRME ES TOMADA DE LOS ESTUDIOS DE OPERACION DE LOS EMBALSES Y GENERACION ANUAL, DE LOS ANALISIS DEL SISTEMA

Note: Firm capacity is from the reservoir operation studies and annual generation is from the system analyses



PROYECTO PROJECT	CAPACIDAD INSTALADA INSTALLED CAPACITY	CAPACIDAD FIRME FIRM CAPACITY	GENERACION ANUAL * ANNUAL GENERATION
PASO REAL	50 MW	21 MW	196 GWh
COPALAR	330 MW	160 MW	1413 GWh
TOTAL	380 MW	181 MW	1609 GWh

* AÑO PROMEDIO
Average Year



PROYECTO PROJECT	CAPACIDAD INSTALADA INSTALLED CAPACITY	CAPACIDAD FIRME FIRM CAPACITY	GENERACION ANUAL ANNUAL GENERATION
PASO REAL	50 MW	21 MW	199 GWh
EL CARMEN	70 MW	28 MW	317 GWh
COPALAR	275 MW	82 MW	850 GWh
TOTAL	395 MW	131 MW	1366 GWh

* AÑO PROMEDIO
Average Year

EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988
ESTUDIO DE PREFACTIBILIDAD FASE II
RIO GRANDE DE MATAGALPA
ALTERNATIVAS DE DOS PRESAS Y TRES PRESAS
CAPACIDAD Y ENERGIA GENERADA
TWO DAM AND THREE DAM ALTERNATIVES
CAPACITY AND ENERGY GENERATED

INTERNATIONAL ENGINEERING COMPANY, INC.

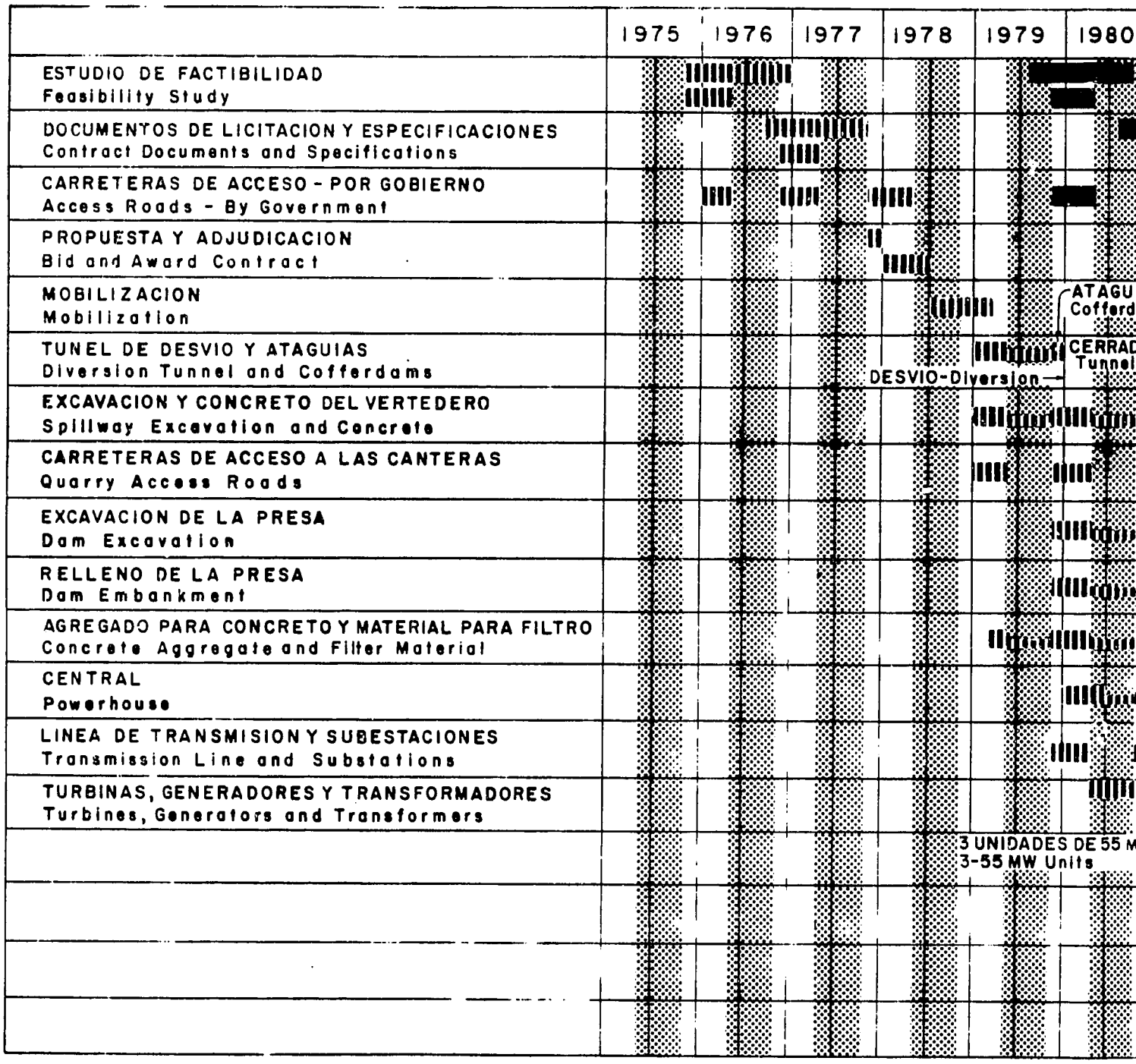
DIBUJO MILTON ROMERO | REVISO | APROBADO

IECO
220 MONTGOMERY STREET
SAN FRANCISCO CALIFORNIA 94104

FECHA AGOSTO 29, 1975

RIO GRANDE

ALTERNATIVA DE TRES PRESAS
SIN COMPRAS DE ENERGIA
CRONOGRAMA PRELIMINAR DE TRABAJO



LEYENDA - LEGEND

COPALAR

EL CARMEN

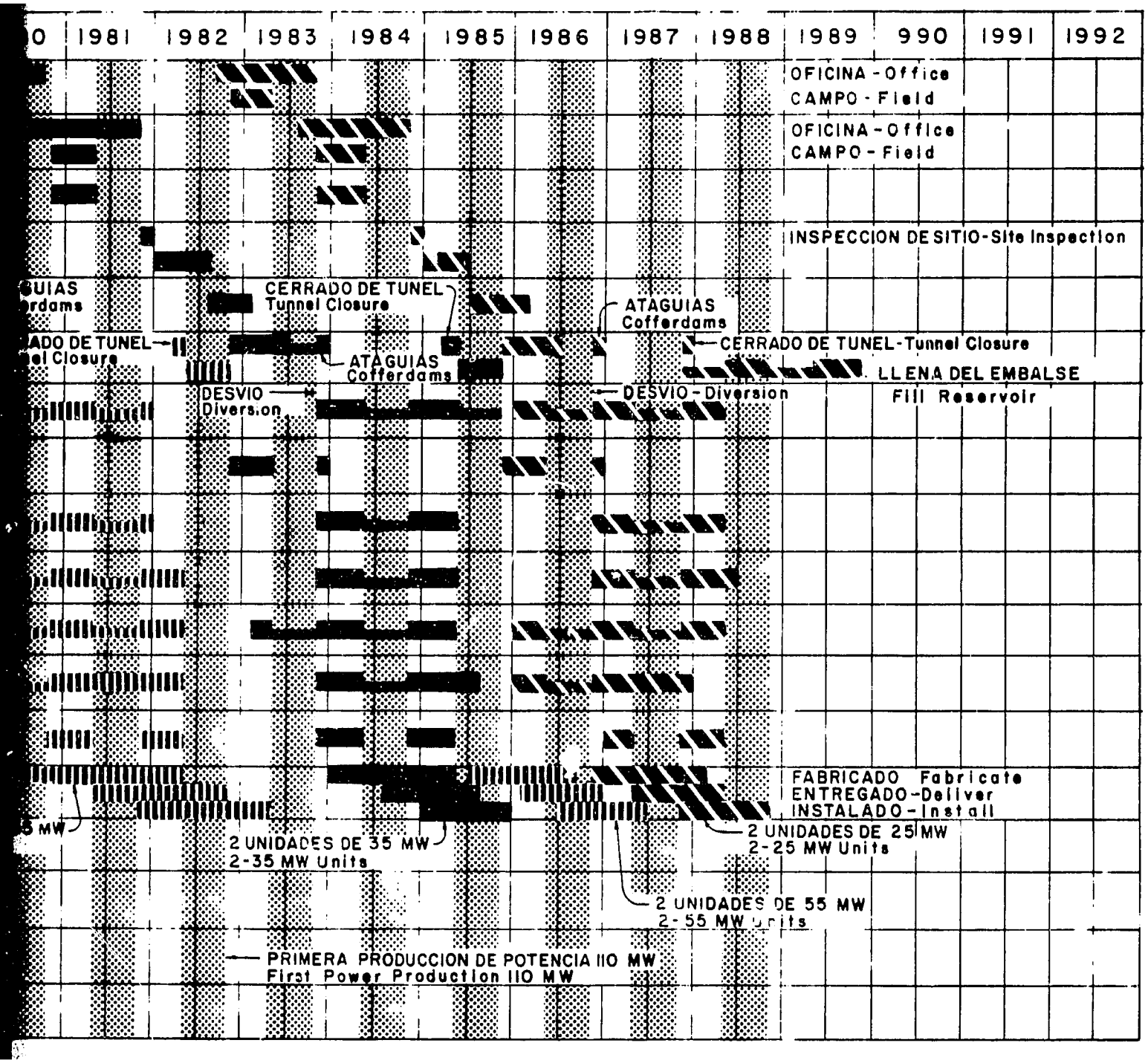
PASO REAL

ESTACION LLUVIOSA
Wet Season

CONSTRUCCION LIMITADA
Limited Construction

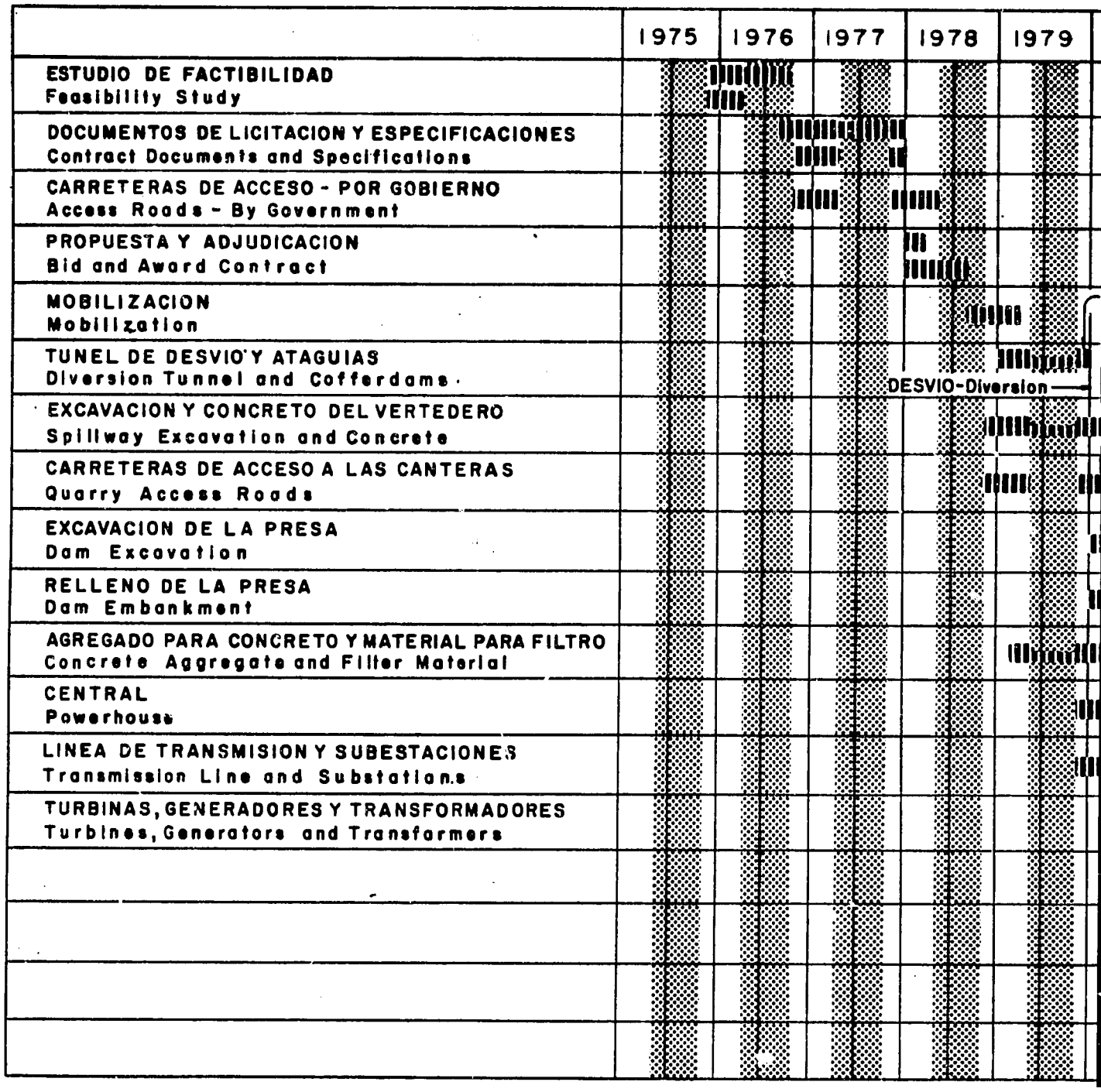
DE MATAGALPA

THREE DAM ALTERNATIVE
WITHOUT ENERGY PURCHASES
PRELIMINARY WORK SCHEDULE



RIO GRAND

ALTERNATIVA DE DOS PRESAS
SIN COMPRAS DE ENERGIA
CRONOGRAMA PRELIMINAR DE TRABAJO



LEYENDA - LEGEND

COPALAR

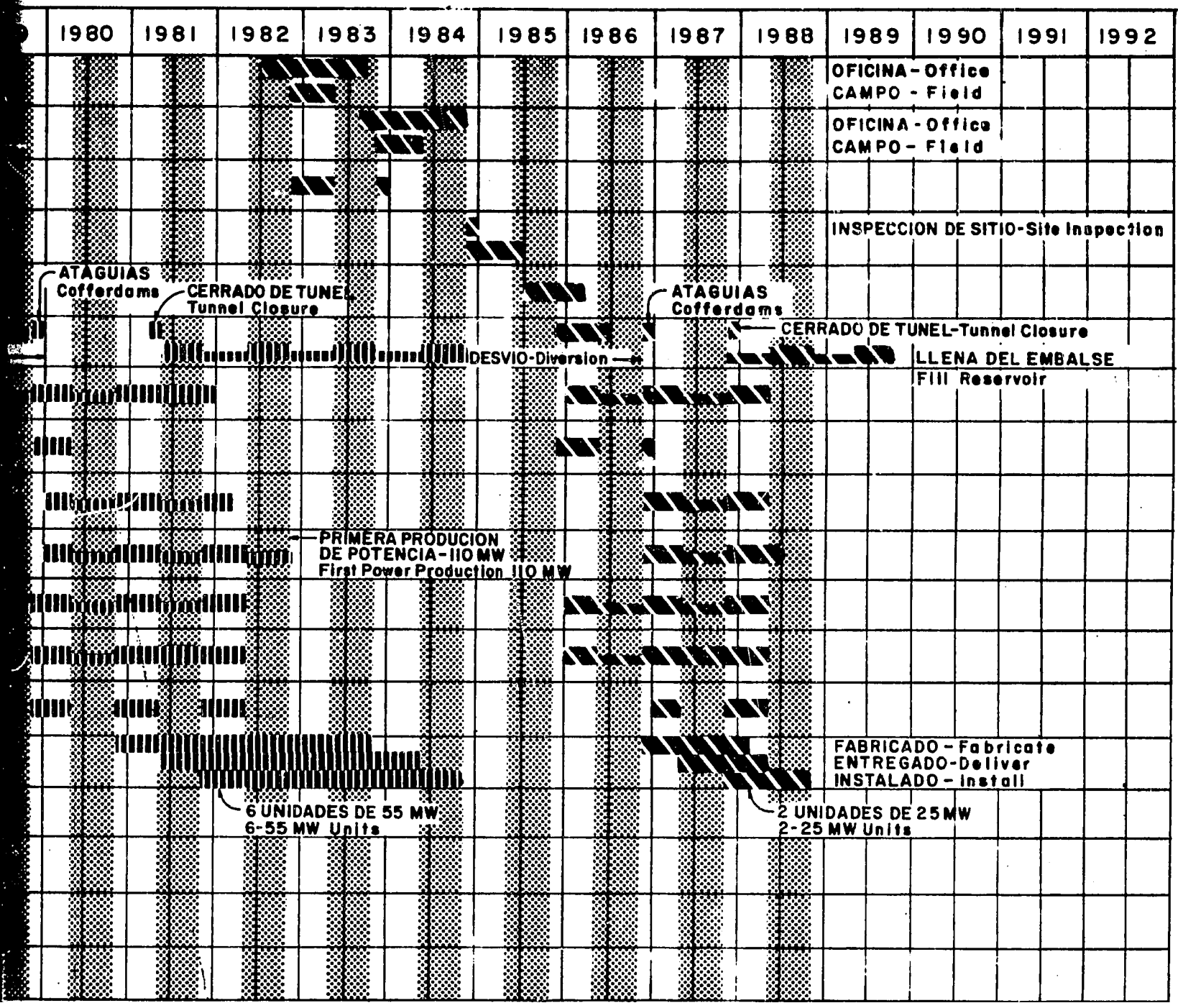
PASO REAL

ESTACION LLUVIOSA
Wet Season

CONSTRUCCION LIMITADA
Limited Construction

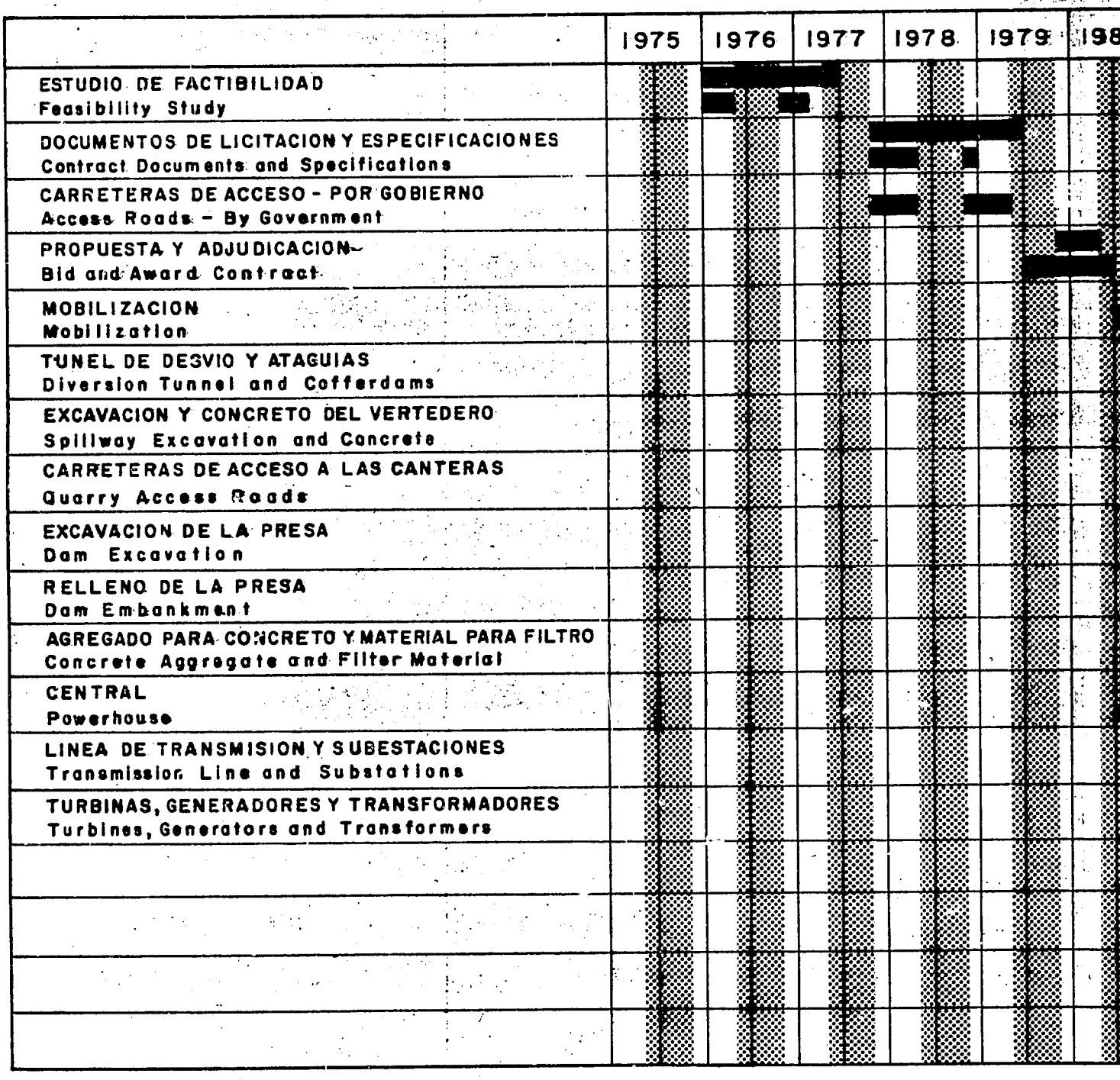
NDE DE MATAGALPA

TWO DAM ALTERNATIVE
WITHOUT ENERGY PURCHASES
O PRELIMINARY WORK SCHEDULE



RIO GRANDE

PROYECTO COPALAR
ALTERNATIVA DE DOS PRESAS
CON COMPRAS DE ENERGIA
CRONOGRAMA PRELIMINAR DE TRABAJO



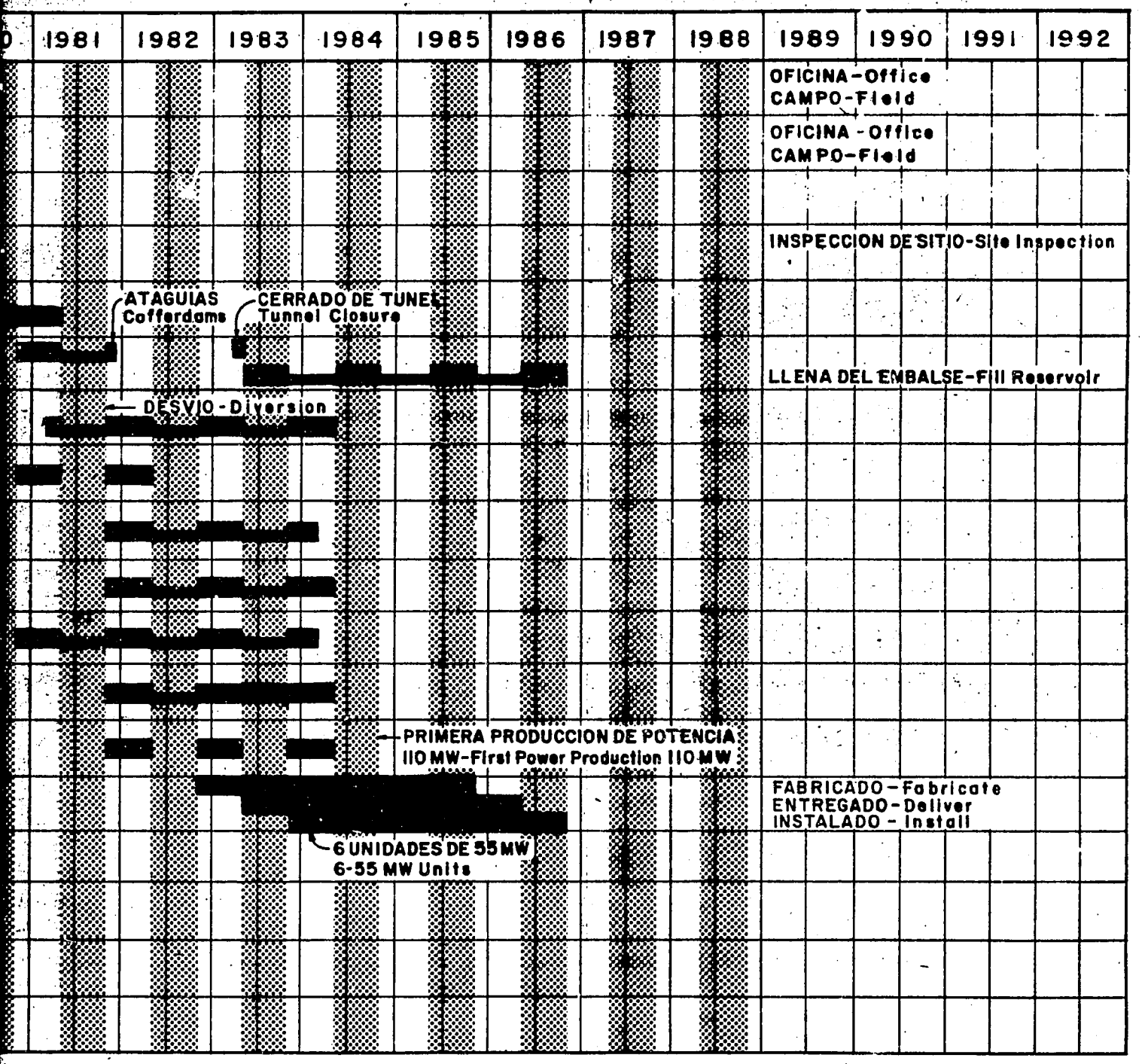
LEYENDA - LEGEND

ESTACION LLUVIOSA
Wet Season

CONSTRUCCION LIMITADA
Limited Construction

DE MATAGALPA

COPALAR PROJECT
TWO DAM ALTERNATIVE
WITH ENERGY PURCHASES
PRELIMINARY WORK SCHEDULE



CAPITULO IV

ASUNCIONES
Y
CRITERIOS

CHAPTER IV

ASSUMPTIONS
AND
CRITERIA

CHAPTER IV

ASSUMPTIONS AND CRITERIA

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CHAPTER IV

ASSUMPTIONS AND CRITERIA

4.1 GENERAL CRITERIA IMPLICIT TO PLAN FORMULATION

The basic intent, guiding the formulation of plans for system expansion, was to ensure that the elements included were consistent with the over-all planning objectives and accorded with specific technical criteria. The principal assumptions and planning criteria are discussed in the following sections.

4.1.1 PRIMARY RELIANCE ON INDIGENOUS RESOURCE DEVELOPMENT

When planning for firm additions to generation sources, it is preferable to consider only assured resources for inclusion in a basic expansion plan. The prime indigenous resources of Nicaragua,to be utilized for power generation, will consist of potential hydro energy and proven geothermal reserves. Both of these natural resources are available for development in sufficient magnitude to justify a certain optimism regarding the provision of firm energy supplies in the future.

The intention of current development plans is to concentrate on the exploitation of geothermal resources for short-range generation expansion, under the impetus of the urgent need to rapidly develop alternative forms of generation, rather than being forced to rely on the expansion of oil-fired thermal plants. A continuing program of steam-well drilling is underway at the geothermal field on the slopes of Momotombo volcano, following the successful completion of the first deep exploration well in April, 1975.

As geothermal resources are only subject to reliable assessment as a firm energy source after being fully proven by field production drilling and steam testing, it is too early to judge the full extent of geothermal resources available for future power development. However, the results of exploratory surveys and field drilling completed to date are indicative of the potential available and support the inclusion of limited geothermal plant capacity increments in generation expansion plans. Once the field development is sufficiently advanced to allow completion of feasibility studies relating to geothermal generating plant, the scheduled capacity additions may be revised to incorporate the consultant's findings.

The lead time associated with the development of major hydro power resources precludes the early introduction of hydroelectric plant additions in generation expansion plans. The approach taken in this study has been that of scheduling hydro unit additions to meet long-range system load growth, consistent with minimum lead time necessary to complete construction of civil works and power facilities. It is taken as axiomatic, that hydroelectric energy resources should be utilized as early as warranted by system requirements. There are abundant hydroelectric energy resources indigenous to Nicaragua, their development will enable the nation to be placed in the advantageous position of being progressively less reliant on the importation of fuel oil to sustain the long-term growth of the economy. Geothermal and hydro resources are complementary within the generation "mix";geothermal is suitable for base load supply, with pondage hydro sufficiently flexible to allow mid-range and peaking operation.

4.1.2 MINIMAL OPERATION OF OIL-FIRED THERMAL PLANTS

Present oil price levels and uncertainty regarding the future escalation of the price base, emphasizes the need to restrict the future use of fuel-oil as far as possible to improve operating economy. This intent will be realized by the careful utilization of thermal generation as a supplementary source, to augment the complementary hydro and geothermal generation, once these new sources are introduced to system operation.

The existing system relies heavily on thermal generation and very little can be done to improve the supply situation until alternative sources are developed. Short-term system additions consist of two 50 megawatt oil-fired thermal units, to be installed at the new Puerto Somoza plant located on the Pacific Coast, approximately 55 kilometers west of Managua.

The introduction of these two units in the last quarter of 1976 will represent a major addition to base-load capability, the thermal units being expected to operate at relatively high plant capacity factors during the first few years of operation, prior to the introduction of geothermal units. These two thermal units were committed before the full impact of the energy crisis was realized and although essential to short-term development, they represent the last major installation of thermal plant to burn oil as fuel. As soon as alternative base-load energy is available from geothermal power sources, the operation of the oil-fired units on the system will be reduced,with consequent operating economies. The Puerto Somoza units will then be operated as mid-range units, together with the 45 megawatt unit at the Managua plant, the remainder of the thermal units in the system being placed on reserve.

The energy associated with the future hydro power development on the Rio Grande de Matagalpa will displace thermal generation to a great extent and enable minimal usage of thermal plant in the years following the introduction of hydro units through the remainder of the period of expansion to 1988.

The extent to which thermal generation is reduced will improve with the utilization of interconnections. As will be demonstrated, the careful scheduling of purchased power, in conjunction with indigenous hydro and geothermal sources, will dispense almost entirely with the need for thermal generation during the period 1982 through 1987.

4.1.3 ECONOMIC UTILIZATION OF SYSTEM INTERCONNECTIONS

In planning for the future interconnection of the ENALUF system with the Empresa Nacional de Energia Electrica (ENEE) system of Honduras and the Instituto Costarricense de Electricidad (ICE) system of Costa Rica, the criteria to be followed, for the evaluation of both on-peak power purchases and off-peak energy purchases, will consist of the definition of their economic worth in comparison with the independent development and operation of the ENALUF system. Breakeven rates will be determined to provide ENALUF with a frame of reference for assessment of projected interchange tariffs, to compare the cost of future purchases with the additional costs of independent operation.

Purchases of power from ENEE are assumed to be firm allocations, based on the major development of pondage hydro at the El Cajon site in Honduras.

These allocations will provide on-peak power, beginning in 1982, that will enable ENALUF to defer the initial power installation at the Copalar site, this be the next economic hydro site selected for development in Nicaragua, on the Grande de Matagalpa. The breakeven rate for firm energy purchased from ENEL will reflect both the postponement of the prime hydro development at Copalar and the associated deferral of capital expenditures, together with the savings resulting from the utilization of hydro energy rather than equivalent thermal generation.

The interconnection with Costa Rica will make available to the ENALUF system, surplus off-peak energy from run-of-river hydro plants on the ICE system, which will serve to replace thermal generation, this being reflected in the breakeven rate for off-peak energy purchases.

4.1.4 CONDITIONS GOVERNING ECONOMIC DISPATCH OF PUMPED-STORAGE PLANT

The economic operation of pumped-storage is contingent upon the availability of a suitable source of pumping energy, at a cost level that will permit economic dispatch of the pumped-storage plant, in conjunction with other system generation. The source of pumping energy should preferably be a base-load plant with a low production cost, such as nuclear or geothermal, to enable the full benefits of the complementary modes of generation to be realized, by optimization of the combined operation.

The capacity of the low cost pumping energy source should be sufficient to supply the pumping units in addition to the nocturnal (base) load of the system. If there is insufficient capacity available to satisfy this condition, then economic dispatch of pumped-storage is made difficult, or impossible. This is because an alternative higher cost source of pumping energy usually results in the situation, whereby it is more economic to dispatch additional thermal generation at peak hours, rather than utilize pumped-storage plant, due to the inherent efficiency of the pumped-storage cycle. Thus the advantages of pumped-storage are nullified in a system that has insufficient base-load capacity associated with low cost energy sources. In such a system, pumping energy would be drawn from thermal sources at cost levels determined by future oil price levels. It is inconceivable that this situation could result in operating economies for the benefit of the utility system. Under analysis, the dispatch of pumped-storage would be determined by the relative economics of the pumped storage cycle, with thermal energy used for the pumping mode, in comparison to the cost of dispatch at peak load of older, less efficient thermal units, which would normally be held on reserve.

4.1.5 CONTINGENCY PLAN FOR ALTERNATIVE TO GEOTHERMAL DEVELOPMENT

As geothermal resources have to be fully proven and tested before they can be considered sufficiently reliable to provide a firm source of supply, it is prudent to devise a suitable contingency plan, in the event that projected plans for geothermal power are not fully realized, or schedules are delayed for any reason.

In this study two alternatives for base-load supply are compared, so that ENALUF will be in a position to evaluate the geothermal development program at a later date, in relation to projected system requirements and scheduled in-service dates for geothermal plant.

If the drilling program is positive in its results but due to delays or other unforeseen events, the required lead-time for geothermal plant additions would preclude their installation to meet projected system demand, an interim solution could be found in the placement of equivalent diesel generating capacity. For this purpose large capacity, high efficiency units are proposed, using Bunker C oil for fuel, to minimize investment and production costs.

If the realized yield of the geothermal field is less than the steam flow required to support the entire complement of geothermal plant capacity included in the basic plan, then a long term solution would be to install additional capacity at the Puerto Somoza site.

However, this solution should be one of last resort and an alternative would be to install a minimum number of diesel units with sufficient capacity to provide for the anticipated deficit. In order to compare economic merits of the two forms of base-load generation, an analysis has been made for an additional 50 megawatt unit at the Puerto Somoza plant and an equivalent diesel installation, consisting of four diesel units each having an effective operating capacity of 12.5 MW. Both installations are assumed to use Bunker C fuel oil; however, the delivered price for fuel is different because the diesel plant is assumed to be located at Masaya. The results of the study are contained in Chapter VIII, Section 8.3.

4.2 CRITERIA RELATING TO GENERATION PLANNING

The technical criteria followed for detailed generation planning relate mainly to the methodology associated with the establishment of generation reliability levels, used to determine specific unit introduction schedules for the expansion plans. These criteria directly affected the method of computation and preferred setting of loss-of-load probability (LOLP) indices used during the study.

The definitive load forecast, developed during Phase I of the prefeasibility study, was modified to allow for the probability of departure from forecast load levels through time. This provision was included in the ENALUF program used for system risk analysis, by defining a probable bandwidth in terms of multiple standard deviations over the forecast period.

The preferred loss-of load probability, index used during the study, was set in relation to a value obtained by marginal cost analysis, which defined the optimum reserve margin at the point where the marginal cost to supply was equal to the marginal cost of losses to the consumer.

4.2.1 PROVISION FOR LOAD FORECAST UNCERTAINTY

Any forecast of future load has a degree of uncertainty associated with it and planning for installed generating capacity must therefore account for load forecast variations as well as generation outages. The usual way to allow for uncertainty is by means of a probability curve, such as shown in Figure IV.1A.

FIGURA IV · I

REPRESENTACION DEL MODELO DE PROBABILIDAD DE LA INCERTIDUMBRE DEL PRONOSTICO DE CARGA

FIGURE IV · I

PROBABILITY MODEL REPRESENTATION OF LOAD FORECAST UNCERTAINTY

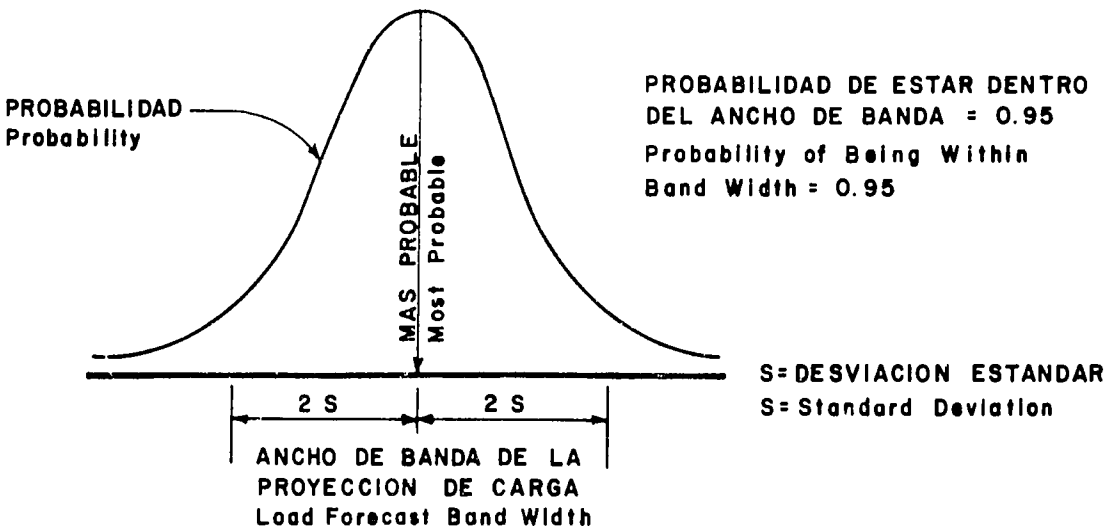


FIGURA IV·I A REPRESENTACION CONTINUA

Figure IV·I A Continuous Representation

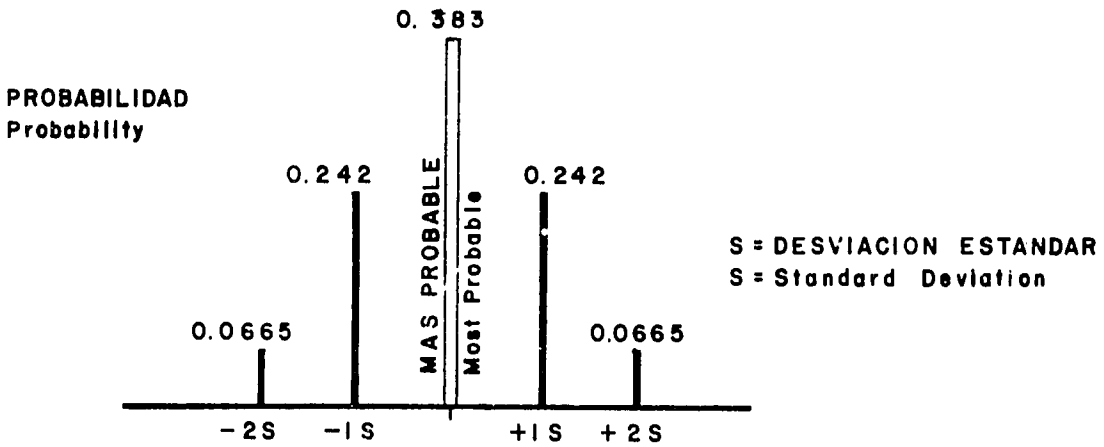


FIGURA IV·I B REPRESENTACION DISCRETA

Figure IV·I B Discrete Representation

The probability curve for the ENALUF demand forecast was derived using the range of possible values developed in Chapter I of the Phase I Report. The following methodology serves only to quantify, for purposes of generating planning, the assumptions explicitly stated in deriving the projected range ("Low", "Average" and "High) and "Most Probable" value of the forecast demand. Table I.18 of the Phase I Report summarizes the "Low", "Average" and "High" load projections and "Most Probable" load forecast based on two independent analyses:

1. A macro-analysis relating projected growth rates for economic parameters and energy consumption per capita, to derive estimates of total energy consumption.

2. A micro-analysis which totalized forecasts relating to sectoral energy sales within load zones of the service territory, to yield a total demand forecast.

A comparison of these independent forecasts showed a very close parallel. The forecast derived from the micro-analysis aligned closely with the "Average" projection obtained from the macro-analysis, while the macro-analysis was in turn based on the "Most Probable" growth of GDP. This comparison provided the basis for designating the resultant forecast the "Most Probable".

Referring to Figure IV.1A, the "Most Probable" load forecast corresponds to the maximum value of the probability curve. Values for the "Most Probable" load forecast would then correspond to those given in Table I.16 of the Phase I Report.

The variability of the forecast is defined in terms of the standard deviation about the mean value. Due to the assumption regarding the shape of the probability curve, the mean value is in this case, the same as the most probable value. A small standard deviation would imply a high degree of certainty in the forecast demand. For this study the standard deviation will be used to define "bandwidth" of the forecast. The "bandwidth" will be defined as being within the two standard deviation limits (Figure IV.1A). An interpretation of the bandwidth would be to say that there is a 95% chance that the actual peak demand will lie within the limits defined by the bandwidth. Since the uncertainty in a forecast increases with time, the demand value defined by the bandwidth will increase with time, but the probability of being within the bandwidth will remain constant.

Derivation of the standard deviation and the bandwidth of the forecast was based on the "High" and "Low" projections derived using the macro-economic method of load forecasting. It was assumed that these limits defined the range of possible values such that the actual future peak demand would be within the range of the "High" and "Low" forecasts with a probability of 99.8%. In 1988, the horizon year of the study the range was approximately ± 45% (± 256 MW) of the "Most Probable" load forecast of 568 MW. This range does not present cause for concern, since it defines the extreme limits for the forecast. Knowing the range however allows definition of the standard deviation of the forecast.

The derivation of the standard deviation follows.

The "Most Probable" and extreme values as defined by the range of the "High" and "Low" forecasts, were plotted on arithmetic, normal probability paper. The implicit assumption being that each extreme corresponded approximately to the 99.9 percentile or the three standard deviation limit. Connection of these points and derivation of the standard deviation from this plot was straightforward. Figure IV.2 is the probability plot used to derive ± 15% (85 MW) standard deviation for the "Most Probable" 1988 peak demand of 568 MW.

Derivation of the standard deviation and bandwidth for the years prior to 1988 was derived by correlating the trend in the standard deviation, to the increasing trend of the "Most Probable" load forecast.

A cross check of the values for the standard deviation derived from trending was made using probability paper. The plots for 1973, 1978 and 1983 are shown in Figures IV.3, IV.4 and IV.5. The results compare reasonably well with the results obtained using methodology to derive the horizon year (1988) standard deviation. Table IV.1 summarizes the projected values of the "Most Probable" forecast demand and the bandwidth of this forecast over the period 1975 through 1988. Figure IV.6 shows the "Most Probable" load forecast and the upper and lower limits of the bandwidth.

The usual procedure for including load forecast uncertainty in generation planning studies is to reduce the continous representation of the probability curve as shown in Figure IV.1A to discrete probability multipliers as shown in Figure IV.1B.

TABLE IV.1
MOST PROBABLE DEMAND FORECAST
AND BANDWIDTH 1975-1988

YEAR	"MOST PROBABLE" MW DEMAND	BANDWIDTH (± 2 STANDARD DEVIATIONS)	
		PERCENT OF "MOST PROBABLE"	± MW
1975	152	8.2	12.5
1976	172	9.2	15.8
1977	194	10.4	20.2
1978	220	11.7	25.7
1979	241	13.0	31.3
1980	266	14.4	38.3
1981	295	15.8	46.6
1982	326	17.5	57.1
1983	361	19.2	69.3
1984	394	21.0	82.7
1985	431	23.2	100.0
1986	472	25.3	119.0
1987	518	28.0	145.0
1988	568	30.0	170.0

FIG. IV · 2

DERIVACION DE LA INCERTIDUMBRE DE LA PROYECCION DE CARGA

DERIVATION OF LOAD FORECAST UNCERTAINTY

PLOTEO PROBABILISTICO DE 1988

PROBABILITY PLOT 1988

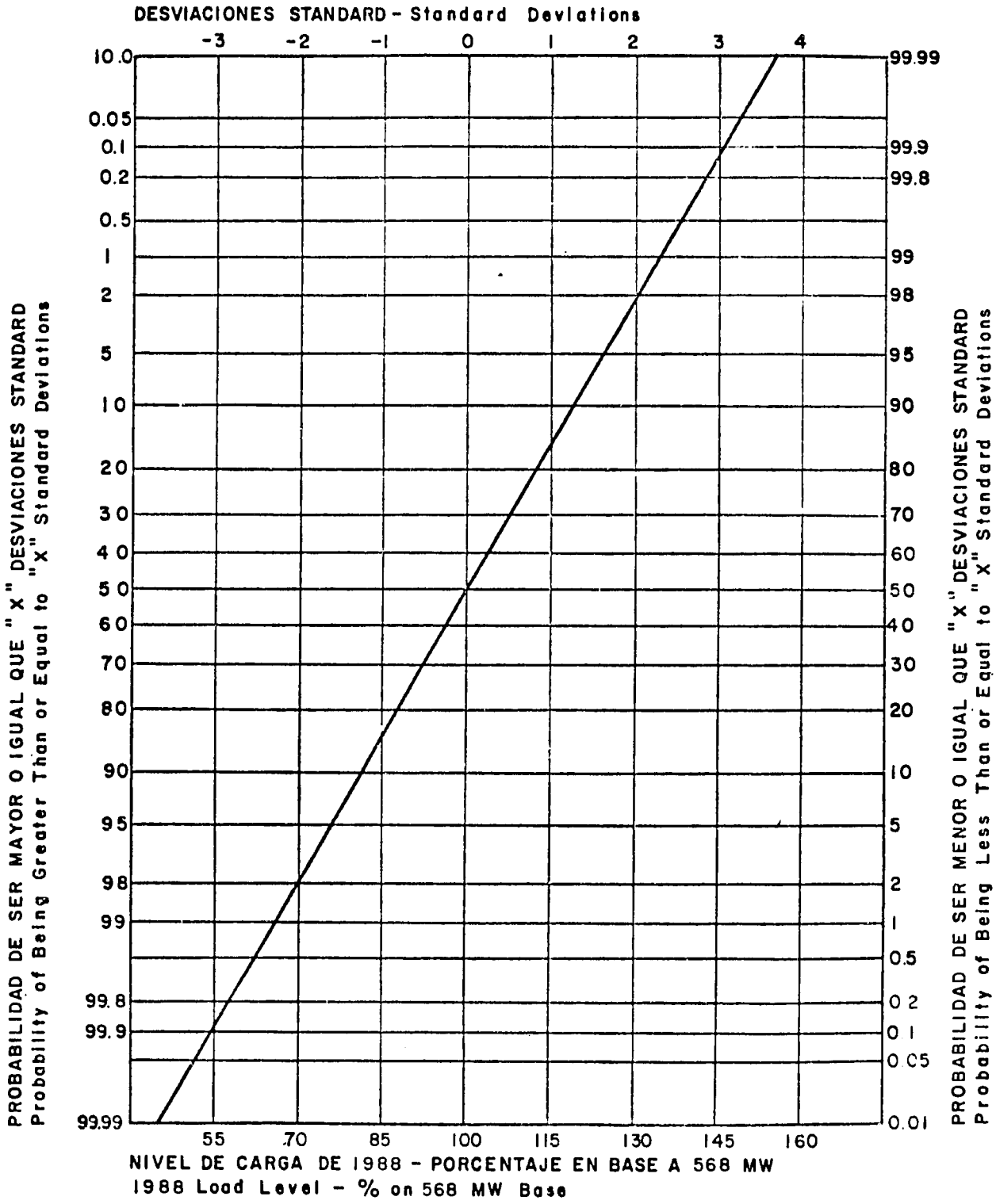


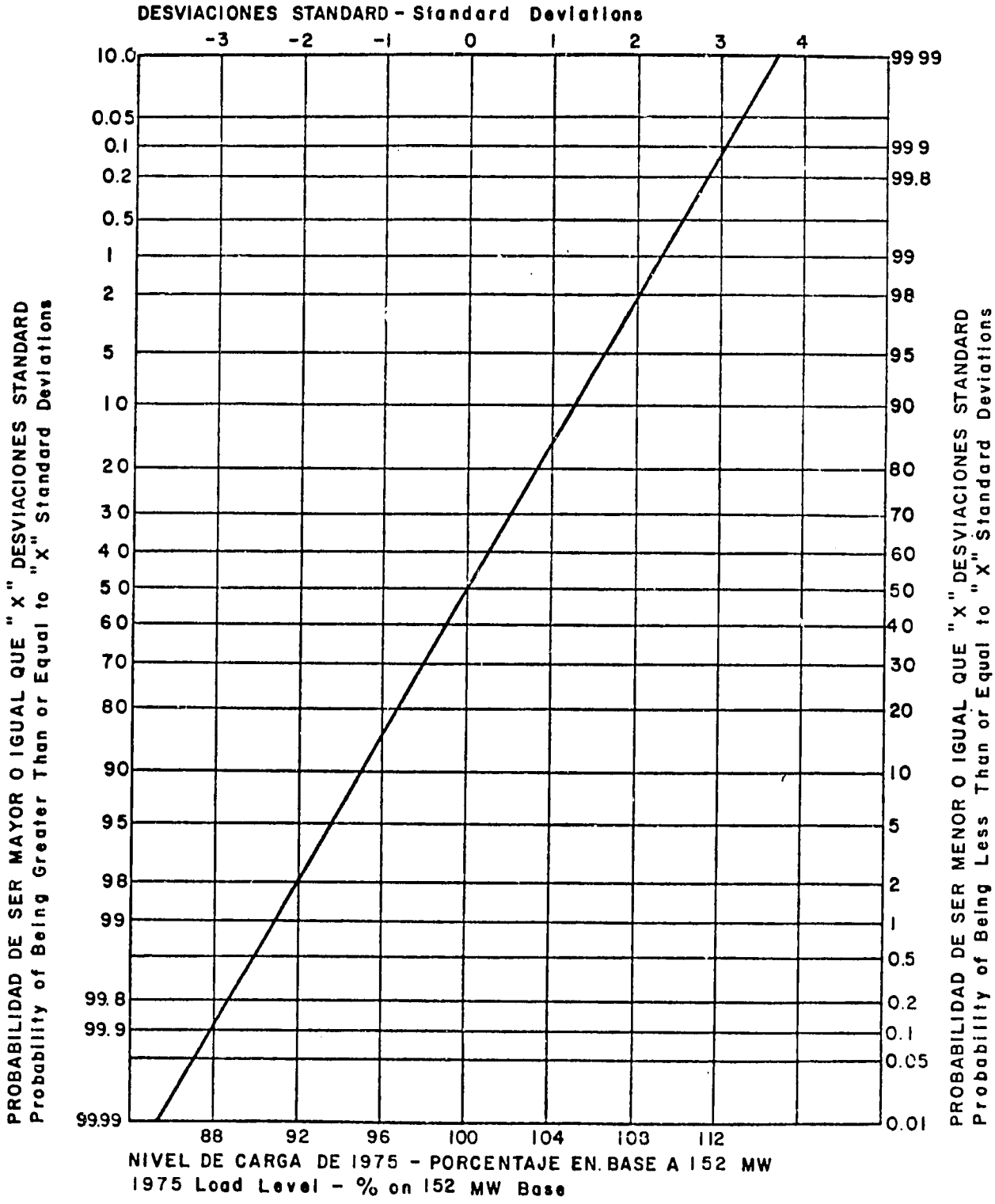
FIG. IV · 3

DERIVACION DE LA INCERTIDUMBRE DE LA PROYECCION DE CARGA

DERIVATION OF LOAD FORECAST UNCERTAINTY

PLOTEO PROBABILISTICO DE 1975

PROBABILITY PLOT 1975

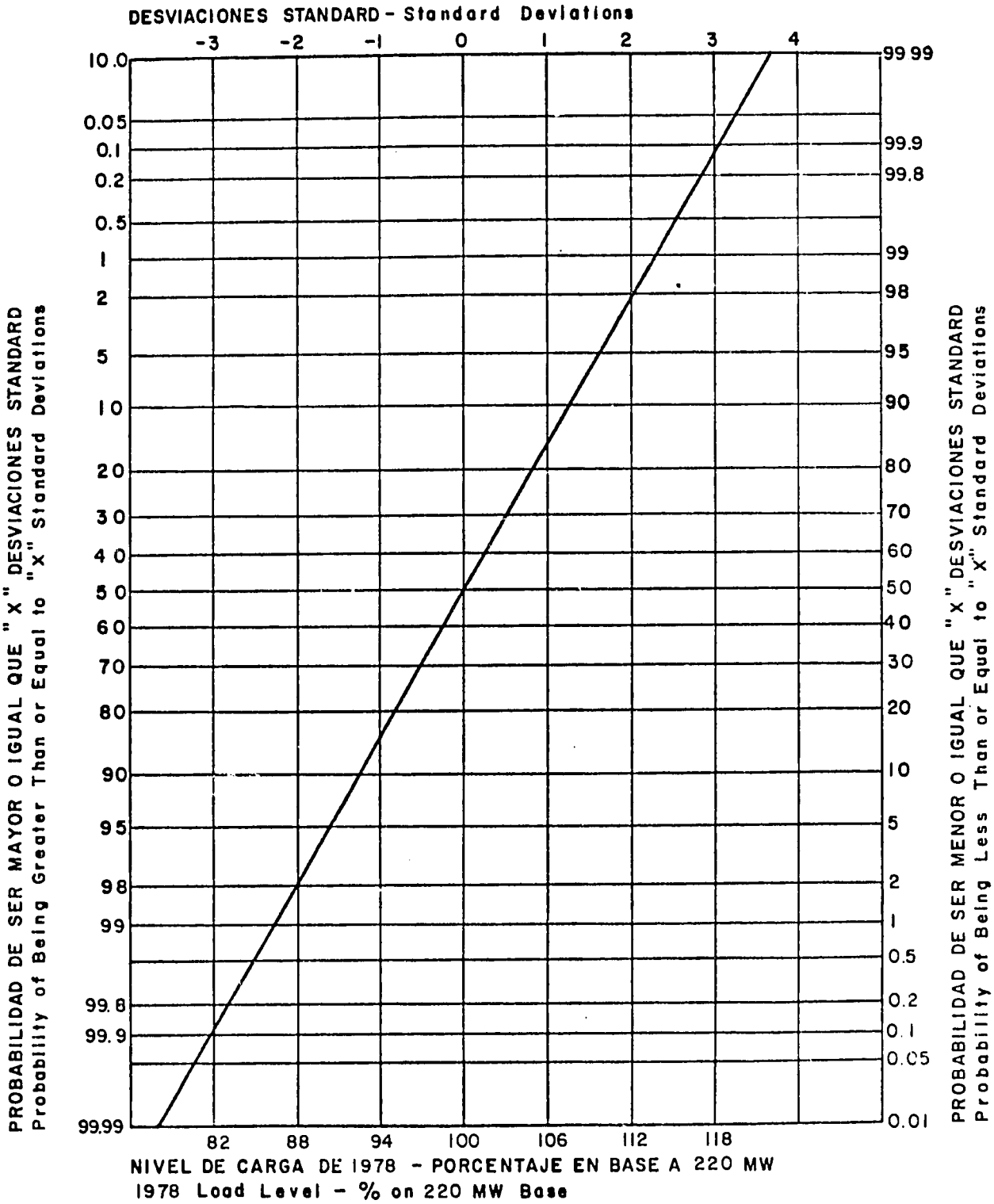


DERIVACION DE LA INCERTIDUMBRE DE LA PROYECCION DE CARGA

DERIVATION OF LOAD FORECAST UNCERTAINTY

PLOTEO PROBABILISTICO DE 1978

PROBABILITY PLOT 1978



DERIVACION DE LA INCERTIDUMBRE DE LA PROYECCION DE CARGA

DERIVATION OF LOAD FORECAST UNCERTAINTY

PLOTEO PROBABILISTICO DE 1983
PROBABILITY PLOT 1983

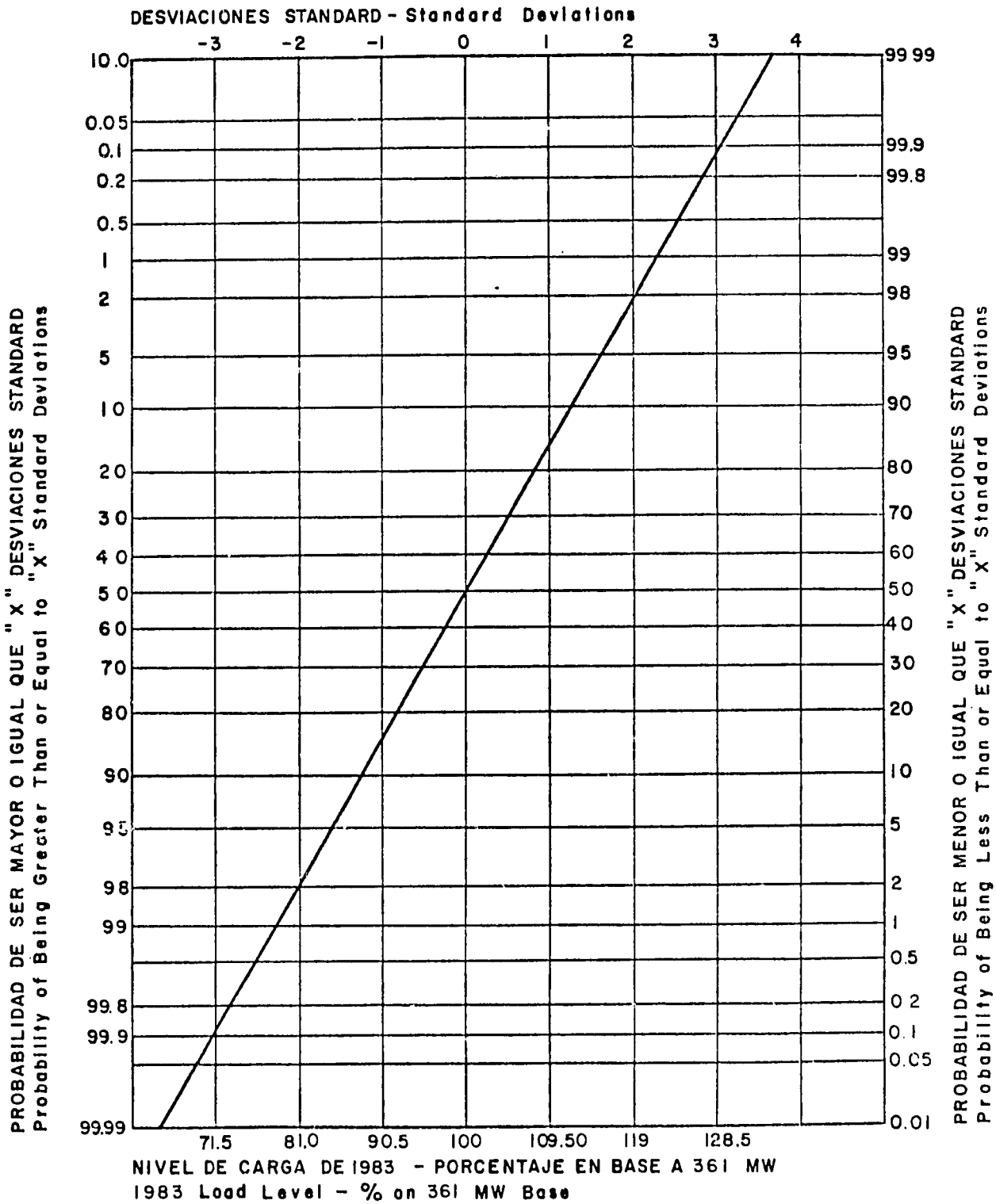
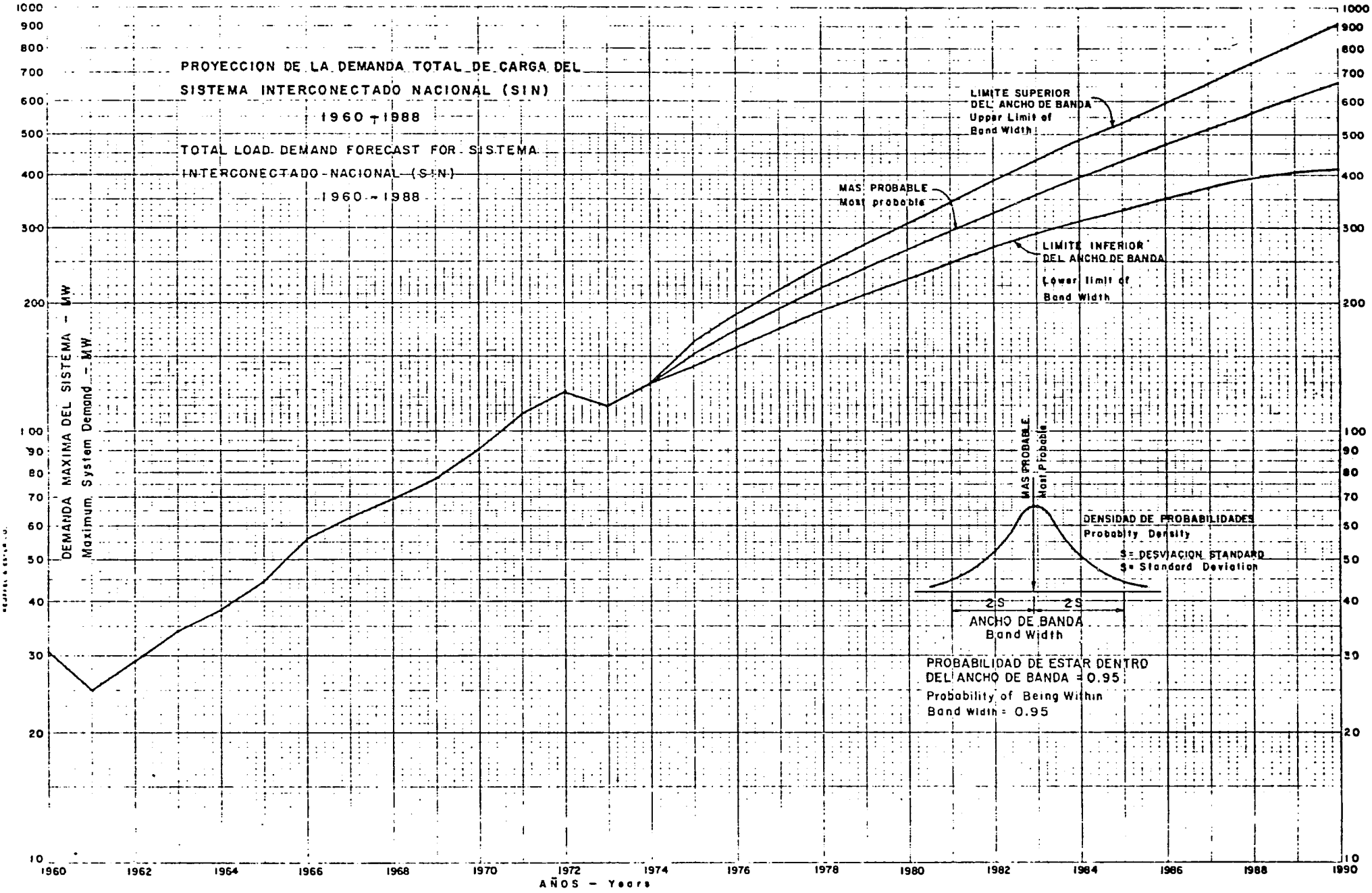


FIG. IV - 6


PROYECCION DE LA DEMANDA TOTAL DE CARGA DEL SISTEMA INTERCONECTADO NACIONAL (SIN)
1960 - 1988
TOTAL LOAD DEMAND FORECAST FOR SISTEMA INTERCONECTADO NACIONAL (SIN)
1960 - 1988
LIMITE SUPERIOR DEL ANCHO DE BANDA
Upper Limit of Band Width
MAS PROBABLE
Most probable
LIMITE INFERIOR DEL ANCHO DE BANDA
Lower limit of Band Width
DEMANDA MAXIMA DEL SISTEMA - MW
Maximum System Demand - MW
MAS PROBABLE
Most Probable
DENSIDAD DE PROBABILIDADES
Probability Density
S = DESVIACION STANDARD
S = Standard Deviation
2S
2S
ANCHO DE BANDA
Band Width
PROBABILIDAD DE ESTAR DENTRO DEL ANCHO DE BANDA = 0.95
Probability of Being Within Band Width = 0.95
AÑOS - Years

This step in the analysis allowed the inclusion of load forecast uncertainty in ENALUF"s loss-of-load probability (LOLP) program, which was then used to determine adequacy of generation resources.

Table IV.2 summarizes the forecast megawatt demand values corresponding to the probability multipliers shown in Figure IV.1B. These values were then used in ensuing generation planning studies.

TABLE IV.2

FORECAST MEGAWATT DEMAND VALUES
CORRESPONDING TO PROBABILITY MULTIPLIERS

YEAR	-2S Load Level (MW)	-1S Load Level (MW)	Most Probable (MW)	+1S Load Level (MW)	+2S Load Level (MW)
1975	140	146	152	158	164
1976	156	164	172	180	188
1977	174	184	194	204	214
1978	194	207	220	233	245
1979	210	225	241	257	272
1980	227	247	266	285	304
1981	248	272	295	318	242
1982	269	297	326	355	383
1983	292	326	361	396	430
1984	311	353	394	435	477
1985	331	381	431	481	531
1986	353	412	472	532	591
1987	387	452	518	584	663
1988	398	483	568	653	738

S = Standard Deviation

Probability Multipliers: Most Probable = 0.383
$\pm$ 1S = 0.242
$\pm$ 2S = 0.0665

4.2.2 GENERATION RESERVE AND SYSTEM RELIABILITY

The analysis of generation reliability for the system expansion plans, formulated for economic comparison, requires the selection of a system generation risk level to set a common standard for preferred reliability, by which alternative plans will be measured. In establishing the risk level, one of the most important considerations involved was to ascertain the relation between the standard of reliability and its worth to the national economy.

The criteria previously used by ENALUF for generation planning were examined to determine their adequacy for long-range planning. Present standards require two

conditions to be satisfied in relation to standby reserve and probabilistic reliability criteria, respectively. The first condition requires that the installed reserve margin be sufficient to allow for the loss of the largest system risk, either a generating unit or interconnection, after deduction of generating capacity on scheduled maintenance. The second system requirement is that sufficient generating capacity be installed to ensure that the probability of generation outages will cause the risk of capacity shortages to be limited to a total of 1.0 day per year. This second condition provides the basis for setting the preferred risk level during analysis of generation expansion plans using methodology pertaining to loss-of-load probability (LOLP). In this study, it was intended that a closer examination of reserve margins would be made, in order to set reliability criteria that would be more representative of the risk level required to balance the cost of reserve margin provision for sustained system reliability, with the penalties which would otherwise be incurred in the form of losses to the economy.

Appendix C contains a technical paper 1/, prepared during the course of the study by members of the project staff, which was directed to the redefinition of a preferred risk level for the ENALUF system. This was determined by a quantitative analysis of the marginal cost of supply, including reserve margin; and the marginal cost of losses to the consumer, as measured in terms of an overall reduction to Gross Domestic Product (GDP).

The marginal cost of supply is susceptible to fairly precise analysis over a range of cost values, representative of different levels of investment for generation facilities. However, the marginal cost of interruptions to normal power supply requires the application of a high degree of judgement, in the estimation of the extent to which the overall GDP is affected by outages causing power supply interruptions. It was assumed that direct losses to GDP were caused by power supply interruptions to customers within the secondary and service sectors of the economy. A rationale was developed to apportion the effect of supply interruptions to energy consumers within the primary sector of the economy, composed principally of agricultural customers.

Thus, on the basis of 1974 statistics for sectoral energy consumption, given in Table 1 of the paper, it was estimated that only 10 percent of the primary sector would be susceptible to losses caused by supply interruption.

As the primary sector contributes approximately 25 percent of the total GDP, the availability of electrical supply was estimated to have a direct effect on a maximum of 77 percent of the total annual GDP. The resultant risk level selected was 0.6 days per year based on analysis conducted for the year 1982, this being the year during which the initial unit installations would be scheduled for the major hydroelectric power development on the Rio Grande de Matagalpa.

1/ Adequacy of Supply for the National Interconnected Power System of Nicaragua. Selection of a Risk Level for Generation Planning. Presented at the IEEE Sixth Central American Convention, August 1975.

The system risk level selected is sensitive to the reserve margin determined by the marginal cost analysis, which in turn is very much dependent on the estimated proportion of GDP directly affected by supply interruptions. The present reliability standards used by ENALUF based on the LOLP risk index of 1.0 day per year, would correspond to a 21 percent reserve margin. This reduction in reserve level entailing the higher index, would be supportable if either the investment cost for generation facilities is increased, or the proportion of total GDP affected by power interruptions decreased. The following summary tabulations are included to indicate the approximate limits to the risk level, for the cost of new generation developed during the course of this study and the conditions under which the present ENALUF risk level would still hold.

COMPARISON OF PARAMETERS PERTAINING TO RESERVE MARGIN
AND
SELECTION OF GENERATION RELIABILITY CRITERIA

RESERVE MARGIN - 21 PERCENT

ENALUF SYSTEM RISK LEVEL - 1.0 DAY PER YEAR

1975 Cost Level for Generation	US$ 700/KW		US$ 900/KW	
Percentage Carrying Charge Rate	12%	15%	12%	15%
Percentage Impact on GDP	44%	52%	55%	70%

RESERVE MARGIN - 25 PERCENT

PREFERRED SYSTEM RISK LEVEL - 0.6 DAYS PER YEAR

1975 Cost Level for Generation	US$ 700/KW		US$ 900/KW	
Percentage Carrying Charge Rate	12%	15%	12%	15%
Percentage Impact on GDP	63%	78%	80%	100%

It may be concluded that a certain degree of latitude must be observed when applying the preferred risk level during generation expansion planning. The cost levels presented in the paper and in the above tabulation are referenced to 1975 estimates but the marginal cost analysis included provision for cost escalation. If the basis for escalation changes then a reassessment of the reserve margin would be in order, as this directly relates to the marginal cost to supply.

Close examination of the impact of interruptions to the power supply on the economy, as measured by the diminution of GDP, would be necessary to determine a more precise estimate of the overall effect of system reserve margins. It is conceivable that the 77 percent proportion advocated in the paper would be reduced still further by judicious scrutiny of the economic effect of power outages based on extensive research.

It suffices for the purpose of this study, to limit annual system risk levels to the extent that the present standard of 1.0 day per year is not exceeded, within the constraints of project construction scheduling. Where possible, the risk level will be reduced using the 0.6 day per year index, as the the preferred optimum limit for the probability analysis of generation expansion.

4.2.3 LOAD MODEL FOR NATIONAL INTERCONNECTED SYSTEM

An existing load model for the ENALUF service area of the National Interconnected System was used for the production costing study, based on data obtained from load records for the year 1972. It was considered that this year had a more typical annual load cycle despite the anomalous December earthquake. The more usual peak load of ENALUF is experienced in mid-December rather than in the Spring, although the historical load record indicates peak loads in February and March for the years 1969 and 1971, respectively. Normal December peak loads were experienced in the years 1968, 1970, 1972 and 1973. In 1974, the annual load cycle exhibited a Spring peak on the 21st of March, with an end of year peak on December 15, which was almost identical in load demand.

The load duration curve and annual load cycle for 1974 are shown on Figures D.1 and D.2 of Appendix D, respectively. The daily load cycle for the annual peak demand day of 1974 is shown on Figure D.3

4.3 TRANSMISSION SYSTEM RELIABILITY CRITERIA

The current and planned development of the national interconnected transmission grid, justified adoption of a more rigorous criteria for transmission planning. Accordingly, transmission system reliability criteria were developed for the ENALUF system and submitted during the Phase I portion of this study, reference Phase I Report - Appendix IIB.

The objective of the criteria is to provide a basis for designing a reliable power transmission system taking into account continuity of service, as affected by the probable outages of system facilities, balanced against capital investment required for preservation of reliability standards.

To summarize, the criteria defines acceptable system operating conditions and provides the basis for recommending facility additions, to solve system problems caused by likely contingency outages. Likely contingencies are defined in the system reliability criteria in terms of N-1 components in service, N-1 generators or N-1 lines, assuming any one generator initially out of service. Transmission system components include lines, breakers, transformers, capacitors, reactors and associated equipment, at transmission voltages of 138 kV and above.

In this study, the transmission system was designed to meet or exceed these criteria. However where extraordinary expenditures were required or a proposed design failed to meet the criteria, the reasons, related costs and risks involved for each case were documented, these being summarized in Chapter VII.

CAPITULO V

PLANES DE EXPANSION DE LA GENERACION

CHAPTER V

GENERATION EXPANSION PLANS

CHAPTER V

GENERATION EXPANSION PLANS

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CHAPTER V

GENERATION EXPANSION PLANS

5.1 EXISTING GENERATION AND COMMITTED PLANT

The total generation sources of the ENALUF interconnected system provide 183 megawatts of effective capacity from the combined hydro/thermal mix. Based on a total nameplate capacity of 203 megawatts, the division of the resource mix is such that 50 percent of generation is provided by pondage hydro plants, 40 percent by oil-fired thermal plant and the remaining 10 percent by gas-turbine and diesel generating units.

This is the basic composition of the system from which expansion plans are formulated, so within the constraints of resource availability, it is necessary that these existing plants be utilized for future operation, consistent with the overall economics of system supply.

5.1.2 EXISTING HYDRO PLANTS

Two pondage hydro plants are presently in operation, these being the Centroamerica Plant and the Somoza Garcia Plant. These two plants have similar power installations, each consisting of two 25,000 kilowatt nameplate rated units. The effective operating capacities at minimum head conditions are 48 and 46 megawatts, respectively, at the Centroamerica and Somoza Garcia plants.

The average annual energy availability is 395 GWH, with the pondage hydro plants of the system operated throughout the year on an average annual plant capacity factor of 48 percent. This mid-range operation is assumed to continue throughout the development period to 1988, with the total available energy dispatched to follow the annual load curve.

5.1.2 EXISTING THERMAL PLANTS

The thermal generation of the existing system is mainly concentrated at the Managua Plant, which provides a total effective operating capacity of 72,500 kilowatts. The installation consists of three oil-fired thermal units; two 16,500 kilowatt and one 49,500 kilowatt, together with three 750 kilowatt diesel generating units.

In addition, a single 15,000 kilowatt gas-turbine unit, located at Chinandega to the northwest of Managua, provides an effective operating capacity of 14,000 kilowatts to the interconnected system. Diesel generation is also located in Rivas, southeast of Managua, with a four unit installation providing 2,050 kilowatts of effective operating capacity, based on a combined nameplate rating of 3,330 kilowatts.

The third unit at the Managua Plant was placed in service during February, 1971 and, with an effective operating capacity of 45 megawatts, is the largest and most efficient thermal unit of the existing system. The unit is operated on base-load to complement the operation of the Centroamerica and Somoza Garcia hydro plants, which operate with average plant capacity factors of 50 and 40 percent, respectively. The two smaller capacity oil-fired thermal units of

the Managua Plant each have an effective operating capacity of 13,000 kilowatts. These are operated to meet system peak load requirements and provide a margin of standby and spinning reserve. The three diesel units at the Managua Plant represent standby reserve capability at the system load center.

The gas-turbine is a useful component for peaking and standby reserve, in addition to providing base-load supply for emergency operation, as occurred following the 1972 earthquake.

In the future, following the introduction of new generating plant, the smaller capacity, less efficient thermal units will form part of the system reserve, with the diesel units on permanent standby.

5.1.3 PUERTO SOMOZA OIL-FIRED THERMAL PLANT

The next major addition to generating capacity supplying the interconnected system will be the two unit thermal plant, located at Tiscuco near Puerto Somoza on the Pacific Coast. As presently scheduled, the first 50 megawatt unit at the Puerto Somoza Plant will be placed in service during September 1976, to be followed by a second, identical unit in December 1976 or early 1977.

The plant design is suitable for two units, each nominal 50 MW turbine-generator unit being supplied with steam from a 470,000 pounds per hour steam generating unit, operating at 1300 p.s.i.g. and 960°F at the superheater outlet. The steam generating units will be of the pressurized furnace design, suitable for burning Bunker C oil as primary fuel and light oil for emergency operation.

Each turbine-generator unit will consist of a condensing turbine operating at 3600 R.P.M., with steam conditions of 1250 p.s.i.g. and 950°F at the throttle, coupled to a hydrogen-cooled generator rated 53,000 KW, 0.85 PF, 62,000 KVA, 13.8 KV, 3 phase, 60 cycles. The unit condenser will operate with a normal back-pressure of 2-1/4 inches Hg absolute. Cooling water will be drawn from the ocean and returned via a stilling basin to a nearby estuary.

Each unit transformer will have a FOA rating of 60,000 KVA and will step-up from 13.8 KV generator voltage to 230 kV for switching at the plant substation. Transmission lines terminated at the plant 230 kV switchyard, will connect the Puerto Somoza plant to the Leon and Los Brasiles substations.

The effect of the introduction of these two units to the system will be to change the existing hydro/thermal ratio to a value of approximately 1:2, which will result in a predominantly thermal based-system in the years 1977 and 1978. The two units will provide energy to satisfy base-load requirements, until the introduction of major increments of geothermal plant capacity. In addition, firm energy generated at the Puerto Somoza plant will be transmitted to the ENEE system of Honduras over the 230 kV interconnection, to be commissioned in 1976.

5.2 GEOTHERMAL POWER DEVELOPMENT

The impact of the large increase in fuel oil costs has rendered imperative, the need to fully utilize indigenous sources of energy such as geothermal resources as a substitute for the extended use of imported oil for base-load generation.

The prospects for geothermal development in Nicaragua are good, with the principal prospect areas located in the vicinity of Momotombo Volcano, and San Jacinto.

Estimates have been made of the power capacity that could be supported by the geothermal reservoirs, based upon field surveys and previous test drilling. However, until a more definitive assessment of the geothermal reserves is possible, it is prudent to adopt a conservative approach to the planned limits for geothermal power development. In this study, the total geothermal power plant capacity included in generation expansion plans is less than previous UNDP estimates of the capacity that could be supported by geothermal reserves.

5.2.1 PLANNED CAPACITY INSTALLATIONS

The field development program currently underway has the present objective of completing the drilling of four exploration wells, to enable sufficient experience and test data to be gained for the completion of a feasibility report on the prospects for geothermal generation at Momotombo.

In a previous report [1/] prepared under the auspices of the UNDP, a total planned capacity of 140 megawatts was projected as a realistic target, based on the results of field investigations which indicated that the Momotombo geothermal area could support a power installation in excess of 150 megawatts. The plan envisaged an initial installation of two 10 megawatt units in December 1976, followed by a period of intensive production well drilling, sufficient to support an additional 120 megawatts of plant capacity. The construction program would entail the installation of a two-unit, 60 megawatt power plant in the period 1979-1980, followed by an identical plant, to be completed within the period 1981-1982, the unit size considered being 30 megawatt for both plants.

The economics of geothermal installations are directly related to the unit cost associated with the plant. Therefore, normal economies of scale would suggest that rather than a combination of 10 and 30 megawatt unit sizes, the most economical installation would consist of multiple units, each unit having a rating of 45 megawatts. This capacity corresponds approximately to the rating of the largest thermal units on the ENALUF system and is in addition less than the normal design limits for geothermal units. Accordingly, three 45 megawatt units have been included in generation expansion plans, to provide a total installed capacity of 135 megawatts by the end of 1981.

5.2.2 PROGRESS WITH FIELD DRILLING PROGRAM

The present steam well drilling program is directed toward the completion of four deep exploration boreholes, to demonstrate the potential of the Momotombo field as a source of commercially exploitable steam. The FORAMINES drilling company is conducting field drilling operations under the supervision of ELECTROCONSULT, who will also complete the feasibility study for the geothermal development based on the results of the steam testing program.

1/ Geothermal Resources Development NIC/71/510 - Report on the Status of the Project and Tentative Development Plan for Geothermal Energy in Nicaragua, UNDP, June 1973.

The first well was drilled to a depth of 695 meters with an initial release of steam, but the characteristic of the well indicated that the yield will not support generation, due to a temperature inversion at depth.

The second well was successful, being completed in April 1975 and was opened to atmosphere in June, 1975. A series of steam tests are presently being conducted by ELECTROCONSULT to provide basic data for the feasibility study.

During the drilling of the third well, an unfortunate blow-out took place, at a depth of 298 meters. The occurrence took place on June 23, 1975 since that date the well was brought under control and drilling was resumed during August.

5.2.3 SCHEDULE REQUIRED TO MEET SYSTEM GROWTH

The introduction of geothermal generating units has been planned such that system reliability requirements are met, with sufficient lead-time following the demonstration of feasibility, to allow for manufacture of the turbine-generator units and the extended production drilling program required to supply sufficient steam to support generation.

In order to maintain a system generation reliability risk level which corresponds to a LOLP index of 1.0 day/year or less, the first 45 megawatt geothermal unit will be required at the end of the first quarter of 1979. The additional generating capacity will thus be in service to meet the spring peak load on the system and subsequent energy generation will be available to the system during the dry season,to enable substitution of geothermal for thermal generation.

An elapsed time of approximately 15 months is allowed, before the second 45 megawatt unit is scheduled for commissioning in mid-year 1980. The maintenance periods are arranged, such that the first unit is scheduled to go on maintenance as the second unit is placed in service, to preserve continuity of generation.

The third unit is scheduled for service at the beginning of the last quarter of 1981, with a similar allowance of 15 months between the introduction of Units 2 and 3. This schedule allows the second unit to go on maintenance as the third unit goes on-line and preserves the system risk levels as given below:

Year	1979	1980	1981
Risk Level - Days/Year	0.94	0.62	0.87

It is possible that this schedule could be improved, should conditions allow the earlier introduction of Units 2 and 3. However, the plan for unit introduction assumes that a fairly optimistic schedule for the development of geothermal resources will enable system risk levels to be maintained as indicated above. These are quite adequate to meet the generation reliability criteria established in Section 4.2.2 of Chapter IV.

The development of firm geothermal capacity earlier than 1979, would improve the system risk level for 1978 but this possibility is dependent upon field drilling progress and the acceleration of schedules for introduction of feasible generating plants.

5.3 DEVELOPMENT OF THE RIO GRANDE DE MATAGALPA HYDRO POTENTIAL

The most assured sources to be included in future expansion plans are the hydroelectric power developments on the Rio Grande de Matagalpa and these are more susceptible to definitive scheduling for an extended construction period. As a definite limit, of 135 megawatts,has been assumed for the geothermal plant installed capacity, the introduction of hydroelectric plant capacity is necessary in the latter part of 1982, in order to preserve system risk levels that accord with the criteria established in Section 4.2.2. This is predicated on the basis of an independent system expansion,relying mainly on the development of indigenous resources, with no expansion of thermal generation.

5.3.1 SELECTION BETWEEN ALTERNATIVE HYDRO DEVELOPMENTS

The results of Phase I of the prefeasibility investigation indicated that two alternative developments were worthy of detailed comparison, to examine the relative merits of each scheme. The technical aspects of the two and three dam alternatives are discussed in Chapter III of this report on Phase II of the prefeasibility study. However, to determine the relative economic advantages of the two schemes, an economic analysis was made to compare the effect of the inclusion of one or other of the schemes in overall system expansion plans.

A combination of a high dam at Copalar together with Paso Real was examined at the system level, in comparison with the second alternative of a low dam at the Copalar site, in combination with the El Carmen and Paso Real developments. A close comparison was made of the two alternative hydro development schemes set in context of the entire system expansion, including existing hydro plants, geothermal power developments and supporting thermal plants, together with their respective transmission system components. In this way the economic trade-off's between levels of plant investment associated with the two schemes and respective thermal production costs, determine the most economic hydro development to include in the basic plan for system expansion. The larger investment costs of the high dam at Copalar are offset by the additional hydroelectric energy available with this alternative. The principal determinant, bearing on project selection, is the relative production costs associated with the thermal energy required to support the two and three dam alternatives. The results of the economic comparison are given in Chapter VIII.

5.3.2 SCHEDULING OF ALTERNATIVE HYDRO DEVELOPMENTS

The inclusion of alternative hydro power sources in generation expansion plans, corresponding to either the two or three dam development schemes, requires the scheduling of unit additions within normal construction restraints, to satisfy generation reliability risk levels established according to the criteria of Section 4.2.2.

The downstream site of Copalar is to be developed first for both the two and three dam alternatives, so initial generating capacity additions will be provided by the first two unit installations for either the high or low dam alternatives at the Copalar site.

The lead time necessary for completion of a feasibility study, financial arrangements, engineering design and construction of either a high or low dam at Copalar will require a minimum of seven years to bring the first power on line. This allows the most optimistic in-service scheduling of the initial units for the end of year 1982.

Figures V.1 and V.2 indicate the scheduled increments of generating capacity for the two and three dam development alternatives, in relation to the growth of peak load on the Sistema Interconectado Nacional (S.I.N.). These charts are shown for independent system expansion, without recourse to purchased power over transmission interconnections.

In the case of the high dam, the reservoir will require the run-off corresponding to three wet seasons to fill completely and so the normal maximum reservoir elevation will not be reached until the end of year 1984. The total installed capacity will then be 330 megawatts, comprising six 55 megawatt units. After the initial installation of two 55 megawatt units in November 1982, the remaining four units will be scheduled for service, at intervals of approximately six months through the end of year 1984. The two 25 megawatt units of the Paso Real power plant will be brought into service at the end of year 1988, to complete the two dam development.

The scheduling of the three dam development requires a staged development at the Copalar low dam, in order to minimize overlap between Copalar and El Carmen construction schedules. After the initial two unit installation in November 1982, a third 55 megawatt unit is scheduled for May 1983, to complete the first stage construction. The El Carmen power plant will consist of two 35 megawatt units, these being introduced at the beginning of year 1986, to be followed in 1987 by the second stage installation at Copalar. The total plant complement at the Copalar low dam will be 275 megawatts, this being reached by the addition of two additional 55 megawatt units, one in January and the second in July 1987. To complete the three dam development the two 25 megawatt units at Paso Real are introduced at the end of year 1988, similar to the two dam scheme.

The detailed work schedules for the two and three dam developments are shown on Annexes III-14 and III-15 to Chapter III.

Both of the alternative development schemes satisfy the system requirements for the planned expansion to 1988, the differential installed capacity between the two developments being 15 megawatts. This corresponds to the difference in installed capacity of the two 35 megawatt units at the El Carmen plant, over the sixth 55 megawatt unit at the Copalar high dam. The identical installations at Paso Real in 1988, superimposed on the alternative generation expansions for the two and three dam developments, result in different levels of system reliability in that year. However, both are well within the preferred risk limit but additional generation will be required in the following year, 1989, to maintain generation reliability according to system criteria.

It is recommended that serious consideration be given to continuing the development of hydroelectric resources in the same geographical area, logical choices for power developments being within the Tuma River Basin and at the Tumarin site, located downstream of Copalar on the Rio Grande de Matagalpa.

FIG. V-1

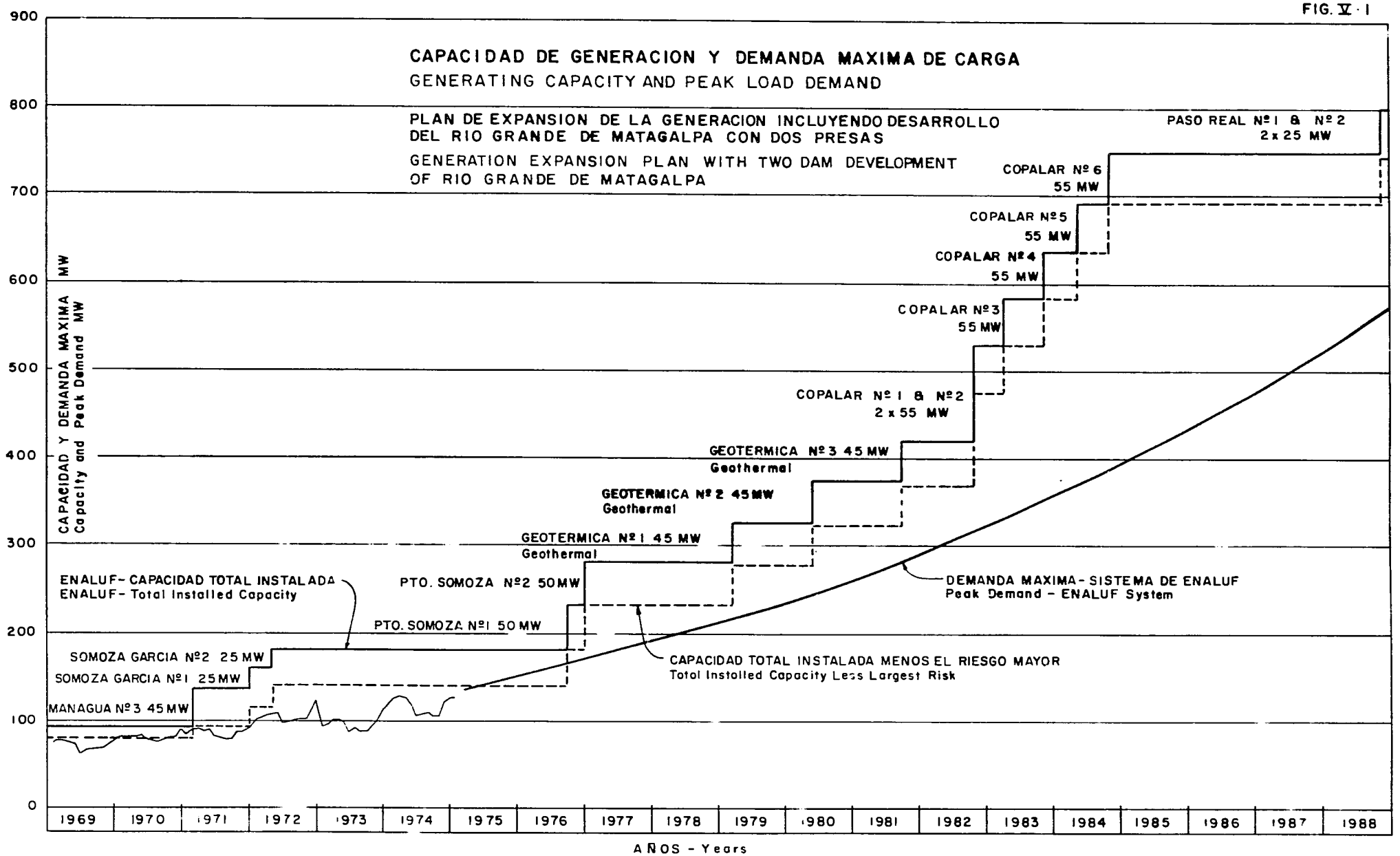
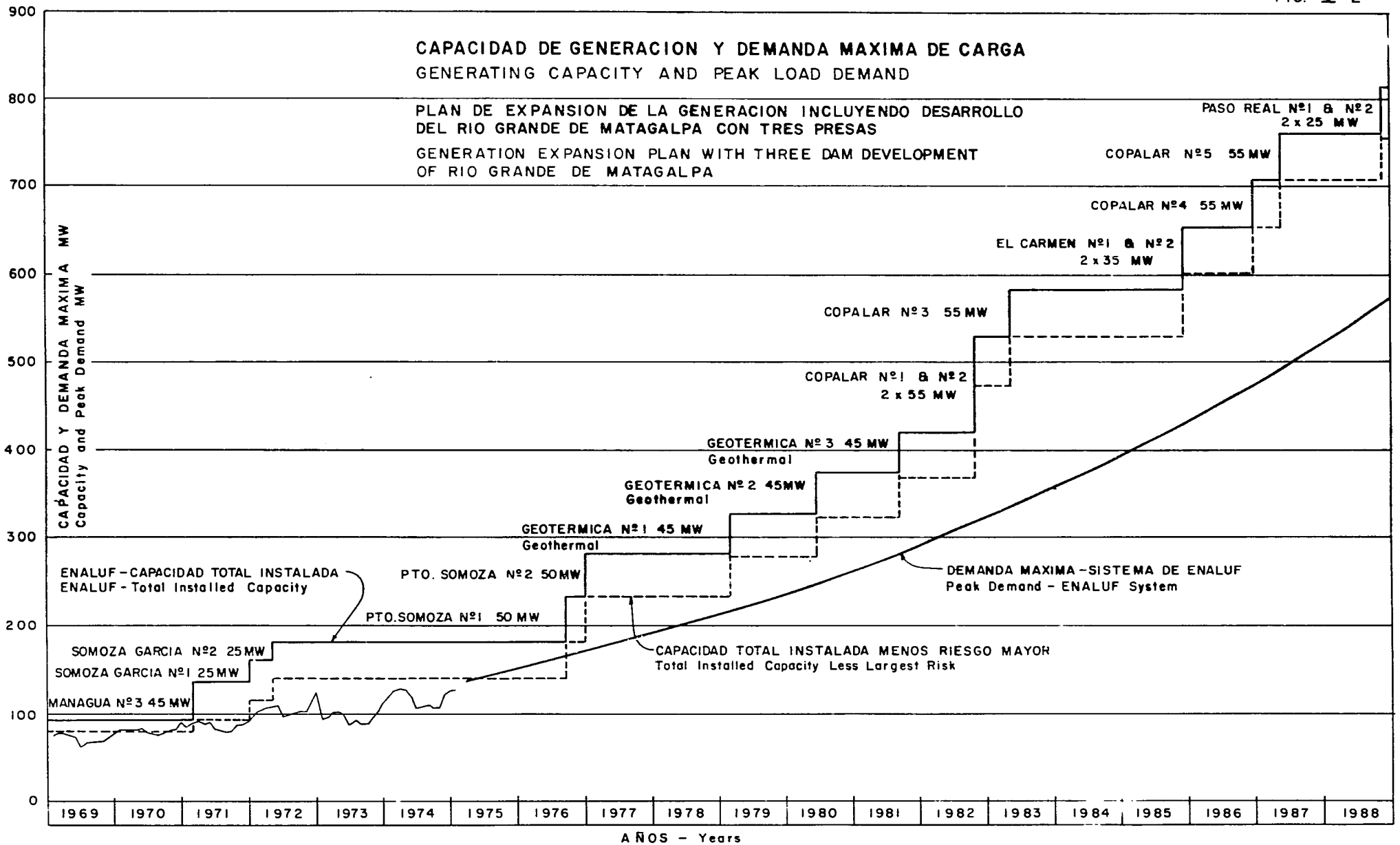

CAPACIDAD DE GENERACION Y DEMANDA MAXIMA DE CARGA
GENERATING CAPACITY AND PEAK LOAD DEMAND
PLAN DE EXPANSION DE LA GENERACION INCLUYENDO DESARROLLO DEL RIO GRANDE DE MATAGALPA CON DOS PRESAS
GENERATION EXPANSION PLAN WITH TWO DAM DEVELOPMENT OF RIO GRANDE DE MATAGALPA
CAPACIDAD Y DEMANDA MAXIMA MW
Capacity and Peak Demand MW
900
800
700
600
500
400
300
200
100
0
PASO REAL Nº1 & Nº2
2 x 25 MW
COPALAR Nº6
55 MW
COPALAR Nº5
55 MW
COPALAR Nº4
55 MW
COPALAR Nº3
55 MW
COPALAR Nº1 & Nº2
2 x 55 MW
GEOTERMICA Nº3 45 MW
Geothermal
GEOTERMICA Nº2 45 MW
Geothermal
GEOTERMICA Nº1 45 MW
Geothermal
PTO. SOMOZA Nº2 50 MW
PTO. SOMOZA Nº1 50 MW
SOMOZA GARCIA Nº2 25 MW
SOMOZA GARCIA Nº1 25 MW
MANAGUA Nº3 45 MW
ENALUF- CAPACIDAD TOTAL INSTALADA
ENALUF- Total Installed Capacity
DEMANDA MAXIMA- SISTEMA DE ENALUF
Peak Demand - ENALUF System
CAPACIDAD TOTAL INSTALADA MENOS EL RIESGO MAYOR
Total Installed Capacity Less Largest Risk
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
AÑOS - Years

FIG. V-2


CAPACIDAD DE GENERACION Y DEMANDA MAXIMA DE CARGA
GENERATING CAPACITY AND PEAK LOAD DEMAND
PLAN DE EXPANSION DE LA GENERACION INCLUYENDO DESARROLLO DEL RIO GRANDE DE MATAGALPA CON TRES PRESAS
GENERATION EXPANSION PLAN WITH THREE DAM DEVELOPMENT OF RIO GRANDE DE MATAGALPA
CAPACIDAD Y DEMANDA MAXIMA MW
Capacity and Peak Demand MW
900
800
700
600
500
400
300
200
100
0
PASO REAL Nº1 & Nº2 2 x 25 MW
COPALAR Nº5 55 MW
COPALAR Nº4 55 MW
EL CARMEN Nº1 & Nº2 2 x 35 MW
COPALAR Nº3 55 MW
COPALAR Nº1 & Nº2 2 x 55 MW
GEOTERMICA Nº 3 45 MW Geothermal
GEOTERMICA Nº 2 45MW Geothermal
GEOTERMICA Nº1 45 MW Geothermal
PTO. SOMOZA Nº2 50MW
PTO.SOMOZA Nº1 50 MW
SOMOZA GARCIA Nº2 25MW
SOMOZA GARCIA Nº1 25MW
MANAGUA Nº3 45 MW
ENALUF-CAPACIDAD TOTAL INSTALADA
ENALUF - Total Installed Capacity
DEMANDA MAXIMA-SISTEMA DE ENALUF
Peak Demand - ENALUF System
CAPACIDAD TOTAL INSTALADA MENOS RIESGO MAYOR
Total Installed Capacity Less Largest Risk
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
AÑOS - Years

5.3.3 CONSIDERATION OF OPERATIONAL CHARACTERISTICS

The introduction of hydro power, from sites on the Rio Grande de Matagalpa, necessitates the selection of appropriate plant operational characteristics. The existing hydroelectric plants of Centroamerica and Somoza Garcia operate with average annual plant capacity factors of 50 and 40 percent, respectively. The new plants to be introduced on the Rio Grande de Matagalpa are also intended to operate as intermediate-range supply sources, with annual plant capacity factors ranging from approximately 35 to 50 percent. A summary of the resultant plant capacity factors is given in the following tabulation.

COMPARISON OF ALTERNATIVE OPERATIONAL CHARACTERISTICS
FOR
RIO GRANDE DE MATAGALPA HYDROELECTRIC DEVELOPMENTS

Year	1983	1984	1985	1986	1987	1988	1989
Two - Dam Development							
Copalar (High Dam)	39.4	34.3	49.1	49.1	49.1	49.1	48.9
Paso Real	-	-	-	-	-	-	44.8
Three - Dam Development							
Copalar (Low Dam)	62.8	54.8	54.8	55.4	36.4	36.6	35.3
El Carmen	-	-	-	46.4	46.4	46.4	51.7
Paso Real	-	-	-	-	-	-	45.3

The Copalar high dam of the two dam development will operate at a lower than long-term average plant capacity factor during the first two years of operation, due to the fact that during this period the reservoir is still filling. The capacity factor of the plants, comprising the two alternative developments, are changed slightly due to regulation of stream flow by successive upstream developments.

5.4 RELIABILITY STUDY OF GENERATION EXPANSION PLANS

The generation expansion plans for the period 1978-1988 may be divided into two phases, beginning from the basic system projected for the year 1978, with the existing generation augmented by the addition of the two 50 megawatt thermal units at the Puerto Somoza Plant. The first phase consists of the staged development of geothermal power at Momotombo, three 45 megawatt units being scheduled for introduction over the period 1979-1981.

The year 1982 begins the second phase, with two alternative hydro power development schemes available for the staged introduction of generating plant through 1988. These two alternative developments are referred to as the two and three dam schemes, comprising, respectively, the high dam at Copalar with Paso Real and the low dam at Copalar with El Carmen and Paso Real. Each alternative has been examined as part of the overall study of generation reliability, the system risk level being measured in terms of the loss of load probability (LOLP) index for each year of the expansion. This index was computed using a program developed by ENALUF, with modifications recommended by IECO during the course of this study. A sample printout of this program, for the base system of 1978, is included as Annex C-1 of Appendix C.

5.4.1 LOSS OF LOAD PROBABILITY FOR TWO DAM SCHEME

A summary of the annual loss of load probability (LOLP) is contained in Table V.1, together with the unit introduction schedule and forced outage rates for the generation expansion plan, corresponding to the two-dam development scheme.

As discussed in Section 4.2.2, the criterion set for generation reliability is subject to constraints imposed by the construction schedule. Although the preferred reliability level for 1982 would be provided by a loss of load probability index of 0.6 days/year, this would entail the introduction of the first two units at Copalar as early as August 1982. As the reservoir is still filling during the wet season, in the latter half of the year, the first two units are not scheduled for initial service until the twelfth period, in November 1982. This schedule still enables a satisfactory generation reliability level to be attained, which corresponds to a loss of load probability index of approximately 1.0 day/year.

The LOLP index falls to a very low level in 1983 following the successive addition of Units 3 and 4 in May and November, respectively. The index of 0.006 indicates the system is exceedingly reliable and subject to a low probability of outages causing a critical loss of load carrying capability. This situation is further improved during 1984, after the installation of the remaining two Units 5 and 6, such that the security of supply is assured. During 1985 the system is at its most reliable level with a loss of load probability of 0.00001 days/year and Copalar fully developed, with the reservoir at normal operating levels following the final months of filling during the wet season of 1984. The annual index then increases in following years, due to load growth.

No more power installations are required until the latter part of 1988, when the two 25 megawatt units at Paso Real are brought into service during the twelfth period, to allow final reservoir filling during the wet season of 1988. A loss of load probability index of 0.79 days/year for 1988 indicates an adequate level of system reliability. To improve this to 0.6 days/year would require the Paso Real units to be scheduled for service as early as July 1988, which would not allow completion of reservoir filling prior to operation. The construction schedules and reservoir filling periods are then seen to be the principal determinants of system reliability, for the years 1982 and 1988.

The reason for a certain degree of latitude in regard to generation reliability risk levels is readily apparent, it is essential to maintain flexibility in order to accommodate tight construction schedules with constraints imposed by numerous exigencies.

TABLE V.1

UNIT INTRODUCTION SCHEDULE AND FORCED OUTAGE RATES FOR TWO-DAM DEVELOPMENT SCHEME AI

IN SERVICE DATE	EFFECTIVE CAPACITY MW	UNIT	No.	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Existing	25	Centroamerica	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	25	Centroamerica	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	25	Gral. Somoza G.	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	20	Gral. Somoza G.	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	15	Managua	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	15	Managua	2	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	45	Managua	3	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	15	Chinandega		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Sept. 1976	50	Puerto Somoza	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Dec. 1976	50	Puerto Somoza	2	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Mar. 1979	45	Momotombo	1		0.060	0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
June 1980	45	Momotombo	2			0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Oct. 1981	45	Momotombo	3				0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Nov. 1982	55	Copalar	1					0.020	0.020	0.010	0.010	0.010	0.010	0.010	0.010
Nov. 1982	55	Copalar	2					0.020	0.020	0.010	0.010	0.010	0.010	0.010	0.010
May 1983	55	Copalar	3						0.020	0.010	0.010	0.010	0.010	0.010	0.010
Nov. 1983	55	Copalar	4						0.020	0.010	0.010	0.010	0.010	0.010	0.010
May 1984	55	Copalar	5							0.010	0.010	0.010	0.010	0.010	0.010
Nov. 1984	55	Copalar	6							0.010	0.010	0.010	0.010	0.010	0.010
Nov. 1988	25	Paso Real	1											0.020	0.020
Nov. 1988	25	Paso Real	2											0.020	0.020

SUMMARY OF LOSS OF LOAD PROBABILITY (LOLP)

RISK LEVEL - DAYS/PERIOD

PERIOD	FROM:	TO:											
1	Jan. 1	Jan. 28	0.025585	0.135119	0.058168	0.027790	0.020784	0.000556	0.000005	0.000000	0.000013	0.000369	0.033174	0.101602
2	Jan. 29	Feb. 25	0.057554	0.312838	0.130044	0.076597	0.061865	0.002125	0.000034	0.000002	0.000098	0.002644	0.121665	0.337439
3	Feb. 26	Mar. 25	0.033330	0.150340	0.077922	0.040637	0.026088	0.000804	0.000006	0.000000	0.000015	0.000571	0.039853	0.135581
4	Mar. 26	Apr. 22	0.037686	0.020023	0.088947	0.045667	0.038585	0.001068	0.000011	0.000000	0.000042	0.001092	0.068656	0.181270
5	Apr. 23	May 20	0.028123	0.014179	0.062599	0.032735	0.029226	0.000799	0.000009	0.000000	0.000035	0.000964	0.042216	0.131842
6	May 21	Jun 17	0.028674	0.012839	0.063375	0.028368	0.280303	0.000334	0.000002	0.000003	0.000140	0.003524	0.181046	0.339246
7	Jun 18	July 15	0.014718	0.005273	0.029509	0.171651	0.110577	0.000112	0.000000	0.000001	0.000041	0.001098	0.054640	0.158072
8	Jul 16	Aug 12	0.275322	0.079344	0.031195	0.135403	0.077678	0.000062	0.000000	0.000000	0.000012	0.000359	0.029987	0.084781
9	Aug 13	Sep. 9	0.277594	0.078561	0.031089	0.136507	0.078414	0.000066	0.000000	0.000000	0.000014	0.000414	0.031044	0.085221
10	Sep 10	Oct 7	0.314883	0.084111	0.031436	0.142848	0.094854	0.000083	0.000000	0.000000	0.000024	0.000646	0.038577	0.131677
11	Oct 8	Nov 4	0.020483	0.009078	0.003132	0.023090	0.203676	0.000211	0.000001	0.000002	0.000089	0.002192	0.119740	0.267294
12	Nov 5	Dec 2	0.027708	0.012646	0.004513	0.002448	0.000037	0.000001	0.000000	0.000000	0.000019	0.000642	0.006089	0.118196
13	Dec 3	Dec 31	0.042850	0.023044	0.009307	0.004828	0.000099	0.000003	0.000000	0.000001	0.000126	0.002691	0.018624	0.227103

RISK LEVEL - DAYS/YEAR

ANNUAL LOSS OF LOAD PROBABILITY	1.184511	0.937395	0.620236	0.868569	1.022186	0.006224	0.000068	0.000010	0.000668	0.017206	0.792310	2.299325

The LOLP analysis for the year 1989, with generation levels set as of December 1988 with the initial forced outage rate (F.O.R.) of 0.02 assigned to each of the two Paso Real units, results in a LOLP index of 2.3 days/year. This indicates that additional generation will be required during 1989, to maintain recommended generation reliability levels.

5.4.2 LOSS OF LOAD PROBABILITY FOR THREE DAM SCHEME

The summary of the loss of load probability (LOLP) analysis, corresponding to the generation expansion containing the three dam development, is given in Table V.2, similar to that for the two dam development scheme.

The expansion is identical up to and including the year 1982; however, thereafter the LOLP indices correspond to the unit introduction schedule devised to accommodate the construction schedule for the three dam development. In general, the annual LOLP indices are higher than the ones corresponding to the two dam development but are well below the levels recommended for maintenance of adequate system reliability. After the installation of the two Paso Real units in November 1988, the resulting LOLP index for the year is just above 0.48 days/year. However, the following year this index rises to 1.48 indicating additional generation is required in 1989, similar to the two dam scheme.

5.4.3 EFFECT OF DELAYS TO UNIT INTRODUCTION SCHEDULE

The unit introduction schedules of Tables V.1 and V.2 will allow the system reliability criteria to be met, within the construction schedules for individual projects of the two and three dam development schemes.

There are two critical years in the generation expansion, which could be affected by delays to the projected construction schedules for either geothermal or hydroelectric power plant, these being 1979 and 1982, respectively. In order to preserve a system risk index corresponding to at least 1.0 day/year during 1979, the first geothermal unit should be introduced no later than March. If delays to the required drilling program, or other exigencies, cause the in-service date to be postponed, the risk level will be commensurately increased, as shown in the following tabulation.

RELIABILITY OF SYSTEM GENERATION IN 1979
RESULTING FROM DELAYS TO GEOTHERMAL DEVELOPMENT PROGRAM

Geothermal Unit 1 Period	In-Service Beginning	Resulting Annual LOLP Index for 1979 Days/Year
5	April 23	1.138163
6	May 21	1.279975
7	June 18	1.412738
8	July 16	1.470139
9	August 13	2.322401
10	September 10	3.162127
11	October 8	4.031030
12	November 5	4.126026
13	December 3	4.252666

TABLE V.2

UNIT INTRODUCTION SCHEDULE AND FORCED OUTAGE RATES FOR THREE-DAM DEVELOPMENT SCHEME BI

IN SERVICE DATE	EFFECTIVE CAPACITY MW	UNIT	NO.	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Existing	25	Centroamerica	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	25	Centroamerica	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	25	Gral. Somoza G.	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	20	Gral. Somoza G.	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	15	Managua	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	15	Managua	2	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	45	Managua	3	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	15	Chinandega		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Sep. 1976	50	Puerto Somoza	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Dec. 1976	50	Puerto Somoza	2	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Mar. 1979	45	Momotombo	1		0.060	0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Jun. 1980	45	Momotombo	2			0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Oct. 1981	45	Momotombo	3				0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Nov. 1982	55	Copalar	1					0.020	0.020	0.010	0.010	0.010	0.010	0.010	0.010
Nov. 1982	55	Copalar	2					0.020	0.020	0.010	0.010	0.010	0.010	0.010	0.010
May 1983	55	Copalar	3						0.020	0.010	0.010	0.010	0.010	0.010	0.010
Jan. 1986	35	El Carmen	1									0.020	0.010	0.010	0.010
Jan. 1986	35	El Carmen	2									0.020	0.010	0.010	0.010
Jan. 1987	55	Copalar	4										0.010	0.010	0.010
Jul. 1987	55	Copalar	5										0.010	0.010	0.010
Nov. 1988	25	Paso Real	1											0.020	0.020
Nov. 1988	25	Paso Real	2											0.020	0.020

SUMMARY OF LOSS OF LOAD PROBABILITY (LOLP)

RISK LEVEL - DAYS/PERIOD

PERIOD	FROM:	TO:											
1	Jan. 1	Jan. 28	0.025585	0.135119	0.058168	0.027790	0.020784	0.000556	0.000168	0.004208	0.002977	0.002833	0.017998	0.075486
2	Jan 29	Feb. 25	0.057554	0.312838	0.130044	0.076597	0.061865	0.002125	0.000919	0.019271	0.015152	0.015975	0.084296	0.178580
3	Feb. 26	Mar. 25	0.033330	0.150340	0.077922	0.040637	0.026088	0.000804	0.000222	0.005239	0.003858	0.003769	0.026114	0.105554
4	Mar. 26	Apr. 22	0.037686	0.020023	0.088947	0.045667	0.038585	0.001068	0.000380	0.011480	0.006129	0.007066	0.039467	0.115602
5	Apr. 23	May 20	0.028123	0.014179	0.062593	0.032735	0.029226	0.000799	0.000297	0.009343	0.004494	0.005618	0.030472	0.075245
6	May 21	Jun. 17	0.028647	0.012839	0.062375	0.028368	0.280303	0.000334	0.002444	0.040668	0.030003	0.027567	0.115222	0.234053
7	Jun 18	Jul 15	0.014718	0.005273	0.029509	0.171651	0.110577	0.000112	0.000878	0.017694	0.007907	0.000344	0.032934	0.102649
8	Jul. 16	Aug. 12	0.275322	0.079344	0.031195	0.135403	0.077678	0.000062	0.000449	0.008316	0.003497	0.000134	0.015537	0.054624
9	Aug. 13	Sep. 9	0.277594	0.078561	0.031089	0.136507	0.078414	0.000066	0.000481	0.008838	0.003578	0.000141	0.015829	0.058614
10	Sep. 10	Oct. 7	0.314883	0.084111	0.031436	0.142848	0.094854	0.000083	0.000614	0.012504	0.005114	0.000206	0.024078	0.068397
11	Oct. 8	Nov. 4	0.020483	0.009078	0.003132	0.023090	0.203676	0.000211	0.001634	0.029840	0.017824	0.000879	0.063673	0.164361
12	Nov. 5	Dec. 2	0.027708	0.012546	0.004513	0.002448	0.000037	0.000027	0.000211	0.005411	0.003358	0.000178	0.002290	0.073132
13	Dec. 3	Dec. 31	0.042850	0.023044	0.009307	0.004828	0.000099	0.000074	0.000662	0.013854	0.010824	0.001019	0.012117	0.175513

RISK LEVEL - DAYS/PERIOD

ANNUAL LOSS OF LOAD PROBABILITY	1.184511	0.937395	0.620236	0.868569	1.022186	0.006321	0.009359	0.186664	0.114713	0.065729	0.480027	1.481812

If the first geothermal unit is not placed in service during 1979, the resulting system risk level is shown on the printout of the LOLP program, included as Annex C-2 of Appendix C.

A certain degree of latitude regarding levels of reliability in 1979 will be necessary, in view of the uncertainties associated with the introduction of geothermal power plant. One or two months delay is tolerable but beyond mid-year 1979, the system risk levels corresponding to delayed in-service dates for the first geothermal generating unit will increase, period by period, to levels unacceptable by the standards of the planning criteria established for this study.

Once the first geothermal unit is placed in service, overall system reliability improves considerably and the scheduled unit additions, at 15 month intervals, enable a reasonably secure system to be maintained through 1982. It is conceivable that the schedule for Units 2 and 3 can be improved to enable successive installations to be made at intervals of only 12 months. This would not be required to improve system reliability but rather to enable the earlier substitution of lower cost geothermal energy for oil-fired generation.

The next critical year is 1982, which requires the installation of the first two Copalar units in November,to maintain a reliability level which corresponds to a LOLP risk index of approximately 1.0 day/year. A printout of the LOLP program for the year 1982, without the inclusion of the two initial Copalar units in system generation is included, as Annex C-3 of Appendix C, to illustrate the resulting risk level attained. If delays occur to postpone the in-service date to some point in time within 1983, the risk levels shown in the following summary tabulation can be anticipated for either the two or three dam schemes.

RELIABILITY OF SYSTEM GENERATION IN 1983
RESULTING FROM DELAYS TO COPALAR DEVELOPMENT

Copalar Units 1 & 2 Period	In-Service Beginning	Resulting Annual LOLP Index for 1983 Days/Year
1	January 1	0.033132
2	January 29	0.236611
3	February 26	0.828480
4	March 26	1.103248
5	April 23	1.413910
6	May 21	1.637570
7	June 18	3.427376
8	July 16	4.257975
9	August 13	4.874506
10	September 10	5.500321
11	October 8	6.145805
12	November 5	7.379296
13	December 3	7.604039

The scheduling of the initial installation at Copalar was intended to introduce the two 55 megawatt units, to meet the end-of-year peak in 1982. If delays are encountered which postpone the in-service date to as late as March 1983, the resulting annual LOLP index will be almost the same as for 1982, without the introduction of Copalar units. (1.10 as compared to 1.09) This will still enable the initial unit installations at Copalar to be available to meet the March peak of 1983. Beyond this date, the resulting annual LOLP indices caused by delays to the construction schedule are unacceptable by the standards imposed by generation planning criteria. Thus the importance of a well conceived and executed development program is emphasized. Construction schedules must be maintained to preserve adequate reliability of system generation.

CAPITULO VI

COMPRAS DE ENERGIA
POR
INTERCONEXIONES

CHAPTER VI

POWER PURCHASES
VIA
INTERCONNECTIONS

CHAPTER VI

POWER PURCHASES VIA INTERCONNECTIONS

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CHAPTER VI

POWER PURCHASES VIA INTERCONNECTIONS

6.0 INTRODUCTION

Interconnections between the presently independently operated power systems of Nicaragua, Honduras and Costa Rica, will enable the improvement of operating economies resulting from the interchange of power. These economies will be of mutual benefit to the participating utilities, Empresa Nacional de Luz y Fuerza (ENALUF) of Nicaragua; Empresa Nacional de Energia Electrica (ENEE) of Honduras; and Instituto Costarricense de Electricidad (ICE) of Costa Rica. In addition, the future possibility of extended firm power interchange and reserve sharing, will provide a major incentive for re-examination of current expansion plans of the utilities concerned, to minimize investment in reserve capacity for the interconnected systems and utilize complementary resources for the mutual benefit of participants.

6.1 INTERCONNECTION WITH ICE (COSTA RICA) SYSTEM

The interconnection of the ENALUF and ICE systems, will be the subject of a forthcoming feasibility study authorized by the two utilities. In the present study, the effect of this interconnection on basic generation and transmission plans has been examined, to determine the necessary facilities required for its implementation and the resultant tie-line rates which will be necessary to support economic energy purchase by ENALUF, over a range of possible future cost escalation.

6.1.1 AVAILABILITY OF SURPLUS CAPACITY AND ENERGY

The salient feature of existing hydroelectric generation sources of the ICE system is the prevalence of run-of-river plant operation, with limited storage capability. This condition has led the two utilities, ENALUF and ICE, to seriously consider the interconnection of their adjacent systems, to enable the surplus capacity and energy of hydroelectric sources on the ICE system to be made available to the ENALUF system in the form of off-peak power allocations.

The results of recent studies completed by ICE indicate that surplus hydro energy can be made available to the ENALUF system each year during the wet season, to allow off-peak purchases during the daily load cycle between the hours of 10 PM and 6 AM, a period of eight hours per day. The monthly energy available, from mid-year 1978 to end of year 1988, is shown in Table VI.1.

Current plans for the establishment of an interconnection suggest that the earliest date at which the inter-tie could be energized will be July 1978, which coincides with the onset of the wet season. The available capacity and energy, which will be surplus to the nocturnal load requirements of the ICE system, varies from month to month and declines through time over the first seven years to 1984, depending upon the capability of generating sources relative to the magnitude of nocturnal load on the ICE system. In 1985, the level of available energy is substantially increased but a further decline then takes place in the two succeeding years 1986 and 1987. A large increase is projected for 1988, following the commissioning of the Amistad Plant.

TABLA VI.1 - TABLE VI.1
*EXCEDENTE MENSUAL DE ENERGIA PARA EL SISTEMA DEL ICE DE COSTA RICA DISPONIBLE PARA SER COMPRADO POR ENALUF
*MONTHLY ENERGY SURPLUS TO ICE SYSTEM OF COSTA RICA AVAILABLE FOR PURCHASE BY ENALUF
-GWH-

ANO Year	JULIO July	AGOSTO August	SEPTIEMBRE September	OCTUBRE October	NOVIEMBRE November	DICIEMBRE December	TOTAL Total
1978	28.0	27.9	28.1	17.4	24.8	22.7	148.9
1979	22.2	21.7	21.3	12.9	18.1	16.9	113.1
1980	16.2	16.5	15.1	19.3	11.9	11.4	90.4
1981	11.0	11.0	9.7	13.5	6.3	6.5	58.0
1982	6.5	6.7	4.6	8.5	1.5	3.2	31.0
1983	3.4	3.2	0.5	4.5	-	2.0	13.6
1984	2.1	0.8	-	2.6	-	1.9	7.4
1985	1.9	-	11.4	16.1	6.9	3.6	39.9
1986	3.8	5.0	4.3	8.9	1.3	2.0	25.3
1987	2.0	1.2	0.2	4.1	-	1.9	9.4
1988	1.8	-	33.1	34.4	23.8	14.8	107.9

Fuente: Instituto Costarricense de Electricidad
Source: Instituto Costarricense de Electricidad

Nota: *Los valores mensuales de energia corresponden al ano hidrologico promedio
Note: *Monthly energy values correspond to average hydrological year

6.1.2 UTILIZATION OF OFF-PEAK ENERGY PURCHASES

The off-peak energy available from run-of river hydro plants on the ICE system should be utilized as early as possible, otherwise it will be wasted due to lack of adequate storage capability. The principal justification for the purchase of such energy by ENALUF is that this hydro energy can be substituted for equivalent thermal generation, thus conserving fuel-oil, with a resultant cost saving to the ENALUF system. The magnitude of the savings realized will, of course, be dependent on the tie-line purchase rate established. In this study, concentration has been given to analysis of breakeven rates to define maximum limits for purposes of negotiation.

The main constraint on the energy utilized is the limited time period each day, during which off-peak transfers have to be completed. In addition, the interchange of off-peak energy should not interfere with the economic operation of other units on the system. This requirement refers particularly to geothermal base-load units, which are scheduled for introduction to the system during the first two years of tie-line operation. It is preferable, for economic system operation, that the geothermal units be maintained on base-load, with unit loading fairly steady at normal full-load rating. The geothermal energy is available on a 24-hour basis and constant flow conditions are most advantageous for steam well operation.

The displacement of thermal energy will result in more frequent shut-downs of thermal units, if the off-peak energy purchases result in thermal unit loadings falling below the minimum level of operation. This will affect the scheduling of the Puerto Somoza units, for daily operational requirements during the wet season energy transfers. This effect should not be excessive as normal start-up procedure requires eight hours to complete, which corresponds to the daily time period for transfer of off-peak energy. In all probability, the thermal units can be placed on hot standby or spinning reserve for the period of minimum loading.

The operational constraints of the ENALUF and ICE systems, pertaining to optimal off-peak energy transfers, will require more detailed study than was possible with the information available for the completion of this study. In particular, the plant capacity of ICE generation supporting the energy transfer should be obtained on an hour-by-hour basis, to determine the maximum feasible energy transfer. This will allow a more accurate modeling of the energy purchases, as part of production costing for the ENALUF system, than was possible using the average energy values available for the present study.

In order to select the transmission facilities required for economic energy transfer, three options were examined to determine the operating voltage level and terminal location.

I 230 kV operation with terminal at Los Brasiles substation
II 230 kV operation with terminal at Masaya substation
III 138 kV operation with terminal at Masaya substation

These three options were sufficient to examine the most realistic alternatives, for interconnection of the ENALUF system with that of ICE in Costa Rica.

In each case the relative advantages, in terms of production cost savings for thermal generation compared with necessary capital expenditures for transmission facilities, coupled with associated operation and maintenance costs, were examined by present worth analysis to determine the breakeven tie-line rates for energy, over a range of future cost escalation. The results of this analysis are contained in Appendix H.

The first two options require the early construction of certain 230 kV line sections and installation of substation facilities, several years before they would be required with independent system operation. A 230 kV line section is required for Option I between the Los Brasiles terminal and the Masaya substation; and for Option II, the terminal at Masaya will require a 75 MVA, 230/138 kV step-down transformer, in addition to other equipment forming a new 230 kV substation. The only limitation on energy transfer is the capacity of the step-down transformer, the off-peak transfer for a limited period of eight hours each day cannot justify the early addition of more than one 75 MVA transformer. The third option requires the same 230 kV line construction as for Option II, with provision for initial operation at 138 kV. This alternative requires a minimum installation of terminal substation equipment. However, due to limitations of power transfer capability with the lower operating voltage level, definite constraints are placed on the magnitude of energy possible with Option III.

The following tabulation gives the magnitude of energy transferable with the three options and its proportion to the total off-peak energy available:

ENALUF - ICE INTERCONNECTION
POTENTIAL ENERGY AVAILABLE AND TRANSFER LIMITS
F O R
OFF-PEAK ENERGY FROM COSTA RICA

YEAR	1978	1979	1980	1981
Energy Available - GWH	148.9	113.1	90.4	58.0
Option I - 230 KV Operation - Terminal at Los Brasiles Substation				
Energy Transfer - GWH	147.5	112.2	89.6	57.5
Percentage Interchange	99%	99%	99%	99%
Option II - 230 KV Operation - Terminal at Masaya Substation				
Energy Transfer - GWH	106.7	100.7	88.8	57.5
Percentage Interchange	72%	86%	98%	99%
Option III - 138 KV Operation - Terminal at Masaya Substation				
Energy Transfer - GWH	69.4	69.4	67.4	56.3
Percentage Interchange	47%	61%	75%	97%

The energy available from 1982 to 1987 is relatively small in magnitude and can be transferred over facilities corresponding to each of the three options. In 1988 there is a fairly large increase in energy available (107.9 GWH), which

would cause definite interchange limits to be imposed by transfer capability with interconnection options II and III. Apart from the limitations imposed by transformer capacity in Option II, the following range of line loadings, for power transfer, were used to determine maximum permissible energy interchange capability.

230 kV Operation .....94 to 145 MW ; Average - 120 MW

138 kV Operation .....35 to 53 MW ; Average - 44 MW

It was assumed that transmission energy losses were supplied by the available hydroelectric energy from Costa Rica.

6.1.3 FORMULATION OF TIE-LINE RATES FOR OFF-PEAK PURCHASES

The energy available for transfer from Costa Rica to Nicaragua is surplus to the load requirements of the ICE system. Until the completion of the Arenal pondage hydro plant, it is essentially dump energy from the run-of-river plants in Costa Rica, which will be lost if not transferred to the ENALUF system for utilization in Nicaragua. In setting purchase rates for such energy, the potential benefit to the ENALUF system is determined by the equivalent cost of thermal energy generation, which is replaced by energy purchased over the interconnection. However, to enable purchases to be made, the necessary tie-line and terminal facilities have to be built, operated and maintained, so a cost is incurred by the purchaser, ENALUF. The relative value of purchases is then determined by the present worth of capital investment, operation and maintenance expenses, offset by discounted savings resulting from substitution of off-peak energy for thermal generation.

In order to determine the breakeven tie-line rate, which would induce ENALUF to purchase off-peak energy from ICE, the cost of independent operation is compared with the costs associated with interconnected operation. The detailed rate analysis is presented in Appendix H, with the effect of cost escalation examined over a range of discount rates corresponding to the cost of capital. The analysis was based on relative costs incurred over the period, 1976 through 1981. Although energy is available for transfer beyond 1981, the availability of large blocks of power from Honduras, after the first stage of the El Cajon Project is brought into service in 1982, will enable hydro energy to totally substitute for thermal generation in that year.

The combination of ENEE firm power allocations from Honduras and new hydro generation on the Rio Grande de Matagalpa in Nicaragua, almost entirely eliminates the need for thermal dispatch on the ENALUF system for the remainder of the development period to 1988. Thus, the possibility of reducing thermal dispatch by utilizing surplus energy from Costa Rica is possible to a limited extent after 1981. However, the abundant hydroelectric energy available from Honduras could easily substitute for the ICE off-peak allocations, assuming the firm allocations are supplied by ENEE. This means that the interconnection with Costa Rica has to prove out economically within the short time-frame of four years, in order to justify its introduction by mid-year 1978. This has the effect of minimizing the tie-line rates applicable to economic interchange. However, in determining a tie-line rate applicable to off-peak energy allocations, it is essential that the transfer be examined to ascertain the economic merit of interchange based on the realities of available sources.

The total energy available during the wet season from Costa Rica declines appreciably, beginning in 1982, as indicated in Table VI.1, and does not increase to the levels of the first four years of interconnected operation until 1988, following the major installation of the Amistad hydroelectric power plant on the ICE system. The breakeven tie-line rates, determined for the period 1978-1981, are applied to seasonal energy transfers from Costa Rica, through the end of the development period in 1988, to determine corresponding breakeven tie-line rates for the interconnection with Honduras. This is a reasonable procedure, in that a nominal value is placed upon the limited energy available for transfer from the ICE System, for utilization in Nicaragua during the period 1982 through 1988.

6.2 INTERCONNECTION WITH ENEE (HONDURAS) SYSTEM

The interconnection of the ENALUF and ENEE systems is currently under implementation, with a 230 KV transmission line, to form the inter-tie between the two systems, scheduled for energization in 1976. This will enable the new Puerto Somoza thermal plant of the ENALUF system, to supply power to the interconnected systems of Nicaragua and Honduras. After an initial period of interruptible power interchange, ENEE plan to purchase power from ENALUF on a firm basis from 1979 to 1981, utilizing base-load energy from Puerto Somoza. Then, following the initial installation at the new El Cajon hydroelectric plant in Honduras, surplus on-peak capacity and energy in excess of the ENEE system requirements, will be available for purchase by ENALUF on a firm basis beginning in 1982.

6.2.1 AVAILABILITY OF FIRM CAPACITY AND ENERGY

The introduction of the El Cajon development to the ENEE system, will provide a major addition to hydroelectric generation sources in Honduras. However, the magnitude of power available from the single source requires that its output be marketed in both Honduras and Nicaragua, until such time as the entire output can be utilized within the ENEE system, this being dependent on future load growth. The most recent power balance prepared by ENEE reflects the effect of Hurricane Fifi on the Honduran economy, in that revisions to the forecast load on the ENEE system will enable larger allocations of El Cajon power to be made available for sale to ENALUF on a firm basis.

The following tabulation of available firm capacity and energy from the ENEE system, provided the basis for the study of on-peak power purchases by ENALUF, from 1982 to the end of the development period in 1988 and the following year.

ENALUF - ENEE INTERCONNECTION
AVAILABILITY OF FIRM POWER FROM ENEE SYSTEM

Year	Capacity MW	Energy GWH	Load Factor %
1982	194	982	58
1983	172	862	57
1984	148	732	56
1985	120	588	56
1986	91	430	54
1987	58	254	50
1988	21	62	34
1989	99	277	32

A steady decline in firm power availability is observed during the period 1982-1988, with an increase in 1989 as additional capacity is installed on the ENEE system.

The magnitude of capacity and energy over the period 1982 to 1985, which is available to ENALUF as a firm power allocation from the ENEE system, provides the basis for postponing the Copalar hydroelectric development in Nicaragua. The deferral will be for a period to be determined by system risk analysis, governed by generation reliability criteria and the economic advantage of substituting hydro energy for thermal energy.

6.2.2 UTILIZATION OF ON-PEAK POWER ALLOCATIONS

On-peak power purchases are usually contracted on the basis of negotiated tariffs, involving a two-part rate for firm capacity and energy. As a premium rate is normally charged for capacity purchases, the annual energy purchased should be associated with an agreed minimum capacity purchase to meet system load requirements. This would require interchange of power at as high a load factor as possible, within the capacity of the purchaser's system to dispatch the power throughout the daily load cycle and at the same time provide adequate load carrying capability to ensure system reliability.

In practice, the transfer of power at high annual load factor is difficult to realize within the generation mix of a system that includes prime sources of base-load capacity, such as geothermal, which are dispatched on a constant basis. An example may be taken in relation to the ENALUF system, to illustrate the type of constraint that is present to limit high load factor transfers. The on-peak power allocations from Honduras are available beginning in the year 1982. At this time, the full complement of geothermal power capacity, included in the intermediate-range generation expansion plan will be in service. In addition, purchases of off-peak energy are possible from the ICE system of Costa Rica. The combination of base-load geothermal, plus off-peak energy purchases, are fully able to supply the daily base-load requirements. This reduces the possibility of high load factor power transfer, until system load growth permits.

In general, power transfer will be made between the ENEE and ENALUF systems at annual load factors, determined by the system load and the generation mix for a particular year.

6.2.3 FORMULATION OF TIE-LINE RATES FOR ON-PEAK PURCHASES

The determination of a suitable basis for setting tie-line rates, for firm power purchases, should take into account both the capacity and energy components of power transferred over the interconnection between the ENEE and ENALUF systems. The most pertinent aspects of this formulation relate to the substitution of firm capacity and associated energy allocations for equivalent firm generating plant capacity, which would otherwise have to be installed on the ENALUF system, together with energy which alternatively would have to be generated by existing thermal plants.

As will be demonstrated, the utilization of power interchange between the ENEE and ENALUF systems, will allow the postponement of the in-service date of the major new hydroelectric source in Nicaragua, the Copalar development on the Rio Grande de Matagalpa. In addition, the associated development of Paso Real

will not be required until 1990 at the earliest, due to the availability of firm power allocations from Honduras. Thus, the power interchange will enable the postponement of major capital investments required for both components of the two dam development. The analysis of interconnected system expansion, in comparison to independent system expansion with the two dam development, was restricted to the single scheme consisting of the high dam at Copalar, together with power purchases from Honduras and Costa Rica. The discussion of the economic analysis pertaining to the breakeven tie-line rate determination is given in Appendix I.

The combination of available energy from existing hydro plants on the ENALUF system, the new Copalar hydroelectric power development and firm power purchases from Honduras, together with geothermal generation and off-peak purchases from Costa Rica, will allow almost complete substitution of thermal generation on the ENALUF system, over the years 1982 to 1987, with a limited dispatch at the end of the development period in 1988.

The methodology used for determining the tie-line rates, applicable to the interchange with the ENEE system is similar to that used for the ICE interconnection. A corresponding breakeven tie-line rate is computed, which, when applied to energy purchased from Honduras, results in the equalization of the present worth of costs associated with the independent and interconnected development of the ENALUF system. Independent development will require the implementation of the two dam scheme, for initial operation of Copalar in 1982. Interconnected development will enable the postponement of Copalar plant installation to 1984, but will entail purchases from both ENEE of Honduras and ICE of Costa Rica. As the breakeven rate for off-peak energy purchases from ICE was determined by a separate analysis for the period 1978-1981, its application to reduced allocations over the period 1982 through 1988, at a constant level, is the equivalent of a production cost to the ENALUF system.

In Appendix I, the effect of escalation on tie-lines rates is examined and a series of curves are developed, which relate the breakeven rate with cost of capital, over a range of escalation profiles developed for comparative analysis.

Thus the breakeven rate will provide the purchaser, ENALUF, with a measure of the composite effect of the postponement of capital expenditures and the saving in annual production costs, due to the substitution of hydro for thermal energy. It represents the upper limit, to a negotiated rate for purchases of firm power, that would be acceptable for contractual purposes and a standard by which a two-part tariff structure can be assessed in future evaluations of potential economies to be obtained by interchange of power.

6.3 MODIFICATIONS TO BASIC GENERATION EXPANSION PLANS

Interconnection of the ENALUF system, with the ICE system of Costa Rica and the ENEE system of Honduras, will enable two major advantages to be realized for the benefit of ENALUF. Both off-peak energy from Costa Rica and energy allocations from Honduras can be used to substitute hydro energy for thermal generation. In addition, the firm capacity available from the El Cajon hydroelectric plant in Honduras, from 1982 on, will enable the postponement of the next major hydro power development in Nicaragua, thus serving to defer associated capital costs and operating expenses.

6.3.1 SUBSTITUTION OF HYDRO ENERGY FOR THERMAL GENERATION

The first possibility for the reduction of thermal generation on the ENALUF system will occur, following the scheduled interconnection with Costa Rica in July 1978. The energy surplus from Costa Rican run-of-river hydroelectric plants, in excess of the ICE system load requirements, will then be available for off-peak transfer to the ENALUF system during the wet season. As the net effect of the energy transfer will be to reduce overall production costs, by diminishing the dispatch of the ENALUF system thermal plants, the only modification to the basic generation expansion plan will consist of the addition of transmission facilities associated with the interconnection. The first four years of interconnected operation will have the most impact on annual production costs, because the available energy from the ICE system after 1981 will be curtailed due to projected load growth in Costa Rica.

The limited off-peak hydroelectric energy available from the ICE system of Costa Rica after 1981 will be augmented by the abundant firm energy associated with the power allocations, scheduled to begin in 1982 from the ENEE system of Honduras. This firm energy, to be purchased by ENALUF, will enable the complete substitution of hydroelectric energy for thermal generation during the years 1982 and 1983, with only a very limited thermal dispatch in 1984. After the introduction of the initial generating units at the Copalar hydroelectric development in November 1984, the firm energy transfer over the interconnection with the ENEE system will be supplemented by the steadily increasing annual energy available from the Rio Grande de Matagalpa development, as the Copalar reservoir fills during the years 1985 and 1986. In 1987, the entire annual energy corresponding to normal reservoir operation is available from the Copalar development, which reduces the energy allocation required from Honduras to supplement indigenous sources. However, with the available combined sources of hydroelectric and geothermal energy, no thermal dispatch is required on the ENALUF system from 1985 until 1988, when only a limited energy allocation of 62 GWH is available from the ENEE system.

The scheduled in-service dates for geothermal and hydro components of the ENALUF generation expansion plan, coupled with the projected power transfers over interconnections with ICE and ENEE, will enable the maximum substitution of hydroelectric energy for thermal generation over the development period. As far as possible within system constraints, the available indigenous resources of Nicaragua, Honduras and Costa Rica will be utilized, to minimize the future use of fuel oil for power generation during the decade of development 1978-1988.

6.3.2 POSTPONEMENT OF COPALAR UTILIZING FIRM POWER PURCHASES

The interconnection of the ENALUF and ENEE systems will be completed in 1976, following the energization of the 230 kV transmission line which will serve as the inter-tie between the Suyapa terminal substation in Honduras and the Leon substation in Nicaragua. During the first six years of interconnected operation, power interchange will be mainly from Nicaragua to Honduras, the energy being generated by ENALUF thermal plant, after the new Puerto Somoza units are placed in service.

The present schedule for the major hydroelectric project of El Cajon in Honduras, will enable the initial generating units to be brought on-line to allow firm power allocations to be made available to the ENALUF system beginning in 1982. In the basic generation expansion plan for the independent development of the ENALUF system, the initial unit installations at the Copalar hydroelectric development in Nicaragua were scheduled for November 1982, followed by successive unit additions at intervals of approximately six months. The firm power available from Honduras, will enable an additional two years of lead-time to be gained for the major development of the Copalar site on the Rio Grande de Matagalpa. The schedule for interconnected development is similar to the basic plan for independent expansion of generation facilities, the first two 55 megawatt units at Copalar will be placed in service in November 1984, followed by additional unit installations at approximately six month intervals.

Figure VI.1 shows the capacity increments and peak load demand for the interconnected system generation expansion plan, with the Copalar high dam development and firm power purchases from the ENEE system of Honduras. Annex III-16 to Chapter III shows the work schedule.

6.3.3 GENERATION RELIABILITY OF INTERCONNECTED SYSTEM EXPANSION

The generation reliability of the interconnected system expansion plan was examined using the loss of load probability (LOLP) method, similar to the generation reliability study made for the basic plans for independent system development discussed in Chapter V.

A summary of the LOLP indices for each year of the interconnected system expansion is given in Table VI.2, together with the unit introduction schedule, effective unit capacity and scheduled on-peak power purchases. The individual unit forced outage rates are also tabulated for each year of the expansion, together with the equivalent forced outage rate associated with firm power purchases.

A study was made of transmission outages on the ENALUF system from operating records. This was correlated with design criteria for the 230 kV transmission line comprising the inter-tie, together with data pertaining to isokeraunic levels for the line route of the interconnection. As the principal source for power allocations from the ENEE system will be the El Cajon hydroelectric plant, a conservative forced outage rate of 0.011 associated with the capacity allocations was used to represent the combination of multiple hydro units and interconnecting tie-line, for computation of the loss of load probability index for the system.

The annual LOLP index for 1982 and 1983 is well within the system reliability level established for the ENALUF system. The scheduled in-service date for Copalar Units 1 and 2, in November 1984, results in a risk level of slightly above 1.0 day per year. This is quite acceptable and compares closely with the level of 1.02 for 1982 with independent system development, this being the year scheduled for initial installation of Copalar units if no firm power purchases are made from Honduras. Annexes C-4, C-5 and C-6 of Appendix C, contain the printout of the LOLP program for the years 1982, 1983 and 1984, respectively, without the inclusion of the Copalar units in 1984.

FIG. VI - 1

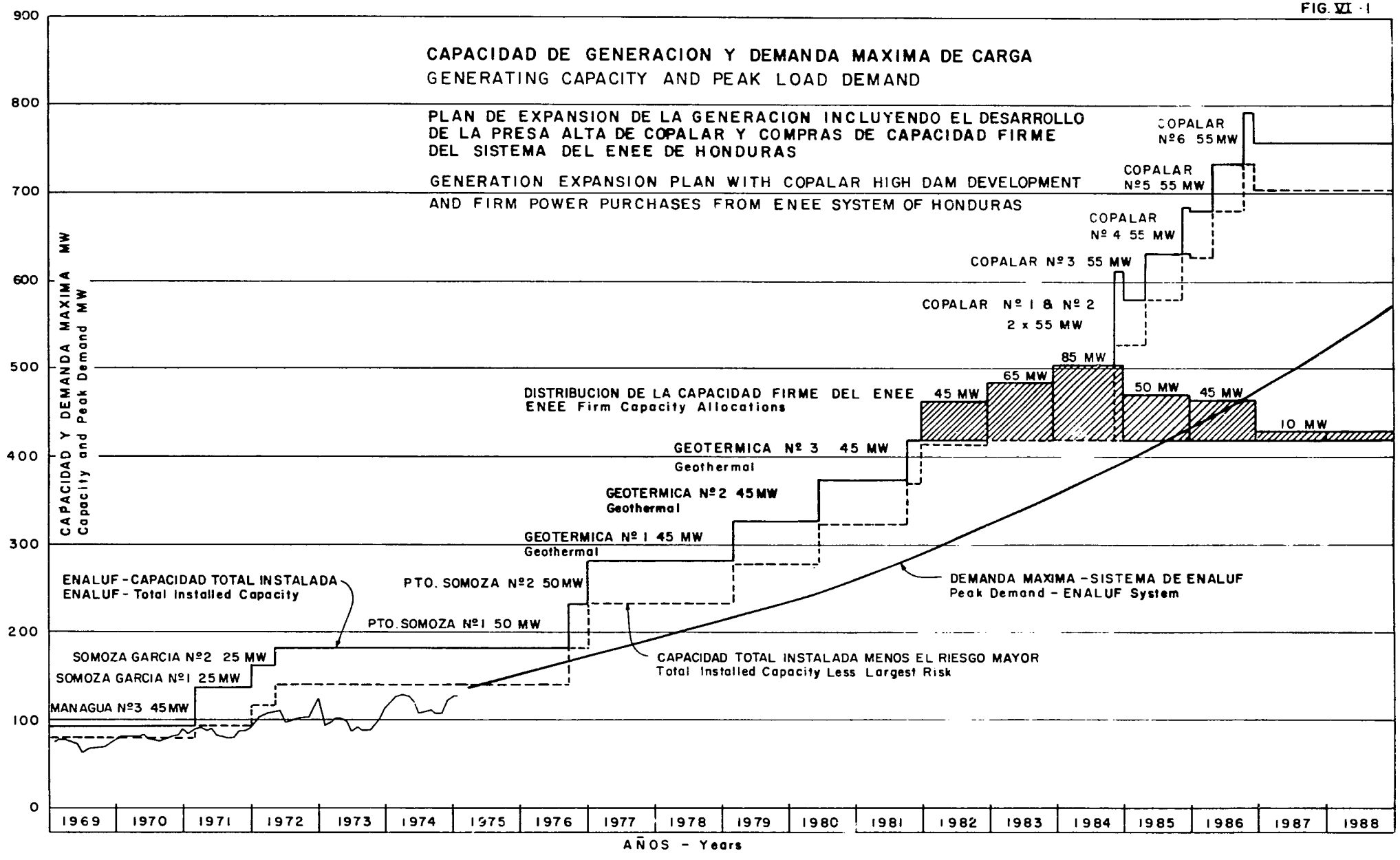
CAPACIDAD DE GENERACION Y DEMANDA MAXIMA DE CARGA
GENERATING CAPACITY AND PEAK LOAD DEMAND
PLAN DE EXPANSION DE LA GENERACION INCLUYENDO EL DESARROLLO DE LA PRESA ALTA DE COPALAR Y COMPRAS DE CAPACIDAD FIRME DEL SISTEMA DEL ENEE DE HONDURAS
GENERATION EXPANSION PLAN WITH COPALAR HIGH DAM DEVELOPMENT AND FIRM POWER PURCHASES FROM ENEE SYSTEM OF HONDURAS
CAPACIDAD Y DEMANDA MAXIMA MW
Capacity and Peak Demand MW
900
800
700
600
500
400
300
200
100
0
COPALAR Nº6 55MW
COPALAR Nº5 55 MW
COPALAR Nº 4 55 MW
COPALAR Nº3 55 MW
COPALAR Nº 1 & Nº 2
2 x 55 MW
85 MW
65 MW
45 MW
50 MW
45 MW
10 MW
DISTRIBUCION DE LA CAPACIDAD FIRME DEL ENEE
ENEE Firm Capacity Allocations
GEOTERMICA Nº 3 45 MW
Geothermal
GEOTERMICA Nº2 45MW
Geothermal
GEOTERMICA Nº 1 45 MW
Geothermal
ENALUF - CAPACIDAD TOTAL INSTALADA
ENALUF - Total Installed Capacity
PTO. SOMOZA Nº2 50MW
PTO. SOMOZA Nº1 50 MW
SOMOZA GARCIA Nº2 25 MW
SOMOZA GARCIA Nº1 25MW
MANAGUA Nº3 45MW
DEMANDA MAXIMA - SISTEMA DE ENALUF
Peak Demand - ENALUF System
CAPACIDAD TOTAL INSTALADA MENOS EL RIESGO MAYOR
Total Installed Capacity Less Largest Risk
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
AÑOS - Years

TABLE VI.2

INTERCONNECTED SYSTEM GENERATION EXPANSION WITH COPALAR HIGH DAM AND FIRM POWER PURCHASES
UNIT INTRODUCTION SCHEDULE, ON-PEAK POWER PURCHASES AND FORCED OUTAGE RATE SUMMARY

IN SERVICE DATE	EFFECTIVE CAPACITY MW	UNIT OR POWER PURCHASE	No.	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Existing	25	Centroamerica	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	25	Centroamerica	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	25	Gral. Somoza G.	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	20	Gral. Somoza G.	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Existing	15	Managua	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	15	Managua	2	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	45	Managua	3	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Existing	15	Chinandega		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Sep. 1976	50	Puerto Somoza	1	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Dec. 1976	50	Puerto Somoza	2	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Mar. 1979	45	Momotombo	1		0.060	0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Jun. 1980	45	Momotombo	2			0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Oct. 1981	45	Momotombo	3				0.045	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Jan. 1982	45	ENEE Purchase	1					0.011							
Jan. 1983	65	ENEE Purchase	2						0.011						
Jan. 1984	85	ENEE Purchase	3							0.011					
Nov. 1984	55	Copalar	1							0.020	0.020	0.010	0.010	0.010	0.010
Nov. 1984	55	Copalar	2							0.020	0.020	0.010	0.010	0.010	0.010
Jan. 1985	50	ENEE Purchase	4								0.011				
May 1985	55	Copalar	3								0.020	0.010	0.010	0.010	0.010
Nov. 1985	55	Copalar	4								0.020	0.010	0.010	0.010	0.010
Jan. 1986	45	ENEE Purchase	5									0.011			
May 1986	55	Copalar	5									0.010	0.010	0.010	0.010
Nov. 1986	55	Copalar	6									0.010	0.010	0.010	0.010
Jan. 1987	10	ENEE Purchase	6										0.011		
Jan. 1988	10	ENEE Purchase	7											0.011	
Jan. 1989	100	ENEE Purchase	8												0.011

SUMMARY OF LOSS OF LOAD PROBABILITY (LOLP)
RISK LEVEL - DAYS/PERIOD

PERIOD	FROM:	T O:												
1	Jan. 1	Jan. 28	0.025585	0.135119	0.058168	0.027790	0.001155	0.006243	0.030886	0.007589	0.000556	0.000200	0.020325	0.024580
2	Jan. 29	Feb. 25	0.057554	0.312838	0.130044	0.076597	0.004224	0.022268	0.096790	0.029776	0.009378	0.001416	0.088850	0.097419
3	Feb. 26	Mar. 25	0.033330	0.150340	0.077922	0.040637	0.001565	0.008555	0.041682	0.010219	0.000899	0.000272	0.030593	0.027683
4	Mar. 26	Apr. 22	0.037686	0.020023	0.088947	0.045667	0.002325	0.011704	0.046284	0.019398	0.001487	0.000577	0.042127	0.060536
5	Apr. 23	May 20	0.028123	0.014179	0.062599	0.032735	0.001796	0.009098	0.031078	0.015743	0.001214	0.000486	0.032487	0.046111
6	May 21	Jun 17	0.028674	0.012839	0.062375	0.028368	0.018857	0.076151	0.269435	0.004331	0.000227	0.002305	0.129554	0.115516
7	Jun. 18	Jul. 15	0.014718	0.005273	0.029509	0.171651	0.006924	0.029258	0.100829	0.001713	0.000067	0.000567	0.037315	0.033036
8	Jul. 16	Aug. 12	0.275322	0.079344	0.031195	0.135403	0.004115	0.019528	0.064437	0.000826	0.000026	0.000181	0.021882	0.016193
9	Aug. 13	Sep. 9	0.277594	0.078561	0.031089	0.136507	0.004250	0.020219	0.066469	0.000883	0.000029	0.000197	0.022301	0.016163
10	Sep. 10	Oct. 7	0.314883	0.084111	0.031436	0.142848	0.005539	0.023285	0.075533	0.001212	0.000043	0.000307	0.028328	0.021962
11	Oct. 8	Nov. 4	0.020483	0.009078	0.003132	0.023090	0.013089	0.049631	0.183114	0.003019	0.000134	0.001343	0.071049	0.066681
12	Nov. 5	Dec. 2	0.027708	0.012646	0.004513	0.002448	0.001449	0.007905	0.000131	0.000029	0.000001	0.000274	0.024740	0.032019
13	Dec. 3	Dec. 31	0.042850	0.023044	0.009307	0.004828	0.003243	0.017104	0.000357	0.000095	0.000010	0.001489	0.060380	0.067600
						RISK LEVEL - DAYS/YEAR								
ANNUAL LOSS OF LOAD PROBABILITY			1.184511	0.937396	0.620236	0.868569	0.068531	0.300948	1.007024	0.094833	0.008071	0.009614	0.609930	0.625500

The following summary tabulation indicates the comparative system risk levels, in terms of LOLP indices, computed for independent and interconnected system development.

COMPARISON OF ANNUAL GENERATION RELIABILITY
LOSS OF LOAD PROBABILITY - DAYS/YEAR

Year	Independent System	Interconnected System
1982	1.022186	0.068531
1983	0.006224	0.300948
1984	0.000068	1.007024
1985	0.000010	0.094833
1986	0.000668	0.008071
1987	0.017206	0.009614
1988	0.792310	0.609930
1989	2.299325	0.625500

It may be observed that the firm allocation from ENEE for the entire year of 1982 greatly improves the overall system reliability, the resulting LOLP index being approximately one-tenth of the recommended risk level of 0.6 days/year derived by marginal cost analysis. The LOLP indices for the remainder of the generation expansion through 1988 are quite satisfactory. Due to an available allocation of 100 MW in 1989, the year immediately following the development period will require no additional generation to maintain the recommended risk level. This is in direct contrast to the alternatives available for independent system development, both of which would require additional generation in 1989, even with the inclusion of Paso Real.

Annexes C-7, C-8 and C-9 of Appendix C contain the printout of the LOLP program for the year 1989. These correspond, respectively, to the system expansion plans for the independent development of the two and three dam schemes and the development of the Copalar high dam, set in context of the interconnection of the ENALUF system with the ENEE system of Honduras, to enable firm power purchases. It should be noted that with interconnected operation of the ENALUF, ENEE and ICE systems, the earliest in-service date required for the Paso Real hydroelectric power development will be 1990.

CAPITULO VII

PLANES DE EXPANSION DEL SISTEMA DE TRANSMISION

CHAPTER VII

TRANSMISSION SYSTEM EXPANSION PLANS

CHAPTER VII

TRANSMISSION SYSTEM EXPANSION PLANS

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CHAPTER VII

TRANSMISSION SYSTEM EXPANSION PLANS

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7.0 INTRODUCTION

One objective of transmission planning was to perform a preliminary study of the transmission facilities associated with the selected hydroelectric developments. The purpose of that study was to select the appropriate transmission voltage and establish the approximate timing and location of transmission facilities.

A voltage study was performed for the selected Copalar Project development on the Rio Grande de Matagalpa, this is contained in Appendix F. The results of the voltage study are coordinated with the following two sections of this Chapter. Section 7.1 reviews the transmission facilities, transmission line arrangement and right-of-way requirements for the two and three dam development alternatives on the Rio Grande de Matagalpa. The installed capacity for both alternatives are similar and differ by only 15 megawatts, therefore the general recommendation for a 230 kV transmission voltage arrived at in Appendix F is applicable to either case.

A second objective of the transmission plans was to coordinate the transmission facilities for the selected hydroelectric development with an overall system expansion plan. The overall development plan for the ENALUF system is contained in Section 7.2, where the transmission facility requirements are reviewed for the period 1978 through 1988, including the impact of the Rio Grande de Matagalpa development. That section summarizes transmission facility requirements, cost estimates and justification for each facility addition for both the short-and long-range development of the ENALUF system.

Overall, the transmission plans as developed are adequate to meet ENALUF service requirements through 1988. However, these plans also consider the possible impact of transmission system interconnections on the Central American Isthmus. Electrical energy from the two major indigenous generating resources in Nicaragua, geothermal and hydroelectric, are planned for direct transformation to a 230 kV transmission grid that extends from the border with Honduras to the border with Costa Rica.

7.1 TRANSMISSION FACILITIES ASSOCIATED WITH THE SELECTED HYDROELECTRIC DEVELOPMENTS

7.1.1 GENERAL STUDY ASSUMPTIONS

The base case development using indigenous Nicaraguan resources for independent system expansion was assumed in evolving plans for the transmission facilities associated with the development of the Rio Grande de Matagalpa. The generation schedules for the two and three dam developments used for planning purposes are given in Figures V.1 and V.2 of Chapter V, respectively.

Performance criteria used to establish the required facilities are given in Section F.2 of Appendix F to this report and in the Transmission System Reliability Criteria contained in Appendix II B of the Phase I report. Substation transformer capacity and bus arrangements generally follow those given in the Transmission System Guidelines and Practices, Appendix IIC of the Phase I report, but were kept similar in both cases to allow an unbiased economic comparison of the alternative developments.

Scheduling for the in-service date of required transmission facilities was assumed to coincide with the initial operation of generating units; generally three months prior to commercial operation. Construction scheduling was assumed to correspond with the date on which the facilities would be needed and no allowance was made for deferral beyond that date.

7.1.2 TWO DAM DEVELOPMENT OF THE RIO GRANDE DE MATAGALPA

The ultimate installed capacity of the two dam alternative is 380 MW and will consist of Copalar with 6-55 MW units and Paso Real with 2-25 MW units. The Copalar units are installed in a staged development with the initial two units in operation in November 1982 and the final 55 MW unit in operation in November 1984. Generation reserves on the ENALUF system, with the Copalar units installed, are such that the date when Paso Real is needed was deferred to November 1988 in the base case development plan. A more detailed discussion of unit scheduling for the base case development of the two and three dam alternatives is given in Section 5.3.2 of Chapter V.

A. TRANSMISSION LINE ARRANGEMENT FOR THE TWO DAM DEVELOPMENT

The resulting transmission line arrangement transmitting hydroelectric energy from the two dam development of the Rio Grande de Matagalpa is given in Figure VII.I. The ultimate line arrangement satisfies all performance criteria regarding maximum transfer capability, voltage regulation, stability, thermal capability and system reliability.

As conceived, the initial development of the Copalar Project will require one double-circuit 230 kV line from the plant to a load center substation located at Masaya. The addition of the fifth 55 MW unit at Copalar will require the third 230 kV line. This will be a single-circuit line following existing right-of-way, but terminating at Brasiles Substation to provide for the two point service to the Managua-Masaya load center and maximize the utilization of existing step-down transformer capacity at Brasiles Substation.

The transmission system has sufficient capability with the addition of the third Copalar line to transmit the additional 50 MW output of the Paso Real Plant. Generation from the Paso Real units is connected to the system by looping the third Copalar line into the Paso Real switchyard to form the Copalar-Paso Real and Paso Real- Brasiles transmission lines.

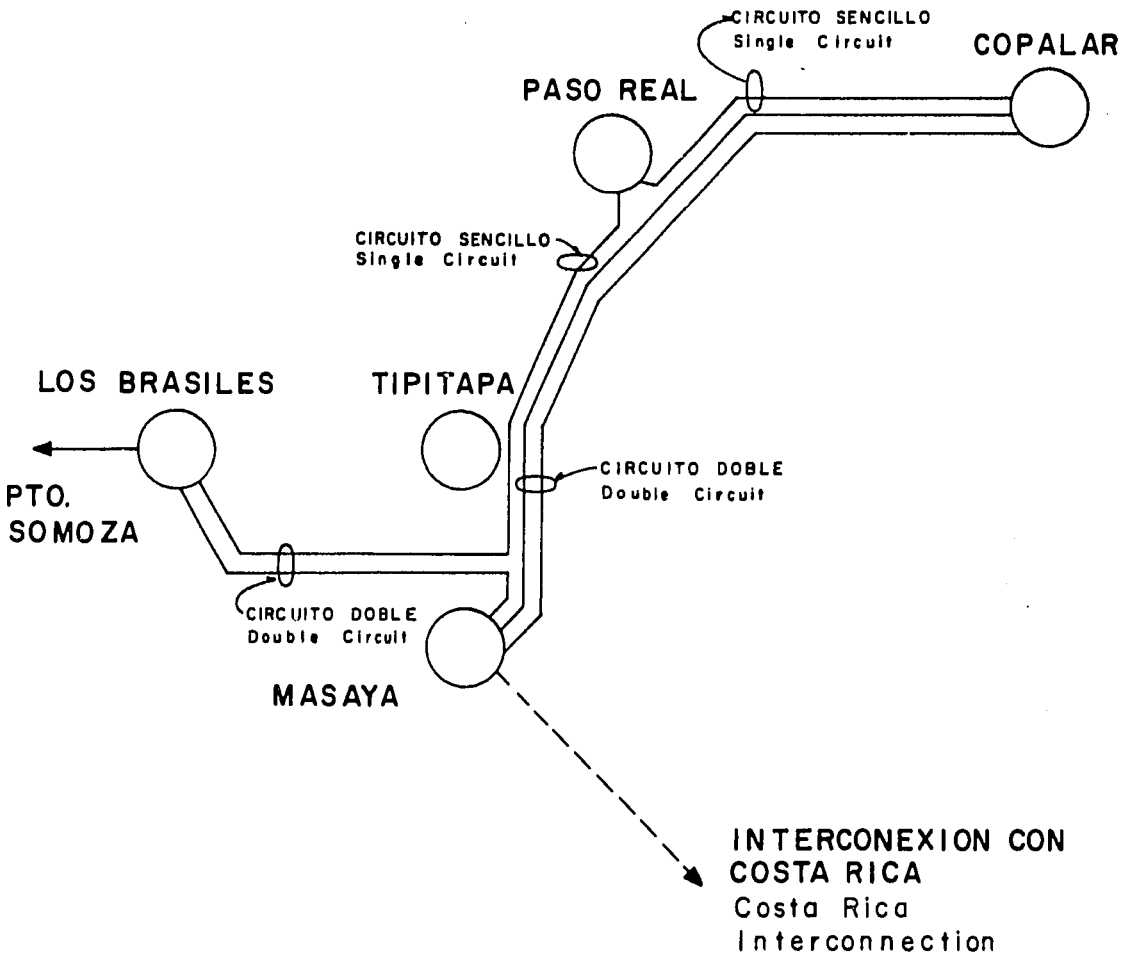
B. RIGHT-OF-WAY REQUIREMENTS FOR THE TWO DAM DEVELOPMENT

The transmission line and access road alignment between Copalar, Paso Real and Boaco is shown on Annex III-11 to Chapter III. The line route was chosen to minimize distance between Copalar and Paso Real allowing for terrain features and the lake formed by the Copalar dam. The coordination of line route with the access road facilitates line accessibility and maintenance. Topographical features in the 69 kilometer section between the two dams are mostly heavily forested, rolling terrain at a median altitude varying between 250 and 300 meters.

FIG VII . I

RIO GRANDE DE MATAGALPA
ALTERNATIVA DE DOS PRESAS
ARREGLO DE LAS LINEAS DE TRANSMISION DE 230 KV

RIO GRANDE DE MATAGALPA
TWO DAM ALTERNATE
230 KV TRANSMISSION LINE ARRANGEMENT



LINEA - Line			LONGITUD Km - Length Km
COPALAR	-	PASO REAL	68.8
COPALAR	-	MASAYA No. I	185.3
COPALAR	-	MASAYA No.2	185.3
PASO REAL	-	LOS BRASILES	143.9
LOS BRASILES	-	MASAYA	48.1
		TOTAL	631.4

The line route extends 45 kilometers from the Paso Real site to the town of Boaco, where it joins the existing right-of-way for the Tipitapa-Boaco, 138 kV line. There is existing right-of-way from this point into the system load centers through flat, rural terrain that can be expanded to form a transmission corridor for the Copalar lines. Respective line lengths and type of construction assumed for this study are given in Figure VII.1.

C. SUBSTATION FACILITIES FOR THE TWO DAM DEVELOPMENT

Connection of the transmission lines will be made at four high voltage substations. Switching facilities will be required at the Copalar and Paso Real powerhouses and at the Masaya and Los Brasiles receiving-end substations.

The Copalar Substation is located at elevation 182 on a terrace in the hillside about 300 meters upstream of the powerhouse. The terrace will be levelled by cutting into the hillside so that a suitable area is obtained for the switchyard equipment and facilities. The generation voltage will be transformed from 13.8 kV to 230 kV transmission voltage by three banks of 135 MVA transformers. Each bank consists of three single-phase, two-winding transformers terminating in a six-element ring bus arrangement. This arrangement will allow for switching flexibility, terminations for the three unit step-up transformers and line terminations for the three, 230 kV transmission lines.

The Paso Real Substation is located about 200 meters from the powerhouse on top of a hill behind the powerhouse. The generation voltage will be transformed from 13.8 kV to 230 kV transmission voltage by one 65 MVA, three-phase two-winding transformer. Transmission voltage switching facilities will be arranged in three-element ring bus configuration to allow for termination of the single unit step-up transformer and two 230 kV line terminations.

Switching facilities at the receiving-end Masaya Substation, which is located on the Masaya highway directly east of the town of Masaya, will have to be expanded. The 230 kV switching facilities must ultimately allow for terminations of two Copalar lines, the 230 kV interconnection line with Costa Rica, the Los Brasiles-Masaya line, an ultimate of four step-down transformers and a bus-tie position. The development of Masaya Substation is contained in a study made by Electroconsult entitled "Alternative Expansion Schemes for Masaya Substation" , September 1974. Step-down transformation at Masaya ultimately will consist of four identical three-phase 45/60/75 MVA, OA/FA/FOA, 230-138 kV transformers. Terminations for the transformers will be in individual positions in the 230 kV and 138 kV buses.

Los Brasiles Substation will be readily expanded to accommodate the additional 230 kV lines from Copalar. Existing step-down transformer capacity will consist of three transformers similar to those located at Masaya Substation and additional capacity will not be required.

7.1.3 THREE DAM DEVELOPMENT OF THE RIO GRANDE DE MATAGALPA

The ultimate installed capacity of the three dam development is only 15 MW more than the two dam alternate; the difference between two 35 MW units at El Carmen and a sixth 55 MW unit at Copalar. The discussion of required facilities; therefore, follows the same logic as the two dam development and only the differences are discussed in the following sections.

A. TRANSMISSION LINE ARRANGEMENT FOR THE THREE DAM DEVELOPMENT

Three 230 kV transmission lines will also be required for the three dam development and the ultimate line arrangement is shown in Figure VII.2. The timing of the third line, however, will coincide with the initial operation of the fourth Copalar unit.

Evolution of the system will involve the initial double-circuit 230 kV transmission line from Copalar to the Masaya Substation. An additional 26 kilometers of double-circuit line will be required to inter-connect El Carmen with the Copalar lines. The interim line arrangement will then be a Copalar-Masaya, and Copalar-El Carmen and an El Carmen-Masaya line.

As previously discussed, the Copalar-Los Brasiles line will be required with the installation of the fifth and final unit at Copalar. The Paso Real plant will be connected to the system in the same manner as discussed in the two dam development by looping the Copalar-Los Brasiles line into the Paso Real Substation.

B. RIGHT-OF-WAY REQUIREMENTS FOR THE THREE DAM DEVELOPMENT

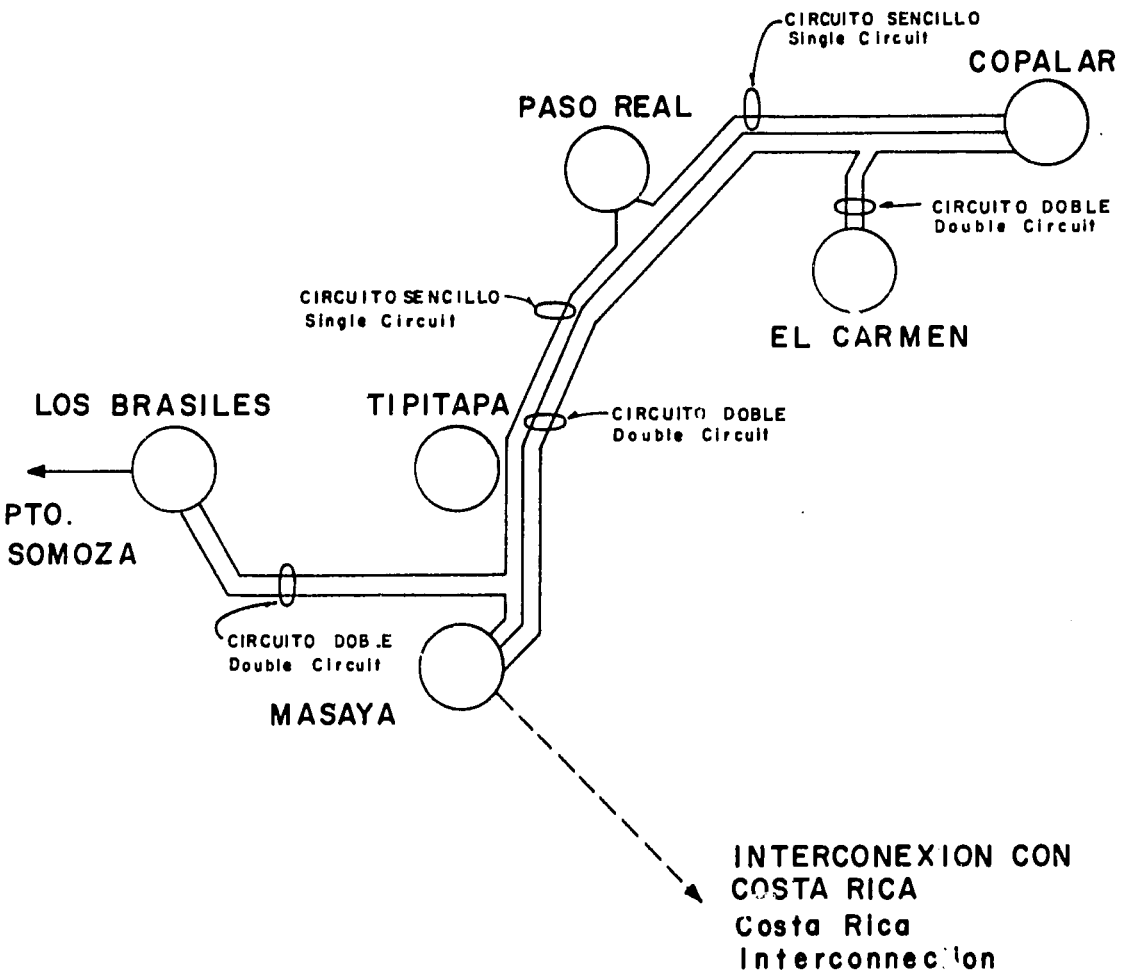
Right-of-way requirements will be similar to those of the two dam development. Annex III-12 shows the alignments of the right-of-way and access roads. Minor changes have been made to shorten the line length between Copalar and Paso Real, by taking advantage of the smaller lake formed by the lower dam at Copalar. The right-of-way length is 3.5 kilometers shorter than the two dam development. The remaining difference between the two and three dam developments is an additional 26 kilometers of double-circuit right-of-way to reach the El Carmen Substation. Right-of-way from Paso Real to the receiving substations of Masaya and Los Brasiles will be identical to that required for the two dam alternative.

C. SUBSTATION FACILITIES FOR THE THREE DAM DEVELOPMENT

Switching facilities for Copalar low dam development will be located at elevation 180 and about 300 meters away on the hillside behind the powerhouse. Switching requirements will remain similar to the high dam development and the six element ring bus arrangement proposed for the Copalar high dam development will also apply for the low dam development. Step-up transformation from the 13.8 kV generating voltage to the 230 kV transmission voltage level will be similar; the only difference being that a single three-phase, 65 MVA, FOA, 13.8-230 kV transformer will be required for Unit No.3. The remaining two transformer banks will be identical to those described in the two dam alternative.

FIG. VII.2
RIO GRANDE DE MATAGALPA
ALTERNATIVA DE TRES PRESAS
ARREGLO DE LAS LINEAS DE TRANSMISION DE 230 KV

RIO GRANDE DE MATAGALPA
THREE DAM ALTERNATE
230 KV TRANSMISSION LINE ARRANGEMENT



LINEA - Line			LONGITUD Km - Length Km
COPALAR	-	PASO REAL	65.3
COPALAR	-	EL CARMEN	60.8
COPALAR	-	MASAYA	181.8
EL CARMEN	-	MASAYA	172.2
PASO REAL	-	LOS BRASILES	143.9
LOS BRASILES	-	MASAYA	48.1
		TOTAL	672.1

The El Carmen switching facilities will be located at elevation 200 on the hillside about 150 meters behind the powerhouse. Switching facilities will be provided to terminate a single unit step-up transformer and two 230 kV line positions. A simple three element ring bus configuration will provide for reliability requirements and switching flexibility. The step-up transformer will be one, three-phase 85 MVA, FOA, 13.8-230 kV unit. The remaining substation facilities at the Paso Real, Masaya and Los Brasiles substations will be identical to those required for the two dam alternative as discussed in Section 7.1.2, Paragraph C.

7.2 GENERAL TRANSMISSION SYSTEM EXPANSION 1978-1988

7.2.1 OBJECTIVES

Expansion plans for the ENALUF transmission system are logically grouped into two growth periods; a short-range program from 1978 through 1981 and a long-range program from 1982 through 1988. The short-range expansion period is the time prior to the possible development of the hydroelectric resources of Nicaragua. During this interval, ENALUF efforts will be concentrated on the development of Nicaragua's indigenous geothermal resources, the construction and operation of initial interconnections with Honduras and Costa Rica, the implementation of distribution plans for service to major load centers and rural electrification of outlying areas. The objective of the short-range transmission program is to provide an estimate of the transmission facilities required for the aforementioned projects, estimate their approximate cost and time schedule and coordinate the development program with the long-range period between 1982 and 1988.

During the 1982-1988 period, the efforts focus on the investigation of various generation alternates available, either from development of hydroelectric resources within Nicaragua or from firm capacity allocations over interconnections. These long-range plans are crucial to present planning since transmission requirements for these projects constitute the framework for the evolution of the present transmission system. Therefore, the objective for the long-range transmission plan is to define the transmission facilities required to transmit electrical energy from these resources to the load centers, while investigating such parameters as levels of service reliability, transmission voltage levels and right-of-way requirements.

7.2.2 SUMMARY

Transmission facilities required for the Copalar project development coupled with those required for the interconnection with the ICE system of Costa Rica form an overlying 230 kV transmission backbone in the mid-1980's for the presently planned 138 kV transmission system. Delivery of 330 MW from Copalar located 185 kilometers from the Managua-Masaya load center requires the construction of one double-circuit 230 kV line to Masaya and one single-circuit 230 kV line to Los Brasiles to provide two point transmission service for the Managua-Masaya 138 kV transmission ring. This arrangement provides for single contingencies to the major load centers of Nicaragua, while maximizing the utilization of existing step-down transformer-bank capacity at Los Brasiles Substation. The 230 kV interconnection

transmission line to Costa Rica, presently planned to terminate at Los Brasiles Substation in 1978, is looped into Masaya Substation and provides the final link for the 230 kV grid.

With the likelihood of major capacity available from the Momotombo geothermal field, ENALUF is able to justify a 230 kV transmission grid from the Honduran to Costa Rican borders solely on the basis of transmission requirements related to development of geothermal and hydroelectric energy sources. Nicaragua is centrally located within the Central American Isthmus and the development of a major transmission grid to wheel energy from these sources alone will be crucial,not only to the economic development of Nicaragua, but also to all of Central America.

The total capital expenditures required solely for the development of the transmission system will be approximately U.S.$45.5 million during the period from 1978 through 1988. The short-range development program for the period from 1978 through 1981 will require U.S.$6.80 million for transmission facilities to interconnect Momotombo geothermal capacity with 230 kV transmission service. An additional U.S.$2.21 million will be needed for ENALUF's share of interconnection facilities with Costa Rica and U.S.$10.32 million for general system expansion.

The expenditures will total US$26.1 million for the longer range development program during the period of 1982 through 1988. The estimated investment includes a nominal U.S.$343 thousand for converting the interconnection with Honduras to 230 kV operation, capital expenditures totaling U.S.$25.1 million for transmission requirements related to the development of the Copalar Project and U.S.$690 thousand for general transmission system development.

Cost and facility summaries are shown in Table VII.1, Table VII.2 and Table VII.3. General development of the National Interconnected System is shown in Figure VII.3. The following section contains a discussion of major transmission projects and a further review of required facilities is contained in Section 7.2.8.

7.2.3 DESCRIPTION OF MAJOR TRANSMISSION PROJECTS

The following six major transmission projects are foreseeable in the 1978-1988 period:

1. 230 kV interconnection with the ICE system of Costa Rica in 1978.

2. Rural electrification of the Zelaya-Rama and Matagalpa-Jinotega zones in 1978.

3. 230 kV transmission facilities serving the dual purpose of transmission service for generation available from the Momotombo geothermal field in 1979 and allowance of firm capacity transfers from Honduras in 1982.

TABLA VII.1
TABLE VII.1

SUMARIO DE LAS LINEAS DE TRANSMISION Y SUBESTACIONES
DEL PROYECTO

SUMMARY OF PROJECT TRANSMISSION LINES
AND SUBSTATIONS

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	TOTAL
SUBESTACION DE GENERACION GENERATING SWITCHYARD												
Colocación de los Disyuntores de 230 kV 230 kV Circuit Breaker Position												
Momotombo	-	3	1	1	-	-	-	-	-	-	-	5
Copalar	-	-	-	-	-	-	3	1	2	-	-	6
LINEA DE TRANSMISION - (Kilómetros) TRANSMISSION LINE - (Kilometers)												
Transmisión de 230 kV 230 kV Transmission												
Nueva - New STSC (1)	119.1	102.0	-	-	0.5	-	-	-	183.0	-	-	404.6
Nueva - New STDC (1)	36.9	-	-	-	-	-	185.3	-	-	-	-	222.2
Línea de Circuito Doble Existente Double-Circuit existing line	-	-	-	-	-	-	-	-	43.0	-	-	43.0
Transmisión de 138 kV 138 kV Transmission												
Nueva - New STSC	94.0	43.0	35.0	-	-	-	-	-	-	-	-	172.0
Nueva - New STDC	2.0	-	-	-	-	-	2.5	-	-	-	-	4.5
Línea de Circuito Doble Existente Double-Circuit Existing Line	-	-	2.0	-	-	-	-	-	-	-	-	2.0
SUBESTACIONES RECEPTORAS RECEIVING SUBSTATIONS												
Colocación de los disyuntores de de 230 kV 230 Circuit Breakers Positions												
Brasiles	1	3	-	-	-	-	-	-	1	-	-	5
León	-	2	-	2	1	-	-	-	-	-	-	5
Masaya	-	-	-	-	3	-	5	-	-	1	-	9
Colocación de los Disyuntores de 138 kV 138 kV Circuit Breakers Position												
Brasiles	-	2	-	-	-	-	-	-	-	-	-	2
León	-	1	1	2	-	-	-	-	-	-	-	4
Masaya	-	1	-	-	1	-	3	-	-	1	-	6
Otros - Others	5	1	2	-	-	-	1	-	-	-	1	10
TRANSFORMADORES 230-138 kV TRIFASICA 45/60/75 MVA, OA/FA/FOA 230-138 kV TRANSFORMERS THREE PHASE 45/60/75, MVA OA/FA/FOA												
Brasiles	-	1	-	-	-	-	-	-	-	-	-	1
León	-	1	-	1	-	-	-	-	-	-	-	2
Masaya	-	-	-	-	1	-	2	-	-	1	-	4

(1) STSC Construcción de Torre de Acero, Diseño de Circuito Sencillo
STDC Construcción de Torre de Acero, Diseño de Circuito Doble

(1) Steel Tower Construction, Single-Circuit
Steel Tower Construction, Double-Circuit

TABLA VII.2
TABLE VII.2

INVERSION EN INSTALACIONES PARA TRANSMISION
EROGACIONES CORRESPONDIENTES A LA FECHA DE INICIO DE LA INSTALACION
DE 1978 A 1988

INVESTMENT IN TRANSMISSION FACILITIES
EXPENDITURE CORRESPONDING TO IN-SERVICE DATE OF FACILITY
1978 THROUGH 1988
U.S.$ x 1,000

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	TOTAL
SUBESTACION DE GENERACION GENERATION SWITCHYARD	-	1,147.4	294.1	294.1	-	-	1,110.6	348.4	705.1	-	-	3,899.7
LINEA DE TRANSMISION TRANSMISSION LINE												
Transmisión de 230 kV 230 kV Transmission	1,921.0	3,275.2	-	-	30.4	-	9,498.0	-	6,077.0	-	-	20,801.6
Transmisión de 138 kV 138 kV Transmission	2,275.8	1,152.5	975.4	-	-	-	106.4	-	-	-	15.5	4,523.6
SUBESTACIONES RECEPTORAS RECEIVING SUBSTATIONS	1,710.4	2,932.7	1,422.6	1,920.1	2,250.9	-	4,356.6	-	324.3	1,033.0	284.6	16,235.2

TABLA VII.3
TABLE VII.3

FLUJO EFECTIVO DE LA INVERSION EN LAS INSTALACIONES DE TRANSMISION
DE 1976 A 1988

CASH FLOW OF INVESTMENT IN
TRANSMISSION FACILITIES
1976 THROUGH 1988
U.S.$ x 1,000

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	TOTAL
SUBESTACION DE GENERACION GENERATION SWITCHYARD	-	57.4	301.6	891.3	279.4	205.9	55.5	295.7	899.9	419.7	493.4	-	-	3,899.7
LINEAS DE TRANSMISION TRANSMISSION LINE														
Transmisión de 230 kV 230 kV Transmission	877.6	1,840.3	1,777.1	701.2	-	-	3,224.4	4,234.0	4,160.9	2,677.2	1,308.9	-	-	20,801.6
Transmisión de 138 kV 138 kV Transmission	815.6	1,428.7	1,344.1	614.6	198.7	-	51.6	36.8	18.0	-	-	-	15.5	4,523.6
SUBESTACIONES RECEPTORAS RECEIVING SUBSTATIONS	85.6	602.7	2,115.8	2,760.4	1,190.3	1,906.7	1,793.5	1,089.1	3,066.1	132.3	499.4	794.2	199.1	16,235.2
DESEMBOLSO TOTAL DEL SISTEMA DE TRANSMISION TOTAL TRANSMISSION SYSTEM EXPENDITURES 1978 - 1988	1,778.8	3,929.1	5,538.6	4,967.5	1,668.4	2,112.6	5,125.0	5,655.6	8,144.8	3,229.2	2,301.7	794.2	214.6	45,460.1

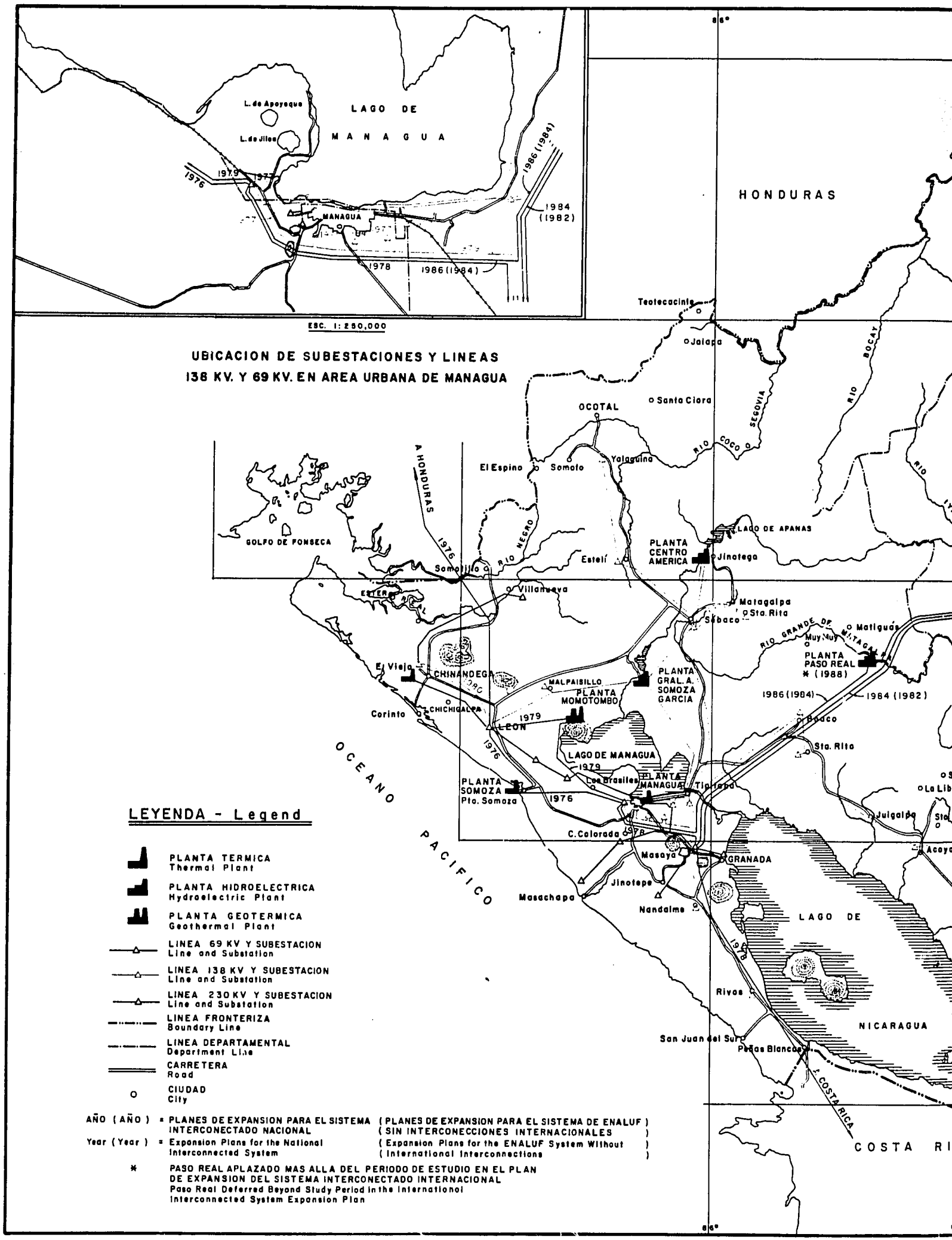
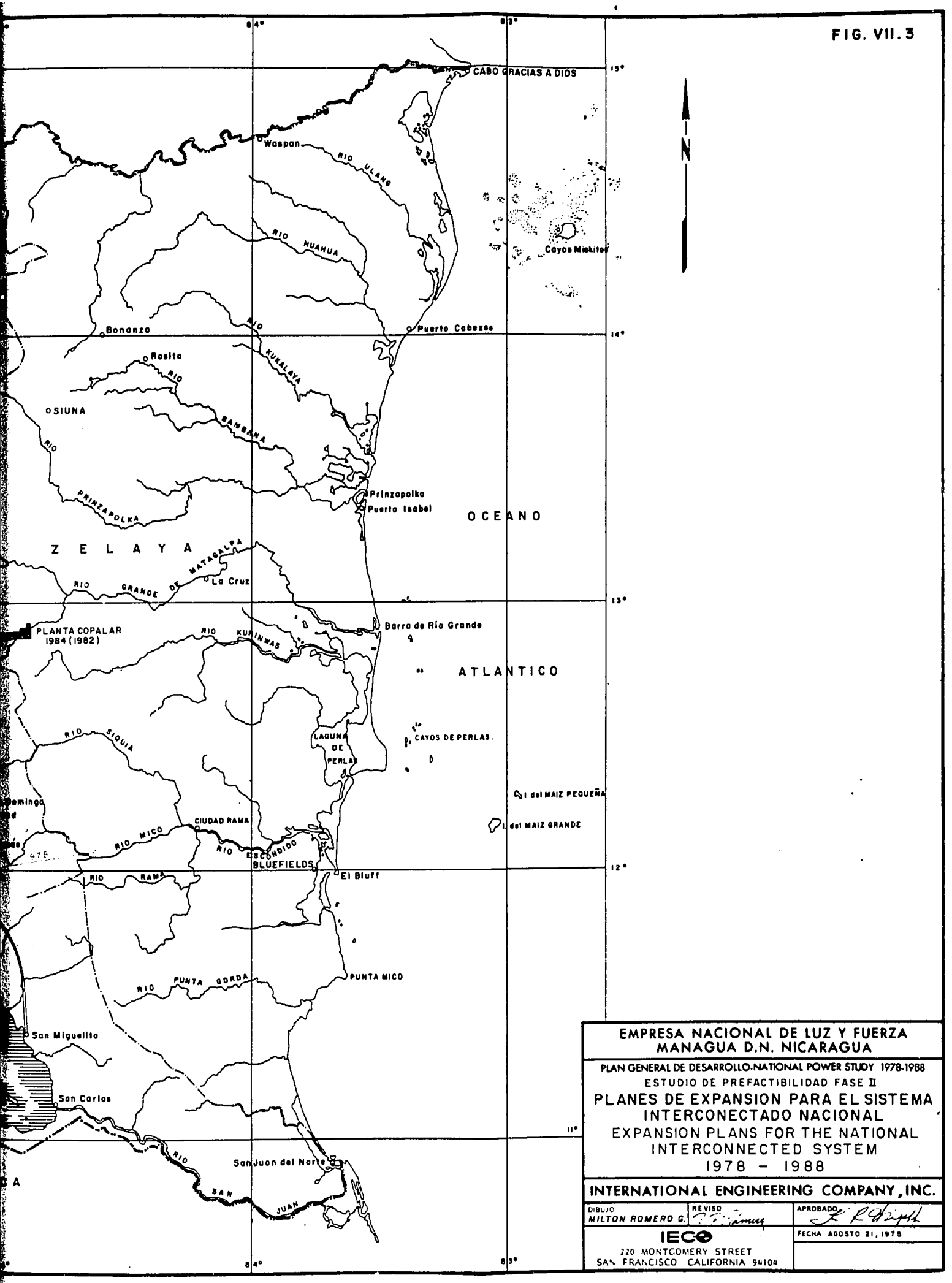

LAGO DE MANAGUA
L. de Apoyeque
L. de Jilloa
MANAGUA
1976
1979
1977
1978
1986 (1984)
1984 (1982)
ESC. 1: 250,000
UBICACION DE SUBESTACIONES Y LINEAS
138 KV. Y 69 KV. EN AREA URBANA DE MANAGUA
HONDURAS
Teotecacinte
Jalapa
Santa Clara
OCOTAL
RIO SEGOVIA
RIO COCO
RIO BOCAY
El Espino
Somoto
Yalaguina
A HONDURAS
GOLFO DE FONSECA
RIO NEGRO
Estelí
PLANTA CENTRO AMERICA
Jinotega
LAGO DE APANAS
Somotillo
Villanueva
ESTERI
Matagalpa
Sta. Rita
Sébaco
RIO GRANDE DE MATAGALPA
Matiguás
Muy Muy
PLANTA PASO REAL
* (1988)
El Viejo
CHINANDEGA
MALPAISILLO
PLANTA MOMOTOMBO
PLANTA GRAL. A. SOMOZA GARCIA
1986 (1984)
1984 (1982)
Corinto
CHICHIGALPA
LEON
1979
Boaco
Sta. Rita
OCEANO PACIFICO
LAGO DE MANAGUA
Los Brasiles
PLANTA MANAGUA
Tipitapa
PLANTA SOMOZA
Pta. Somoza
La Libertad
Juigalpa
C. Colorada
Masaya
GRANADA
Acoyapa
Jinotepe
Masachapa
Nandaime
LAGO DE
Rivas
NICARAGUA
San Juan del Sur
Peñas Blancas
A COSTA RICA
COSTA RI
LEYENDA - Legend
PLANTA TERMICA
Thermal Plant
PLANTA HIDROELECTRICA
Hydroelectric Plant
PLANTA GEOTERMICA
Geothermal Plant
LINEA 69 KV Y SUBESTACION
Line and Substation
LINEA 138 KV Y SUBESTACION
Line and Substation
LINEA 230 KV Y SUBESTACION
Line and Substation
LINEA FRONTERIZA
Boundary Line
LINEA DEPARTAMENTAL
Department Line
CARRETERA
Road
CIUDAD
City
AÑO (AÑO) = PLANES DE EXPANSION PARA EL SISTEMA INTERCONECTADO NACIONAL (PLANES DE EXPANSION PARA EL SISTEMA DE ENALUF (SIN INTERCONECCIONES INTERNACIONALES)
Year (Year) = Expansion Plans for the National Interconnected System (Expansion Plans for the ENALUF System Without (International Interconnections)
* PASO REAL APLAZADO MAS ALLA DEL PERIODO DE ESTUDIO EN EL PLAN DE EXPANSION DEL SISTEMA INTERCONECTADO INTERNACIONAL
Paso Real Deferred Beyond Study Period in the International Interconnected System Expansion Plan

FIG. VII.3



EMPRESA NACIONAL DE LUZ Y FUERZA
MANAGUA D.N. NICARAGUA

PLAN GENERAL DE DESARROLLO-NATIONAL POWER STUDY 1978-1988

ESTUDIO DE PREFACTIBILIDAD FASE II

PLANES DE EXPANSION PARA EL SISTEMA INTERCONECTADO NACIONAL

EXPANSION PLANS FOR THE NATIONAL INTERCONNECTED SYSTEM

1978 - 1988

INTERNATIONAL ENGINEERING COMPANY, INC.

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4. Completion of the 138 kV transmission ring around the Managua and Masaya load centers in 1979 with the construction of the Sur-Masaya 138 kV transmission line.

5. 230 kV operation of the interconnection with the ENEE system of Honduras in 1982.

6. Transmission facilities related to the Copalar Project development in 1984.

The components of the projects, divided between transmission lines and substations in the chronological order of commissioning, with foreign and local currency costs are listed in Section 7.2.8. The principal features are described below.

A. 230 KV INTERCONNECTION WITH THE ICE SYSTEM OF COSTA RICA IN 1978

A 230 kV transmission line, 270 kilometers long will be constructed from Los Brasiles Substation in the ENALUF system to the Canas Substation, which is the most likely termination on the ICE system, to transmit off-peak surplus energy from the ICE system to the ENALUF system. ENALUF's share of transmission facilities will consist of about 156 kilometers of the line from the border with Costa Rica to Los Brasiles Substation, where the line would terminate on the Los Brasiles 230 kV bus. The line will consist of 119 kilometers of single-circuit construction from the border to Masaya and 37 kilometers of double-circuit construction, with a single circuit installed initially, between the Los Brasiles Substation and the intersection of the right-of-way of the future Copalar-Masaya No.1 and No.2 230 kV transmission lines. This double-circuit line section would eventually serve as a portion of the Copalar-Los Brasiles 230 kV line.

B. RURAL ELECTRIFICATION OF THE ZELAYA-RAMA AND MATAGALPA-JINOTEGA ZONES IN 1978

Transmission service to these zones was recommended as part of the Nicaraguan rural electrification program. (Reference: ESIN report entitled "Estudio de Factibilidad - Electrificacion Rural de Nicaragua", August 1974). The recommendation was accepted and ENALUF is proceeding with these projects which are scheduled for operation in 1978.

Service to the Zelaya-Rama zone will be provided by constructing 57 kilometers of single circuit, 138 kV transmission line from Acoyapa Substation to a proposed 138/69/24.9 kV La Batea Substation. The Matagalpa-Jinotega zone will be serviced by constructing 37 kilometers of single circuit, 138 kV transmission line from the Sebaco Substation to a proposed 138/69/24.9 kV Santa Rita Substation.

C. MOMOTOMBO GENERATION TRANSMISSION SERVICE

Preliminary estimates based on the assumptions discussed in Chapter IV and Chapter V regarding capacity and energy transfers from Momotombo indicated that 138 kV transmission would be adequate. However, there is presently a great deal of uncertainty regarding the potential not only of the Momotombo

field, but also of the adjacent lowlands between El Hoyo and Momotombo. This latter site has very recently been termed potentially the largest geothermal prospect known today in Nicaragua.1/ Exploration drilling is proceeding at Momotombo and recommendations have been submitted for simultaneous exploration of the lowlands area. Therefore, the possibility of capacity installations in excess of the three 45 MW units assumed is likely; even using conservative estimates of the geothermal potential. Projections contained in the UNDP mid-year report suggest that a plan could be implemented to enable two 10 MW plants to be placed in service by the end of 1977 to be followed by a third identical unit in 1978. Multiple 37.5 MW geothermal plant additions would then follow at intervals, until a total complement of approximately 220 MW would be reached by the end of 1981.

Furthermore, study conditions necessarily concentrated on development of the indigenous resources of Nicaragua with reliance on firm power transfers over interconnections only to the extent of satisfying ENALUF system demand requirements. Thus, intrinsically, the possibility of firm power transfers through the ENALUF transmission system to serve energy requirements of countries to the north and south were minimized.

Since one major objective of the short-range transmission plan is to reflect projected capital requirements and considering the previously mentioned uncertainties; it was assumed that a second 230 kV transmission line from the Leon Substation through Momotombo to Los Brasiles Substations would eventually be proven feasible.

Accordingly, there would be a 230 kV switchyard at the Momotombo plant for terminating the Momotombo-Leon and Momotombo-Los Brasiles 230 kV transmission lines which will be 41 and 61 kilometers long, respectively. The existing 230 kV buses at Leon and Los Brasiles substations would have to be extended to provide for line terminations and additional transformer capacity of one three-phase, 45/60/75 MVA, OA/FA/FOA, 230/138 kV transformer at both Los Brasiles and Leon Substations.

D. SUR-MASAYA 138 KV TRANSMISSION LINE

This line is required in 1979 for service reliability to the Managua and Masaya load centers. It will be 43 kilometers long, single-circuit, 138 kV transmission line on galvanized steel towers. Termination of this line at Masaya will require rearrangement of the 138 kV switching facilities of Masaya Substation (Reference ELECTROCONSULT report, entitled "Alternative Expansion Schemes for Masaya Substation", September 1974).

E. 230 KV OPERATION OF HONDURAS INTERCONNECTION IN 1982

Firm capacity transfers in 1982 will exceed the 55 MW stability limit for 138 kV operation of the Leon-Pavana interconnection between the ENALUF system and the ENEE system of Honduras (Reference: General Electric Study,

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1/ Geothermal Development in Nicaragua, Tentative Plan for Initial Action, UNDP, July 1975.

entitled, "Dynamic Stability Study of the ENEE and ENALUF Systems" , 1972). However, the limited duration of firm capacity transfers solely to serve load growth on the ENALUF system reduces the probability of the construction of the second interconnection line. Preliminary estimates indicate further study of firm capacity transfers between countries to the north and south of Nicaragua are required before the construction of the second Leon-Pavana 230 kV line can be justified.

F. TRANSMISSION FACILITIES RELATED TO COPALAR PROJECT DEVELOPMENT

The straight line distance from the Copalar powerhouse to the load center in Managua is 170 kilometers. The connection of the powerhouse to the existing system requires two transmission lines. One transmission line is a 230 kV, double-circuit line which has sufficient capacity to transmit the power of four 55 MW units from Copalar without increasing the line capacity. The second is a 230 kV single-circuit line required with the addition of the fifth 55 MW unit at Copalar.

The connection to the existing transmission and distribution network requires 230 kV switching facilities at three high voltage substations. One is located at the Copalar powerhouse and transforms the voltage from 13.8 kV to 230 kV. The second is the Masaya Substation and is located east of the city of Masaya. It transforms the voltage from 230 kV to 138 and 69 kV. The third is the planned Los Brasiles Substation located to the northwest of Managua and will transform the voltage from 230 kV to 138 kV.

The Copalar Substation is located on a terrace in the hillside about 300 meters upstream of the powerhouse. The terrace will be levelled by cutting into the hillside so that a suitable area is obtained for the switchyard equipment and facilities. The voltage will be transformed from the 13.8 kV generation voltage to the 230 kV transmission voltage by three banks of 135 MVA transformers. Each bank consists of three single phase transformers.

The transmission voltage will be transformed at the Masaya Substation from 230 kV to 138 kV and 69 kV subtransmission voltages by four 75 MVA transformer banks consisting of three phase transformers. This substation will have an installed capacity of 300 MVA when the interconnection to the Copalar powerhouse is made. The Los Brasiles Substation will have existing 230/138 kV transformation of 225 MVA consisting of three similar 75 MVA, three phase transformers and additional transformer capacity will not be required.

The line and substation arrangement for the Copalar Project is shown schematically in Figure VII.2. The 230 kV transmission service shown from Copalar, combined with a Los Brasiles-Masaya 230 kV line, forms the 230 kV transmission grid for the system in 1984. The Los Brasiles-Masaya 230 kV line was previously formed in the planned expansion program by looping the interconnection line with Costa Rica into the Masaya Substation. Completion of the 230 kV transmission grid ties Copalar hydroelectric generation directly into a possible Central American transmission network and relegates the 138 kV transmission ring around the Managua-Masaya load centers

effectively to a main transmission voltage for service to distribution substations.

7.2.4 STUDY ASSUMPTIONS

The following assumptions were used in this study:

1. Generation Resource Schedule per Table S.4 in the summary of this report.

2. ENALUF available generating capacity in megawatts for use in load flow studies per Table G.1, Appendix G.

3. Projected transmission substations coincident peak loads from 1978 through 1988 per Table G.2, Appendix G.

4. Transmission system representation included transmission voltages of 138 kV and above.

5. The power factor at the high side of the 138/69 kV and 138/13.8 kV substations within the Managua load area was assumed corrected to 95 percent for initial study conditions. The power factor at the 138 kV bus of all other substations was assumed to be 85 percent.

6. Transmission interconnection with the Honduras system (ENEE) at Leon was assumed open, under on-peak conditions through 1981 for load-flow studies. Starting in 1982, the interconnection was assumed closed to allow the delivery of firm capacity from ENEE to the ENALUF system.

7. The study did not investigate the impact of contingencies in neighboring utilities on the ENALUF system or vice-versa, since detailed investigation of interconnections was beyond the scope of this study.

8. Detailed representations of the Honduras and Costa Rica power systems were not included for load flow studies.

9. All interconnecting lines with other utilities were assumed closed for short-circuit studies.

10. Systems operation assumed that the scheduled voltages at all regulated 138 kV buses were maintained at 140 kV, or 1.015 per unit and the Managua thermal plant on cold-reserve, standby operation starting in 1982.

11. Distribution substation load and transformer data was taken from ENALUF's Transformer Capacity Program for 1975-1988. The Transformer Capacity Program was prepared by ENALUF in accordance with the load forecast developed by IECO for the ENALUF system. The IECO load forecast is contained in Chapter I of the Phase I Report, Energy and Economic Growth, Load Forecast for Interconnected System.

7.2.5 STUDY METHODS AND CRITERIA

The transmission System Reliability Criteria and the related Transmission System Guidelines and Practices, contained in Appendices IIB and IIC of the Phase I Report, were used to develop the recommended system expansion program through 1988. The criteria defines acceptable system operating conditions and provides the basis for recommending facility additions to solve system problems caused by likely contingency outages. Likely contingencies are defined in the Criteria as N-1 component, N-1 generator, or N-1 lines assuming any one generator initially off. Transmission system components include lines, breakers, transformers, capacitors, reactors and associated equipment, at transmission voltages of 138 kV and above.

The study approach was to determine horizon year (1988) alternative transmission systems for the two and three dam Rio Grande de Matagalpa developments using the Transmission System Reliability Criteria and the projected substation coincident demands. The horizon year analyses aided the resolution of the most economical alternative for the Rio Grande de Matagalpa development and year-by-year expansion plans through 1988.

Detailed load flow studies were made on a year-by-year basis examining the transmission system first on the basis of the base case, on-peak conditions. Load flow studies were then made under off-peak conditions with all transmission lines in service and generation rescheduled. Finally the transmission system was analyzed under likely contingencies with peak load conditions.

Transmission interconnections with Honduras and Costa Rica were assumed open for on-peak load flow studies unless firm capacity transfers were planned. Firm power transfers were represented by fixed loads or generating sources at the assumed point of transfer. Generating capacity assumed available to ENALUF for load flow studies is summarized in Table G.1, Appendix G.

7.2.6 EXCEPTION TO CRITERIA

The transmission system program as proposed for the 1978-1988 decade meets the Transmission System Reliability Criteria, dated March 1975, with the following exception:

> Single contingency loss of the single circuit Pavana-Leon 230 kV interconnection with Honduras will result in the interruption of planned firm capacity transfers of 45 MW, 55 MW and 85 MW at 100 percent load factor, in 1982 through 1984 respectively. With firm capacity purchases by ENALUF from ENEE reduced to 10 MW by 1987 and limited information available on wheeling arrangements between countries to the north and south of Nicaragua, the construction of a second line in 1982, solely for ENALUF load requirements was not recommended. An exception to the criteria is required for three years until the Copalar units are placed in operation in November 1984. The estimated cost to eliminate this exception is US$2.57 million.

7.2.7 STUDY RESULTS

A. LOAD FLOWS

Load flows plots supporting the required 1978-1988 transmission system expansion program are shown in Figures G.2 through G.26 of Appendix G. Base case and minimum load conditions, single contingencies resulting in deviations from recommended service criteria and the recommended solution to these system problems are given in those figures.

B. TEMPORARY OPERATING PROCEDURES

A significant amount of line compensation will be required to absorb excess vars generated by the 230 kV transmission grid under minimum load conditions (Reference Appendix F) and costs for compensation of the Copalar lines were included in the cost estimates. However, it was assumed for load flow studies that ENALUF would try to minimize these expenditures. Accordingly the various load flow cases contained in Appendix G show minimum load cases with lines removed from service to relieve overvoltage problems which would otherwise occur.

7.2.8 PROJECTED FACILITY REQUIREMENTS

The following estimate of facilities relate specifically to transmission system projects. These include estimates of facilities required for generation switchyard terminations of transmission lines, transmission system components, transmission substations, including line extensions and terminations required for substations served from the 138 kV system. Distribution transformer capacity additions or new distribution substations including 138-69 kV and 138-13.8 kV substations are not included.

Typical transmission line construction, substation equipment and related transmission facilities as outlined in the Transmission System Guidelines and Practices were assumed for this study. The Guidelines and Practices were not intended to represent final design recommendations since it is beyond the scope of this study to evaluate all the possible alternatives that would best suit the ENALUF system. Moreover, the Guidelines and Practices were meant to outline current ENALUF practices with reasonable allowances for increased levels of service reliability as warranted by ENALUF system load growth.

A tabulation of projects with components divided between transmission and substation facilities in chronological order of commissioning with foreign and local currency costs is shown in Table VII.4.

7.2.9 RECOMMENDED STUDIES

The required projects were formulated with the aid of load flow calculations and as constituted herein are adequate to meet the projected loads in 1988. However, the planned additions do not represent optimal solutions. Further study is required in the five areas discussed in the following paragraphs.

TABLE VII.4
FACILITY REQUIREMENTS FOR TRANSMISSION SYSTEM DEVELOPMENT
1978 THROUGH 1988

TRANSMISSION LINES

I T E M	QUANTITY AND TERRAIN	REASON	EXPENDITURE - U.S.$ x 1000 FOREIGN	LOCAL	TOTAL
1978					
Brasiles-Asososca-Sur, 138 kV, 4.5km D/C, 20 km S/C 556.5 MCM ACSR, steel towers	24.5 km flat urban terrain	Transmission service for Asososca and Sur 138-13.8 kV Substations	681.0	355.0	1,036.0
Acoyapa-La Datea, 138 kV, S/C, steel towers, 336.4 MCM, ACSR	57.0 km flat rural terrain	Rural Electrication of Zelaya-Rama Zone	1,011.0	317.7	1,328.7
Sebaco-Santa Rita, 138 kV, S/C, steel towers, 336.4 MCM ACSR	37.0 km flat rural terrain	Rural Electrification of Matagalpa-Jinotega Zone	656.2	206.3	862.5
Brasiles-Penas Blancas 230 kV, 37 km D/C-1 119 km S/C , steel towers	156.0 km flat terrain, 28% urban	Interconnection with ICE system of Costa Rica	3,675.0	2,070.0	5,745.0
1979					
Momotombo-Brasiles, and Momotombo-Leon, 230 kV, S/C, steel towers, 795 MCS ACSR	102.0 km flat rural terrain	Transmission service for Momotombo generation and transmission grid for major power transfers over interconnections	2,518.1	757.1	3,275.2
Sur-Masaya, 138 kV, S/C, steel towers, 556.5 MCM ACSR	43 km flat urban/ rural/terrain	Two line service to two major distribution substations	828.9	323.6	1,152.5
1980					
Leon Viejo No. 2, 138 kV, S/C, steel towers 556.5 MCM ACSR	35 km flat urban/ rural terrain	Two Line service to a major distribution substation	674.7	290.4	965.1
1982					
Brasiles-Masaya, 230 kV, D/C, steel towers, 795 MCM ACSR	0.5 km flat rural terrain	Voltage drop in excess of 7% at three major distribution substations with single contingency loss of Brasiles-Asosoca 138 kV line	20.0	10.4	30.4
1984					
Asososca-Independencia-Sur, 138 kV, D/C-1, steel towers, 556.5 MCM ACSR	2.5 km flat urban terrain	Transmission service to Independencia substation	64.4	41.8	106.2
Copalar-Masaya No. 1 and No. 2, 230 kV, D/C, steel towers, 795 MCM ACSR	185 km rural flat/ rolling terrain, 51% heavily forested	Delivery of hydroelectric energy from Copalar Project	7,503.0	1,995.0	9,498.0
1986					
Copalar-Brasiles, 230 kV, S/C, D/C-2, steel towers, 795 MCM ACSR. Install insulators and conductor on 43 km of existing structures	226 km total, 183 km new S/C, rural flat rolling terrain, 42% heavily forested	Delivery of hydroelectric energy from Copalar Project	4,801.0	1,276.0	6,077.0
1988					
Asososca-Independencia and Independencia-Sur, 138 kV. Install insulators and conductors	2.5 km flat urban terrain	Two line service to a major distribution substation	10.1	5.4	15.5
TOTAL TRANSMISSION LINE EXPENDITURES			22,443.4	7,648.7	30,092.1

Legend:

S/C Single Circuit — D/C-1 Double circuit construction with one circuit installed
D/C Double Circuit — D/C-2 Install second circuit on existing structure

Continued following page ....

TABLE VII.4 - Continued

SUBSTATIONS

ITEM	REASON	EXPENDITURE - U.S. $ x 1000 FOREIGN	LOCAL	TOTAL
1978				
Asososca: Equip two single bus 138 kV line positions and revise line protection at Brasiles and Sur substation	Transmission service to Asososca substation	404.4	164.8	569.2
Acoyapa and La Batea: Equip one single bus 138 kV line position at each substation	Rural electrification of Zelaya-Rama zone	404.4	164.8	569.2
Sebaco and Santa Rita: Equip one single bus 138 kV line position at each substation	Rural electrification of Matagalpa-Jinotega zone	404.4	164.8	569.2
Brasiles: Equip one single bus 230 kV line position	Interconnection with ICE System of Costa Rica	232.0	55.4	287.4
1979				
Momotombo: Generation switchyard; Construct a single bus 230 kV switching facility. Equip 1 bank and 2 line positions	Transmission service for Momotombo generation	715.3	432.1	1,147.4
Brasiles and Leon: Purchase and install one three phase 45/60/75 MVA, OA/FA/FOA, 230-138 kV transformer at each substation. Equip one 230 kV line position at each substation to terminate lines from Momotombo. Install transfer bus and bus tie breakers in 230 kV switching facilities at Brasiles	Transformer loadings in excess of rating with single contingency loss of one other 230-138 kV transformer at the same station	2,185.4	747.3	2,932.7
Sur and Masaya: Equip one single bus 138 kV line position at each substation. Rearrange 138 kV switching facilities at Masaya as required	Two line service to two major distribution substations	404.4	164.8	569.2
1980				
Momotombo: Equip one single bus 230 kV position and terminate the step-up transformer for Momotombo Unit No. 2	Transmission service for Momotombo generation	212.0	82.1	294.1
Leon and Viejo: Equip one single bus 138 kV line position at each station	Two line service to a major distribution substation	404.4	164.8	569.2
1981				
Leon: Purchase and install one, three-phase, 45/60/75, OA/FA/FOA, 230-138 kV transformer. Install transfer bus and bus-tie breakers in 230 kV and 138 kV switching facilities	230-138 kV transformer loading in excess of emergency rating with single contingency loss of one other 230-138 kV transformer	1,360.6	559.5	1,920.1
Momotombo: Equip one single bus 230 kV position and terminate the step-up transformer for Unit No. 3	Transmission service for Momotombo generation	212.0	82.1	294.1
1982				
Leon: Equip one double bus 230 kV line position and terminate Pavana-Leon 230 kV line	Transfer interconnection from 138 kV to 230 kV position. Firm power purchase exceed stability limit	243.5	99.0	342.5
Masaya: Purchase additional land as required to install three single bus 230 kV position and one 138 kV position. Equip two 230 kV line positions. Purchase and install a three phase 45/60/75, OA/FA/FOA 230-138 kV transformer	Voltage drops in excess of 7% at three major distribution substations with single contingency loss of Brasiles-Asososca 138 kV line. Same facilities required in two years for Copalar Project	1,296.7	611.7	1,908.4

continued following page .....

TABLE VII.4 - Continued

SUBSTATIONS - Continued

ITEM	REASON	EXPENDITURE - U.S. $ x 1000 FOREIGN	LOCAL	TOTAL
1984				
Independencia: Equip one single bus 138 kV line position and terminate tap of Asososca-Independencia-Sur 138 kV line	Transmission service to Independencia 138-13.8 kV Substation	202.2	82.4	284.6
Copalar Switching Station: Construct a six-element ring bus and equip one bank and 2 line positions. Terminate step-up bank for Units No. 1 and No. 2 and the Copalar-Masaya No. 1 and No. 2 transmission lines	Transmission service for Copalar Project	524.4	586.2	1,110.6
Masaya: Expand existing 230 kV and 138 kV switching facilities. Install transfer buses and bus tie breakers in 230 kV and 138 kV buses. Equip two 230 kV line positions. Purchase and install two, three-phase 45/60/75 MVA, OA/FA/FOA, 230-138 kV transformers	Transmission service for Copalar Project	3,090.5	981.7	4,072.2
1985				
Copalar: Equip one 230 kV position and terminate step-up transformer for units No. 3 and No. 4	Transmission service for Copalar Project	200.0	148.4	348.4
1986				
Copalar: Equip one 230 kV line and one 230 kV bank position. Terminate Copalar-Brasiles line and step-up transformer for units No. 5 and No. 6	Transmission service for Copalar Project	406.1	299.0	705.1
Brasiles: Equip one 230 kV line position and terminate Copalar-Brasiles line	Transmission service for Copalar Project	206.1	118.2	324.3
1987				
Masaya: Purchase and install one, three-phase 45/60/75 MVA, OA/FA/FOA, 230-138 kV transformer	230-138 kV transformer loading in excess of emergency ratings with single contingency loss of one other 230-138 kV transformer	816.7	216.3	1,033.0
1988				
Independencia: Equip one single bus 138 kV line position	Two line service to a major distribution substation	202.2	82.4	284.6
TOTAL SUBSTATION EXPENDITURES		14,127.7	6,007.8	20,135.5
TOTAL TRANSMISSION LINES (FROM FIRST PAGE)		22,443.4	7,648.7	30,092.1
TOTAL TRANSMISSION LINES AND SUBSTATION		36,571.1	13,656.5	50,227.6

A. MOMOTOMBO TRANSMISSION SERVICE

The economic feasibility of 230 kV transmission remains to be determined. Present generation plans assumed a nominal capacity of 135 MW from the Momotombo geothermal field and no wheeling arrangements through the ENALUF system for power transfers between countries to the north and south of Nicaragua. Therefore, the preliminary study indicated that 138 kV transmission voltage would be satisfactory. However, the uncertainty associated with either of the previously mentioned sources justifies consideration of 230 kV as the transmission voltage and that transmission voltage was assumed for Momotombo.

B. DISTRIBUTION STUDIES FOR MANAGUA, MASAYA AND LEON LOAD AREAS

Study of distribution requirements for these load areas is required because the timing and location of transmission facilities is directly influenced by results of the studies performed during this investigation. Significant deviations of load from the projected values can be expected during the 11 years included in the study period. The effects of changes of the estimated loadings on substations served from the 138 kV transmission system will cascade through the transmission system and change the estimated loadings on transmission line and transformers; thereby affecting the recommended timing of facilities. Therefore, distribution studies for the major load centers should be reviewed and updated on an annual basis. Near term future load flow calculations reflecting these changes should also be made yearly,to update estimated transmission line and transformer loadings.

C. POWER FACTOR CORRECTION

Shunt capacitance at the distribution voltage level has been assumed at several stations within the Managua-Masaya load area to raise the power factor to 95 percent. However, it is the practice in many utilities to maintain power factor considerably above this figure; as high as 99 percent in some cases. A study should be made to determine the economic breakeven value of capacitance versus power and energy losses and to determine the optimum location for capacitor installations. The quantity and location of capacitance should then be adjusted accordingly. This study should be made in conjunction with the study for the following item because the power factor of the line loads will affect the economic conductor size for transmission lines.

D. TRANSMISSION LINE CONDUCTOR SIZE

The transmission line costs assumed herein are based on a single conductor per phase and the size of conductor. Generally, the conductor sizes are 795 MCM ACSR for 230 kV and 556.5 MCM ACSR for 138 kV. However, significant savings might be realized by the use of different sized conductors for different line loadings because a smaller conductor results in a lower line cost, but greater power and energy losses. For any given schedule of line loadings, there will be one size of conductor for which the sum of the line cost plus the present worth of the annual power and energy losses over the life of the line are a minimum. The economic

conductor size is found by a comparative analysis of the value of the power and energy losses and line costs for various conductor sizes. The value of power and energy losses required to make the foregoing analysis for a given period of time is obtained from line loadings and load flow studies. The economic calculations based on loading data can be made on a computer and the results can be applied to lines at all voltages. The U. S. Rural Electrification Administration sizes the conductor for its distribution lines on this basis. Potential savings are much greater at higher voltages where large blocks of power are transmitted than for lower voltages and less power.

E. NEED FOR A SYNCHRONOUS CONDENSOR IN THE ENALUF SYSTEM

The extensive use of geothermal and hydroelectric energy by 1982 will result in light loads on the 230 kV lines from the Puerto Somoza plant and a net surplus of reactive power from these lines will exist. In addition, without temporary shunt compensation, there will be a net surplus from the Copalar-Masaya No. 1 and No.2 lines due to the staged installation of units at Copalar. The net result will be voltages that exceed the recommended 105 percent limit even under peak load conditions; minimum load conditions would result in voltages exceeding 115 percent. Conversely, loss of a single 230 kV line from Copalar with 4-55 megawatt units installed, results in a net deficiency of reactive power and voltage drops exceeding 115 percent. These conflicting reactive power requirements require careful study of overall system var requirements. Therefore, temporary compensation equipment must be installed in the system in some cases, to absorb the large surplus of reactive power and limit overvoltages during both peak and light load conditions; while in other instances, a var source must be available to meet reactive power requirements under single contingency outages of 230 kV transmission lines.

Static compensation of the 230 kV transmission line using shunt reactors and capacitors is an expensive solution since the light line loading problems on the 230 kV lines are only temporary and power factor correction of load is generally most economical at the distribution voltage level. A synchronous condensor is the most flexible means of meeting the foregoing requirements.

The Managua units will be on cold standby status by 1982 and will normally not be required for service. These units will serve only as emergency capacity if other units are unavailable. Suitable modification to the excitation systems of the generators and inclusion of a hydraulic coupling between the turbine and generator is one possible solution which could be studied. Such an arrangement would allow synchronous condensor operation of the older Managua units without loss of capacity credit to the system.

The result would yield two, 15 MVAR synchronous condensors in the Managua load center which would serve effectively to alleviate temporary line compensation problems on the 230 kV system, plus improve voltage regulation at the Managua 69 kV and 138 kV buses.

A standard synchronous condensor is capable of supplying kilovars to the system equal to its rating, as well as absorbing them to an extent equal to 50 percent of its rating. A comparative analysis should be made between the conversion of the Managua units for synchronous condensor operation and capacitors at full kilovar rating plus a shunt reactor of 50 percent kilovar rating.

CAPITULO VIII

EVALUACION ECONOMICA

CHAPTER VIII

ECONOMIC EVALUATION

CHAPTER VIII

ECONOMIC EVALUATION

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CHAPTER VIII

ECONOMIC EVALUATION

8.0 INTRODUCTION

The economic analysis of alternative power system development plans presented in this report is divided into five separate studies, to examine the particular aspects of each component of the overall plan for development. In this chapter, alternative basic plans for long-range development of hydro power resources were examined for independent system expansion from 1982 to the end of the development period in 1988, followed by a 50-year period of operation. In order to examine possible alternatives to geothermal power development, two short-range contingency plans were compared, to provide ENALUF with an estimate of the relative costs involved, if actual geothermal development falls short of present expectations.

Once the selection of the basic plan for independent development of indigenous resources had been made, the effect of interconnected system expansion was examined. Analyses were made with postponement of major plant additions and the substitution of purchased hydro energy for thermal generation on the ENALUF system. Breakeven tie-line rates were determined for both off-peak energy purchases from Costa Rica and firm power purchases from Honduras. The results are contained in Appendix H and Appendix I, respectively.

8.1 METHODOLOGY OF ECONOMIC ANALYSIS

Comparison of discounted present worth of future cash flow for capital investment, fuel costs, together with operation and maintenance expenses, for alternative plans was the principal method of analysis and plan selection. The determination of tie-line rates for power purchases was made using a technique to equalize the present worth of alternative plans, for a series of discount rates, over a range of escalation from 1975 cost levels.

8.1.1 COST STUDY OF ALTERNATIVE PLANS

The preparation of costs for economic evaluation of alternative plans required detailed estimates of capital investment and operating and maintenance expenses, as well as the computation of the energy production costs of thermal plants on the system.

A. CAPITAL INVESTMENT

Concentration was given to detailed cost estimation for the dams and power plants of hydroelectric developments, together with associated transmission line and substation facilities, these being the principal facilities included in long-range plans. As the short-range expansion from 1978 to 1981 was identical for basic long-range plans, it was unnecessary to prepare estimates for geothermal plant additions during this period. The economic evaluation of basic expansion plans was then confined to the civil works, dams, generating plants and transmission facilities required for the two and three dam developments on the Rio Grande de Matagalpa.

The total cost of specific facilities or items of plant and equipment was then disbursed through the construction period on a yearly basis. As costs were to

be discounted to mid-year 1975, the amount of each annual disbursement was estimated to correspond to an equivalent mid-year cost. The total facility costs and annual disbursements for the two and three dam developments corresponding to system expansion plans A1 and B1, are given in Tables D.1 and D.2 of Appendix D. Costs are presented for the high and low dam developments at Copalar, together with the upstream developments of El Carmen and Paso Real.

These plant costs are combined with costs for the associated transmission system expansions of alternative plans A1 and B1. The annual disbursements for these comprehensive plans relevant to the independent expansion of the ENALUF system by development of indigenous hydro resources in Nicaragua, are given in Tables D.3 and D.4 of Appendix D.

The interconnection of the ENALUF system with the ENEE system of Honduras and the ICE system of Costa Rica, will enable ENALUF to purchase power throughout the development period. This will result in a major postponement of generation facilities for a period of two years from 1982 to 1984 and a reduction of installed plant capacity within the development period. The resultant capital investment disbursements corresponding to this interconnected system expansion plan E1 are given in Table D.5 of Appendix D.

B. PRODUCTION COSTS

The production costs associated with energy generated by thermal plants on the ENALUF system were determined using a computer program developed by ENALUF, with modifications made during the course of the study based on recommendations by IECO. The program was used to simulate system generation dispatch to supply a load model for the ENALUF system, with additional capability to simulate the economic operation of pumped-storage and the dispatch of energy purchased over system interconnections. The program represents a convenient method of simulating total generation over 13 four-week periods for each year of the study. A typical printout of this program for the base year of the study (1978) is given in Appendix D, Annexes D-1 through D-14. The printout consists of a separate tabulation of generation dispatch for typical day types of each four-week period, with a summary of energy generation and production costs for each four-week period and the entire year.

The principal generation sources included in development plans consist of hydro plants, geothermal plants and oil-fired thermal plants, supported by the gas-turbine and diesel units. In computation of the production costs, the units were dispatched to generate energy required during two-hour intervals during daily load cycles, according to typical day types for each of the 13 four-week periods. The ENALUF system load model was structured to represent four typical days for each period, consisting of an average weekday, the peak day, Saturday and Sunday. A fairly close representation was thereby made of the variation of system load over the entire year at two-hour intervals, by multiple combination of typical day types within each four-week period, to provide an annual load cycle for each year of the study. This may be observed for the typical day types in Annexes D-1 through D-13, of Appendix D.

The pondage hydro energy available within each of the 13 four-week periods was obtained by proportionate reduction of monthly average energy computed during the reservoir operation study, for each of the two main development plans with individual hydro plants in the unregulated and regulated modes.

Tables D.6 and D.7 of Appendix D give tabulations of the periodic (4 week) pondage hydro energy by year for the two and three dam developments, respectively. This energy was dispatched by the production costing program to satisfy the peak and mid-range load requirements of the system.

Geothermal energy was dispatched on a constant basis to satisfy base-load requirements, except during intervals for plant maintenance. This energy is shown in Tables D.6 and D.7 as a component of the base energy, together with the periodic hydro energy available from existing hydro plants.

The thermal plants on the system are dispatched by the production costing program according to the equal incremental dispatch criterion, the generation of each unit being dependent upon the input-output function of the unit in relation to the other units on the system. The main contributions to thermal generation are made by the two 50 MW units of the Puerto Somoza plant, supplemented by the 45 MW Managua Unit 3. The remaining units of the system will be held on reserve throughout the development period 1978-1988, with the exception of the base-year 1978, when there is a limited dispatch of the 15 MW Managua Unit 1, as shown on Annex D-14 of Appendix D, which gives the annual energy production summary for 1978.

Power capacity and energy balances, prepared for the two and three dam developments of the independent system expansion, will provide a general assessment of the relative dispatch of generation sources on the system. The power balances for Plan A1 (2 Dam) and Plan B1 (3 Dam) are given in Tables D.8 and D.9 of Appendix D. The addition of hydro plant in both plans A1 and B1 results in increased surplus energy for a period of years, after the build-up of geothermal capability from 1979 through 1981. In the two dam development, Plan A1, the high dam at Copalar requires three years of average inflow to fill the reservoir. Therefore, a modified plan was selected to partially fill the reservoir prior to completion of the dam and start power generation on a limited basis, until the reservoir is full. This plan results in a limitation on annual energy availability during 1983 and 1984. Normal annual operation is possible in 1985, with an average annual energy availability of 1418 GWH. This results in an energy surplus for the years 1984, 1985 and 1986, during which time thermal dispatch i not required to satisfy system requirements. There is no extended period of reservoir filling for the three dam development, Plan B1, and the energy surpluses in 1983 and 1984 result in no thermal dispatch during these years. Pondage hydro energy well in excess of system requirements was prevalent during these years and therefore no production costing was necessary. It was assumed that the storage capacity of the pondage hydro would enable modulated operation, in response to system energy requirements, to supply all energy in excess of the base-load energy generated by geothermal units. Geothermal generation was constant for both hydro development alternatives, therefore no costs relating to geothermal energy production had to be taken into consideration for economic evaluation. Thus, production costing was limited to those years when thermal dispatch was required, resulting in tangible fuel costs and variable operation and maintenance expenses.

In addition, the time frame for comparative analysis of long-range plans is 1982-1988, so the geothermal plant investment costs relative to installations in 1979, 1980 and 1981 represent sunk costs and were excluded from consideration in economic analysis.

The power balance for interconnected system expansion with development Plan E1, consisting of the Copalar high dam and the utilization of power purchases from ENEE and ICE, is given in Table D.10 of Appendix D. This power balance shows how the dispatch of thermal plant is affected by a combination of off-peak energy purchases from Costa Rica and firm power purchases from Honduras. The system is entirely supplied by hydro and geothermal energy during the period 1982 through 1987, except for a limited dispatch of 25 GWH in 1984. The first sizable dispatch of thermal plant is in 1988, with the Puerto Somoza Units 1 and 2 operating on annual plant capacity factors of 42 and 7 percent, respectively.

The capacity available for meeting peak load demand on the system is included in the power balances of Tables D.8, D.9 and D.10. The annual reserve margin is indicated as a percentage of system peak load demand and in megawatts.

C. OPERATION AND MAINTENANCE COSTS

The other component of energy production costs is the variable operation and maintenance (O & M) costs associated with the dispatch of thermal plant. The computation of both fixed and variable O & M costs was included as part of the production costing procedure, as a feature of the ENALUF program. However, for purposes of comparative analysis, the fixed costs associated with thermal plant were constant for alternative plans and therefore excluded from analysis. Only variable costs of thermal plant were germane to economic comparisons, as these were directly related to unit dispatch as part of total system generation. Geothermal plant O & M was also common to alternative plans and therefore excluded from comparative analysis. The other generating plant O & M common to all plans was that for the existing hydro plants of Centroamerica and Somoza Garcia, together with the gas-turbine and diesel units.

Table D.11 of Appendix D gives the O & M for generating plant, with a segregation of cost components into the costs common to alternative plans and the comparative O & M costs relevant to economic evaluation of the two and three dam developments. These consisted of fixed costs associated with increments of hydro plant for alternative developments and variable thermal O & M costs.

O & M cost estimates for hydro plant were made by reference to the Hydroelectric Power Evaluation 1/ guidelines published by the United State Federal Power Commission. Annual operation and maintenance expenses for conventional and pumped-storage hydroelectric plants are given in Table 37 of this manual. These were compared with recorded O & M costs for existing hydro plants of the ENALUF system and an estimated O & M cost level for 1975. The resultant cost curve for hydro plant O & M is given on Figure D.4 of Appendix D.

The summary tabulation on the following page contains the fixed and variable O & M costs used for production cost computations.

1/ FPC P-38 Supplement No. 1, Federal Power Commission, 1969

GENERATING PLANT
OPERATION AND MAINTENANCE EXPENSES
1975 COST LEVELS

	FIXED COST $/KW	VARIABLE COST mills/kwh
EXISTING UNITS:		
Managua Plant		
Siemen's Units 1 & 2	12.80	1.70
Franco Tosi Unit 3	5.60	0.35
Chinandega Plant		
Gas Turbine Unit	3.00	-
Hydro Plants		
Centroamerica Units 1 & 2	7.50	-
Somoza Garcia Units 1 & 2	7.50	-
FUTURE UNITS:		
Puerto Somoza Plant		
Thermal Units 1 & 2	5.00	0.30
Momotombo Plant		
Geothermal Units 1-3	7.00	-
Copalar Plant		
Hydro Units 1 & 2	4.75	-
Hydro Units 1-3	3.95	-
Hydro Units 1-4	3.75	-
Hydro Units 1-5	3.65	-
Hydro Units 1-6	3.60	-
El Carmen Plant		
Hydro Units 1 & 2	6.25	-
Paso Real Plant		
Hydro Units 1 & 2	7.50	-

The O & M expenses were obtained from a study of recorded values for the actual cost of operation and maintenance for generating plant of the existing ENALUF system, comparison of O & M costs for similar plant in other countries and estimating data published by the United States Federal Power Commission. See reference 1/. Geothermal O & M costs were obtained by adjustment of estimated costs to compensate for scale effects, using data received by ENALUF relevant to the Ahuachapan geothermal plant in El Salvador. Table D.12 of Appendix D summarizes the recorded values of fixed and variable O & M components for the hydro and thermal plants of the ENALUF system for the period 1967-1974.

Estimates of O & M for the transmission system elements associated with the alternative developments are contained in Tables D.13 and D.14 of Appendix D. The annual O & M for substations given in Table D.13 was obtained in relation to the installed MVA of transformer capacity in substations at sending and receiving ends of the transmission system. Figure D.5 of Appendix D. relates substation O & M, in $/KVA, to the total installed capacity in transformer MVA for sending and receiving end substations. Similar estimates of annual O & M for transmission lines were made for alternative developments, these being contained in Table D.14 The annual transmission line O & M costs were based on fixed $/km values for different types of line construction. Figure D.6 of Appendix D shows annual O & M expenses per kilometer for single and double-circuit steel tower transmission lines over a range of transmission voltage levels.

The following summary tabulation indicates the values used during this study:

ANNUAL OPERATION AND MAINTENANCE EXPENSES FOR TRANSMISSION LINES

230 kV	Steel Tower Double Circuit Construction	-	$580/km
	(With single circuit strung initially)	-	$530/km
230 kV	Steel Tower Single Circuit Construction	-	$480/km

The above values were derived from relative O & M levels for transmission lines contained in Table 44 of reference 1/, suitably related to O & M values used for developing countries and escalated to 1975 cost levels. These are also directly related to the transmission O & M curves of Figure D.6.

Similar estimates of transmission system O & M were made for the interconnected system expansion plan E1, with annual costs relevant to both the development of the Copalar high dam and the operation of the interconnected system. These costs are contained in Tables D.15 and D.16 of Appendix D.

8.1.2 ECONOMIC COMPARISON OF DISCOUNTED 1975 COSTS

The capital investment, fuel costs, operation and maintenance expenses developed during the cost study were compiled and disbursed by year throughout the relevant period of analysis, for economic comparison of discounted future cost-streams. All costs were estimated as of mid-year 1975, the reference to which all future costs were discounted,so annual disbursements were made equivalent to expenditures for a particular year, but concentrated at the mid-year point. The analytical tool used throughout this study for economic analysis of discounted cash flow, was a multiple option computer program (ECONIC), specially developed for economic evaluation of the ENALUF system expansion.

In all,a total of 13 different plans for generation and transmission system expansion were examined using this program. In addition to normal discounting routines, this program has a provision for equalizing the present worth of future cost streams for interconnected system plans. This provision enabled the determination of the breakeven tie-line energy rate for successive discrete discount rates, each one in turn being the equalizing rate-of-return between alternative plans.

Printed copies of the output of this program are given in Appendices E and F, with the use of Program Option A, which computed the present worth of cost streams relating to alternative plans, for purposes of economic comparison and plan selection. The basic economic analysis was conducted at 197 cost levels with zero escalation for expansion plan cost components. The cost components consist of capital investment in generating plant, transmission lines and substations; fuel costs; and operation and maintenance expenses for generating plant, transmission lines and substations. In addition to investment and operating costs, the program has a provision for including the effect of power purchases or sales in comparative analysis of alternative plans. The tie-line purchases are segregated for interchange with both ENEE and ICE. If power sales are relevant to the analysis they are entered as negative purchases and for a year with both purchases and sales, the net purchases (positive) or net sales (negative) value is entered into analysis. A summary printout is provided for comparison of present worth pertaining to total investment; fuel costs; O & M; ENEE and ICE power purchases, together with the total present worth of alternative plans. An asterisk (*) on the printout conveniently indicates the lowest present worth for a particular discount rate, applicable to each element and the total for the plan with the least present worth of future costs. In addition, the actual differential present worth is computed for each element and the total for alternative plans at each discount rate over the range selected.

8.1.3 SENSITIVITY TESTS FOR RANGE OF COST ESCALATION

In addition to economic comparisons at 1975 cost levels, the program has a feature which allows the effect of cost escalation to be examined over a range of escalation profiles, with the possibility of independent escalation of individual cost elements for investment, fuel and O & M. The sensitivity tests applied in the comparative analysis of alternative plans involved the successive examination of the effect of a range of escalation profiles on the selection process. Figures VIII.1, VIII.2, and VIII.3 show the escalation profiles which were used for application to cost streams of investment disbursements, fuel oil costs and operation and maintenance expenses, respectively.

PERFILES DE ESCALAMIENTO DE LOS COSTOS DE INVERSION
INVESTMENT COST ESCALATION PROFILES

PERFIL PROFILE	PORCENTAJE DE ESCALAMIENTO Y PRIMER AÑO DE APLICACION PERCENTAGE ESCALATION AND FIRST YEAR OF APPLICATION		
I/C1	12.0 (1976) ;	11.0 (1981) ;	10.0 (1986)
I/C2	11.0 (1976) ;	10.0 (1981) ;	9.0 (1986)
I/C3	10.0 (1976) ;	9.0 (1981) ;	8.0 (1986)
I/C4	9.0 (1976) ;	8.0 (1981) ;	7.0 (1986)
I/C5	8.0 (1976) ;	7.0 (1981) ;	6.0 (1986)

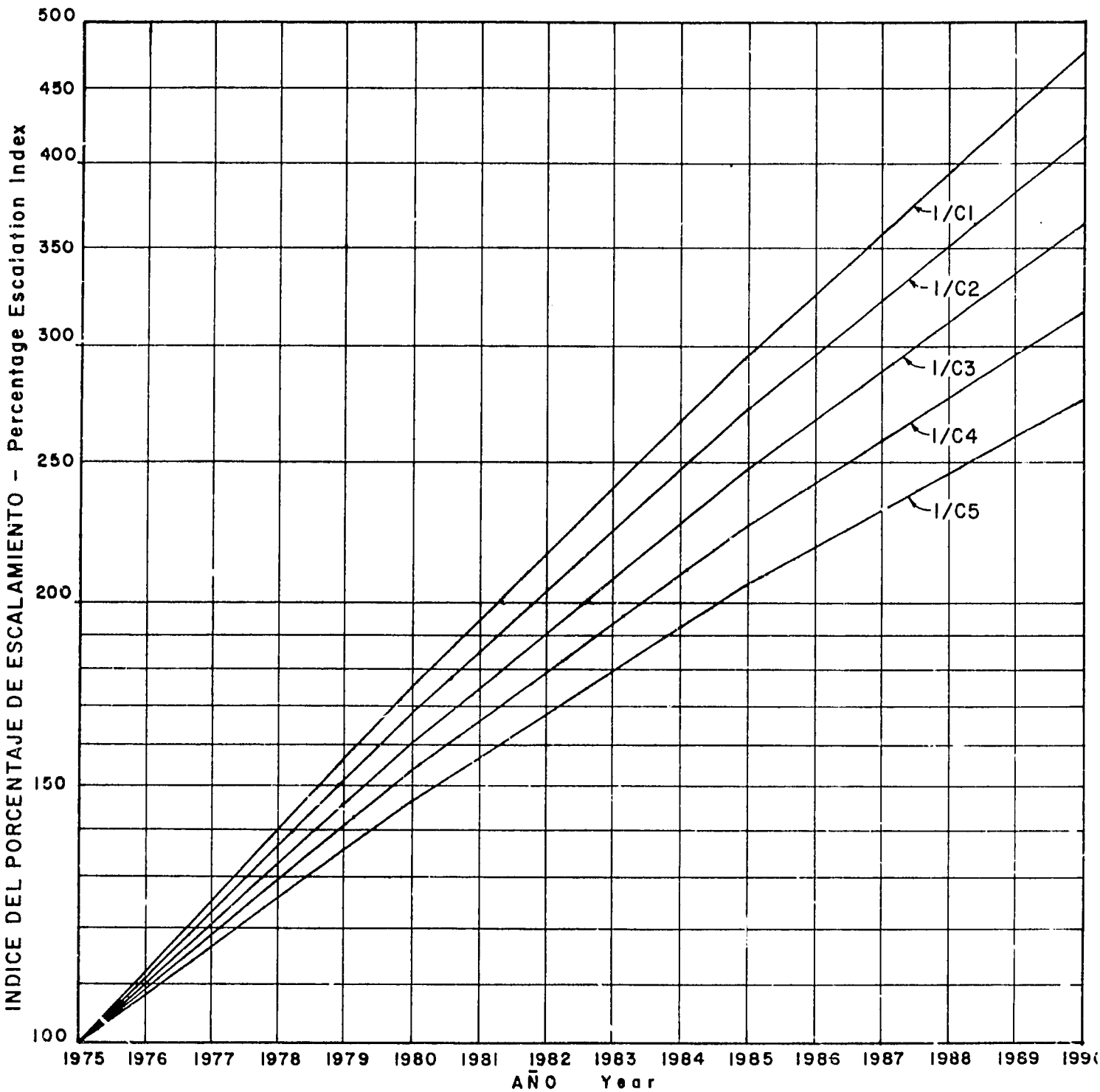
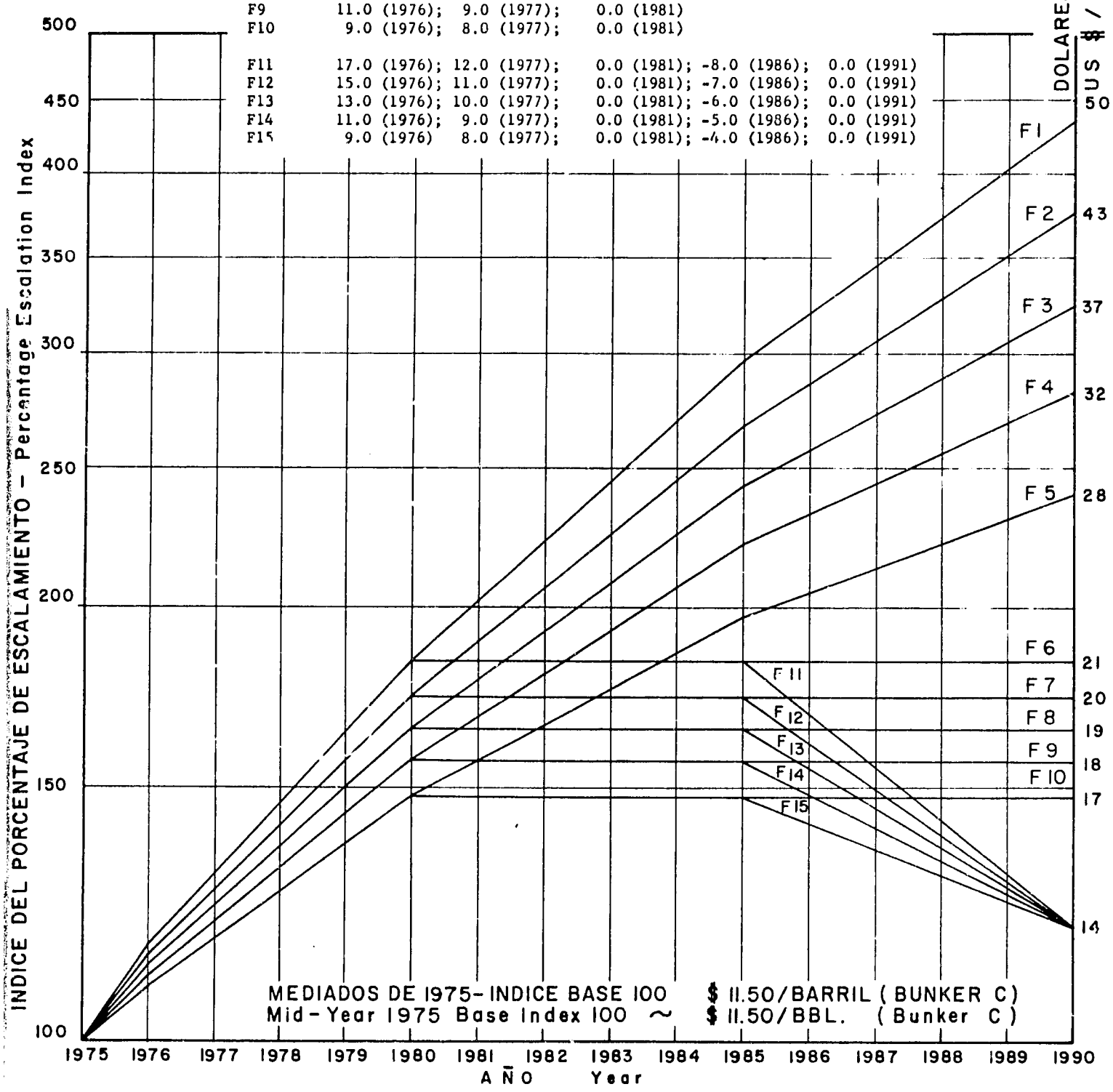


FIG. VIII.2

PERFILES DEL ESCALAMIENTO DE LOS COSTOS DE ACEITE COMBUSTIBLE
FUEL OIL COST ESCALATION PROFILES

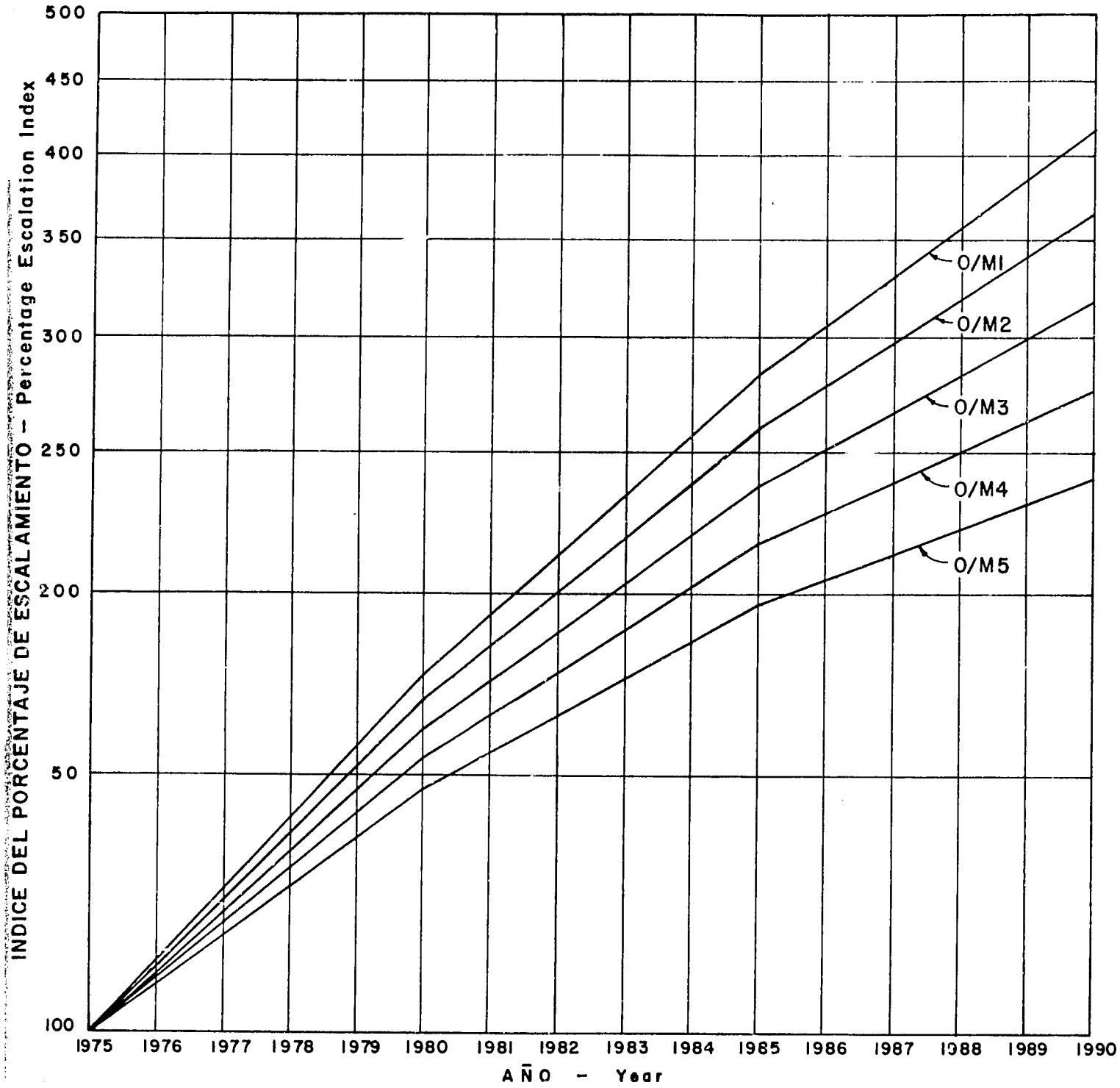
PERFIL / PROFILE	PORCENTAJE DE ESCALAMIENTO Y PRIMER AÑO DE APLICACION / PERCENTAGE ESCALATION AND FIRST YEAR OF APPLICATION				
F1	17.0 (1976);	12.0 (1977);	10.0 (1981);	8.0 (1986);	0.0 (1991)
F2	15.0 (1976);	11.0 (1977);	9.0 (1981);	7.0 (1986);	0.0 (1991)
F3	13.0 (1976);	10.0 (1977);	8.0 (1981);	6.0 (1986);	0.0 (1991)
F4	11.0 (1976);	9.0 (1977);	7.0 (1981);	5.0 (1986);	0.0 (1991)
F5	9.0 (1976);	8.0 (1977);	6.0 (1981);	4.0 (1986);	0.0 (1991)
F6	17.0 (1976);	12.0 (1977);	0.0 (1981)		
F7	15.0 (1976);	11.0 (1977);	0.0 (1981)		
F8	13.0 (1976);	10.0 (1977);	0.0 (1981)		
F9	11.0 (1976);	9.0 (1977);	0.0 (1981)		
F10	9.0 (1976);	8.0 (1977);	0.0 (1981)		
F11	17.0 (1976);	12.0 (1977);	0.0 (1981);	-8.0 (1986);	0.0 (1991)
F12	15.0 (1976);	11.0 (1977);	0.0 (1981);	-7.0 (1986);	0.0 (1991)
F13	13.0 (1976);	10.0 (1977);	0.0 (1981);	-6.0 (1986);	0.0 (1991)
F14	11.0 (1976);	9.0 (1977);	0.0 (1981);	-5.0 (1986);	0.0 (1991)
F15	9.0 (1976)	8.0 (1977);	0.0 (1981);	-4.0 (1986);	0.0 (1991)



PERFILES DE ESCALAMIENTO DE LOS COSTOS DE OPERACION Y MANTENIMIENTO

OPERATION AND MAINTENANCE COST ESCALATION PROFILES

PERFIL PROFILE	PORCENTAJE DE ESCALAMIENTO Y PRIMER AÑO DE APLICACION PERCENTAGE ESCALATION AND FIRST YEAR OF APPLICATION			
O/M1	12.0 (1976) ;	10.0 (1981) ;	8.0 (1986) ;	0.0 (1991)
O/M2	11.0 (1976) ;	9.0 (1981) ;	7.0 (1986) ;	0.0 (1991)
O/M3	10.0 (1976) ;	8.0 (1981) ;	6.0 (1986) ;	0.0 (1991)
O/M4	9.0 (1976) ;	7.0 (1981) ;	5.0 (1986) ;	0.0 (1991)
O/M5	8.0 (1976) ;	6.0 (1981) ;	4.0 (1986) ;	0.0 (1991)



A. INVESTMENT COST ESCALATION

Five profiles for investment cost escalation were applied over an initial range of between 8 and 12 percent per year for the first five years from mid-year 1975. Escalation rates were changed at five-year intervals by decrements of one percent, assuming that the presently adverse inflationary spiral affecting the world economy would be steadily brought under control in the long-range time frame. At the present it appears that this assumption is optimistic; however, without the basic premise of global economic stability in the long-run, the analysis of long-range plans is rendered academic.

In the short-range, it is a fair assumption that inflationary trends will continue and numerous effects will cause the escalation to continue, modulated only in part by the severity of economic counter-measures. The range of investment cost escalation profiles shown on Figure VIII.1 is sufficiently broad to encompass the possible future trends of investment cost escalation relevant to analysis of alternative developments to be included in power system expansion plans.

B. FUEL COST ESCALATION

A total of 15 fuel oil escalation profiles are shown on Figure VIII.2, used in the study and are grouped for comparative application into three main sets. The first set of five profiles (F1 - F5) corresponds to high rates of continuing escalation. The second set of five profiles (F6 - F10) models continuance of fuel oil escalation in the short-range to 1980, followed by a leveling of oil prices over the long-range to 1990. The third set is similar to the second, except for price decreases, caused by the development in the long-run of alternative fuel sources, introduced after 1985, to a stabilization point to be reached by 1990.

The basis for the projection of possible future trends relating to fuel-oil escalation hinges on the magnitude of the oil price increase expected in the fourth quarter of this year. Over the past several months much speculation has revolved in government, industrial, economic and financial communities of the world, regarding the likely price increase per barrel of oil over current posted prices. The amount of the increase, to be agreed to by the Organization of Petroleum Exporting Countries (OPEC), will be the result of deliberations within the OPEC Council, coupled with the realities of the demand and production supply situation, as it affects individual oil producing countries.

The extent of the price increase anticipated has been reported in the international press to range from a low of $0.50 to $0.70 per barrel to a high of $3.50 per barrel. These increases have been demanded in OPEC conferences by certain representatives of member nations, as compensation for the effect of worldwide inflation on the purchasing power of individual oil producing states. This effect has been ostensibly calculated by OPEC economists to amount to a 35 percent reduction in purchasing power since January 1974, when the price freeze on oil revenues went into effect. Some members of OPEC favor the larger price increase, but others are prepared to accept a more reasonable increase to compensate for loss of purchasing power on revenues received from oil consuming nations. The outcome will depend on

the decision making process in the OPEC council and the effect of the present levels of over-supply of oil on the decisions made by individual representatives of producing nations.

A wide range of escalation possibilities lies between the lower and upper limits of 7 and 35 percent for the anticipated price increase for the next year, from July 1, 1975 to mid-year 1976. A narrower range for the initial escalation rate was selected for this study, based on a concensus of opinion of economists directly concerned with fuel price escalation. Price movements have been predicted in the range of $1.00 to $1.90 per barrel based on a posted price of $11.50 per barrel. These increases represent a range of fuel cost escalation between 9 and 17 percent and an average of 13 percent. This range was adopted for the initial escalation profile for 1975 to 1976, with steps of 2 percent between separate projections. After mid-year 1976, it was assumed that oil price escalation would follow worldwide inflationary trends, with OPEC price increases deliberately aligned with general escalatory trends in commodity markets. However, it was further assumed that some restraint would be brought to bear on the inflationary spiral and the short-range escalation would be reduced between one and five percent from that of the initial year (1975-1976). This agrees quite closely with the conclusions reached by the noted oil economist, Consultant Walter Levy, acknowledged dean of U.S. oil experts, that OPEC will raise posted prices by about 12 percent in 1975 and will continue to raise prices on a steady basis thereafter. The recent predictions made by fuel experts suggest that the price of oil will be raised by $1.50 per barrel by October, which on the price base used for escalation profiles ($11.50) would result in a 1976 price base of $13 per barrel. This corresponds to the average of the escalation profiles used in this study.

The principal source of petroleum for Nicaragua is Venezuela and the supplier of fuel oil to ENALUF for thermal generation is Esso Standard Oil, S.A., Ltd. At the time this study of oil price escalation was made in the second quarter of 1975, the contract price for Bunker C fuel oil delivered to the ENALUF Managua thermal plant was $11.65 per barrel. A quotation for fuel oil supplies to the new units of the Puerto Somoza plant was received by ENALUF from Esso. The projected cost on a 1975 price base was $11.52 for delivery of Bunker C fuel to the plant, from a tap-line on the existing pipeline to Managua near to the plant site. These two cost levels for fuel, delivered at the Managua and Puerto Somoza plants, were used for base fuel costs in the production cost study.

The long-range escalation of fuel costs was computed as part of sensitivity analysis using program ECONIC to apply the escalation profiles of Figure VIII.2. The wide range of escalation enabled the impact of future movements of fuel prices to be examined for their effect on plan selection.

The continuing upward trends of profiles F1 through F5 depict a relatively unchecked escalation, both adding to and following worldwide inflationary spirals, until application of stabilizing controls to the global economy will progressively slow the long-term escalation rate.

Profiles F6 through F10 depict the same short-range escalation up to a range of values reached in 1980, from that year on the fuel oil price base is maintained constant by rigidly imposed and enforced controls.

The third set of profiles, F11 through F15 is indicative of the possible effect of alternative energy sources in the long-range, which would tend to force down the price of fuel under market pressures and forced production cutbacks.

The future trend of fuel prices is a major determing factor for the plan selection in this study. It is considered reasonable that the future scenarios, implicit to the fuel cost escalation profiles used, will adequately serve to quantify the overall impact to the end of the expansion period in 1988. It was assumed that no escalation was applied during the period of constant operation beyond the year 1990, to compensate for declining thermal plant usage during the plant service life.

C. ESCALATION OF OPERATION AND MAINTENANCE COSTS

Figure VIII.3 shows the escalation profiles which were applied to annual operation and maintenance costs developed during the study. The range of escalation rates used for O & M costs is similar to those used for investment cost,except for the difference that after the first five years from 1975 to 1980, the rate of increase for O & M is made progressively smaller than that for investment. Successive decrements to the escalation rate are introduced at intervals of five years, resulting in a 2 percent differential by the middle of the next decade. This differential arises from the fact that labor costs are a relatively large component of O & M costs, as opposed to investment in plant and equipment, which are capital intensive. Wages and salaries for operating and maintenance staff were assumed not to rise commensurate with wage-rates paid to construction workers employed on the civil works and installation of plant and equipment for major construction projects. This assumption is made on the basis that labor rates associated with construction are in the main pertinent to unionized trades, which in private industry have more countervailing leverage than operators and maintenance employees of government agencies such as ENALUF.

In order to examine the actual escalation trends associated with principal components of the ENALUF generation and transmission system, a study was made of recorded operation and maintenance costs for the period 1967-1974. Table D.17 of Appendix D indicates the recorded values of annual operation and maintenance for hydro, oil-fired thermal and gas-turbine generating plants, divided into respective fixed and variable components for the entire system.

Table D.18 of Appendix D summarizes the combined costs for operation and maintenance of generating plants, transmission lines and substations. The composite escalation relevant to generating plant varied greatly from year to year, with the most recent increase for 1973-74 being approximately 10 percent.

It was difficult to establish a discernible trend for the escalation of operation and maintenance costs for transmission lines and substations, because they varied somewhat erratically from year to year over the period of record. Therefore, the same escalatory trends projected for generation O & M were used for transmission lines and substations. In order to prepare escalation profiles, an average of 10 percent was selected for application over the period 1975 to 1980, with a total range of between 8 and 12 percent

in single percentage increments. These initial escalation rates were assumed to be successively decremented at 5 year intervals by steps of 2 percent, to range between 4 and 8 percent by 1986. After 1990, it was assumed that no escalation was applied during the period of constant operation to the end of the 50-year service life of facilities.

D. SENSITIVITY TESTS WITH COMBINED EFFECT OF ESCALATION TRENDS

A series of sensitivity tests, combining groups of escalation profiles for capital investment, fuel costs and operating and maintenance expenses, were used during comparative analysis of system plans. The composition of the individual sensitivity tests are given in Table VIII.1, in the form of percentage escalation rates and first years of application. There are three groups corresponding to the five profiles for investment cost and O & M escalation, combined with the three sets of five fuel cost escalation profiles. These sensitivity tests were applied successively by program ECONIC, for sensitivity analysis at escalated cost levels of alternative development plans for power system expansion.

8.2 ANALYSIS OF ALTERNATIVE HYDRO POWER DEVELOPMENTS

The economic comparison of alternative hydroelectric power developments on the Rio Grande de Matagalpa was the first study made to determine the selected scheme for a basic plan for independent expansion of the ENALUF power system utilizing indigenous resources. This was then used to provide a standard of comparison for alternative developments and a means of establishing the tie-line rates associated with interconnected system expansion.

8.2.1 DIFFERENTIAL PRESENT WORTH FOR BASIC PLANS

Appendix E contains the results of the economic comparison of basic alternative plans, A1 and B1, for the two and three dam developments, respectively. The first analysis was made with a comparison of the discounted present worth of future cost streams at 1975 cost levels, without the effect of escalation taken into consideration. The summary of program ECONIC, in Option A mode, for this case (Test 0) is given on Annex E-1, with the respective cost-streams for Plans A1 and B1 given on Annexes E-2 and E-3 of Appendix E.

The economic comparison of Summary E-1 indicates that the equalizing rate-of-return between Plans A1 and B1 lies between 13.0 and 13.5 percent, resulting from the relative values of discounted present worth for investment, fuel costs and O & M for the alternative developments.

There is a direct trade-off between capital investment and fuel costs. Plan B1 for the three dam scheme requires the least investment cost, but incurs higher expenditures for thermal plant operation. At the discount rate corresponding to the opportunity cost of capital, which for Nicaragua was taken to be 12 percent, as advised by the IBRD, the differential present worth of future investment in generation and transmission facilities is $13,363,000 in favor of Plan B1. The corresponding differential present worth of future fuel costs is $15,166,000 in favor of Plan A1. The effect of differences in O & M is relatively minor in comparison, with a relative advantage of $475,000 in favor of Plan A1.

TABLA VIII.1 - TABLE VIII.1

RESUMEN DE PRUEBAS DE SENSITIVIDAD PARA COMPARACION ECONOMICA DE LOS PLANES DE DESARROLLO

SUMMARY OF SENSITIVITY TESTS FOR ECONOMIC COMPARISON OF DEVELOPMENT PLANS

PORCENTAJE DE ESCALAMIENTO Y PRIMER AÑO DE APLICACION

PERCENTAGE ESCALATION RATES AND FIRST YEAR OF APPLICATION

PRUEBA TEST	INVERSION DE CAPITAL CAPITAL INVESTMENT	COSTO DE COMBUSTIBLE FUEL COST	COSTOS DE OPERACION Y MANTENIMIENTO OPERATION AND MAINTENANCE COSTS
0	CASO BASE - ESCALAMIENTO CERO APLICADO AL FLUJO DEL EFECTIVO / BASE CASE - ZERO ESCALATION APPLIED TO CASH FLOW		
1	12.0 (1976) ; 11.0 (1981) ; 10.0 (1986)	17.0 (1976) ; 12.0 (1977) ; 10.0 (1981) ; 8.0 (1986) ; 0.0 (1991)	12.0 (1976) ; 10.0 (1981) ; 8.0 (1986) ; 0.0 (1991)
2	11.0 (1976) ; 10.0 (1981) ; 9.0 (1986)	15.0 (1976) ; 11.0 (1977) ; 9.0 (1981) ; 7.0 (1986) ; 0.0 (1991)	11.0 (1976) ; 9.0 (1981) ; 7.0 (1986) ; 0.0 (1991)
3	10.0 (1976) ; 9.0 (1981) ; 8.0 (1986)	13.0 (1976) ; 10.0 (1977) ; 8.0 (1981) ; 6.0 (1986) ; 0.0 (1991)	10.0 (1976) ; 8.0 (1981) ; 6.0 (1986) ; 0.0 (1991)
4	9.0 (1976) ; 8.0 (1981) ; 7.0 (1986)	11.0 (1976) ; 9.0 (1977) ; 7.0 (1981) ; 5.0 (1986) ; 0.0 (1991)	9.0 (1976) ; 7.0 (1981) ; 5.0 (1986) ; 0.0 (1991)
5	8.0 (1976) ; 7.0 (1981) ; 6.0 (1986)	9.0 (1976) ; 8.0 (1977) ; 6.0 (1981) ; 4.0 (1986) ; 0.0 (1991)	8.0 (1976) ; 6.0 (1981) ; 4.0 (1986) ; 0.0 (1991)
6	12.0 (1976) ; 11.0 (1981) ; 10.0 (1986)	17.0 (1976) ; 12.0 (1977) ; 0.0 (1981)	12.0 (1976) ; 10.0 (1981) ; 8.0 (1986) ; 0.0 (1991)
7	11.0 (1976) ; 10.0 (1981) ; 9.0 (1986)	15.0 (1976) ; 11.0 (1977) ; 0.0 (1981)	11.0 (1976) ; 9.0 (1981) ; 7.0 (1986) ; 0.0 (1991)
8	10.0 (1976) ; 9.0 (1981) ; 8.0 (1986)	13.0 (1976) ; 10.0 (1977) ; 0.0 (1981)	10.0 (1976) ; 8.0 (1981) ; 6.0 (1986) ; 0.0 (1991)
9	9.0 (1976) ; 8.0 (1981) ; 7.0 (1986)	11.0 (1976) ; 9.0 (1977) ; 0.0 (1981)	9.0 (1976) ; 7.0 (1981) ; 5.0 (1986) ; 0.0 (1991)
10	8.0 (1976) ; 7.0 (1981) ; 6.0 (1986)	9.0 (1976) ; 8.0 (1977) ; 0.0 (1981)	8.0 (1976) ; 6.0 (1981) ; 4.0 (1986) ; 0.0 (1991)
11	12.0 (1976) ; 11.0 (1981) ; 10.0 (1986)	17.0 (1976) ; 12.0 (1977) ; 0.0 (1981) ; -8.0 (1986) ; 0.0 (1991)	12.0 (1976) ; 10.0 (1981) ; 8.0 (1986) ; 0.0 (1991)
12	11.0 (1976) ; 10.0 (1981) ; 9.0 (1986)	15.0 (1976) ; 11.0 (1977) ; 0.0 (1981) ; -7.0 (1986) ; 0.0 (1991)	11.0 (1976) ; 9.0 (1981) ; 7.0 (1986) ; 0.0 (1991)
13	10.0 (1976) ; 9.0 (1981) ; 8.0 (1986)	13.0 (1976) ; 10.0 (1977) ; 0.0 (1981) ; -6.0 (1986) ; 0.0 (1991)	10.0 (1976) ; 8.0 (1981) ; 6.0 (1986) ; 0.0 (1991)
14	9.0 (1976) ; 8.0 (1981) ; 7.0 (1986)	11.0 (1976) ; 9.0 (1977) ; 0.0 (1981) ; -5.0 (1986) ; 0.0 (1991)	9.0 (1976) ; 7.0 (1981) ; 5.0 (1986) ; 0.0 (1991)
15	8.0 (1976) ; 7.0 (1981) ; 6.0 (1986)	9.0 (1976) ; 8.0 (1977) ; 0.0 (1981) ; -4.0 (1986) ; 0.0 (1991)	8.0 (1976) ; 6.0 (1981) ; 4.0 (1986) ; 0.0 (1991)

The overall net differential between alternative basic plans, at 12 percent opportunity cost of capital, is $2,578,000. The variation of this differential over the range of discount rates 10 to 15 percent is $10,509,000, corresponding to a maximum of $8,062,000 in favor of Plan A1 at 10 percent discount rate to a maximum of $2,447,000 in favor of Plan B1 at 15 percent discount rate.

This analysis is decisive in terms of the present worth of future costs, with zero escalation. There is a definite economic advantage associated with Plan A1 for the two dam development, represented by the differential present worth of over $2.5 million at the opportunity cost of capital, which is 1.35 percent below the equalizing rate-of-return between alternative plans A1 and B1. This is clearly seen on the base curve of Figure VIII.4, corresponding to Test 0, for differential present worth between alternative plans at 1975 cost levels. The supporting data for this series of curves is given in Appendix E, Annexes E-1 through E-18. Annex E-1 provides a summary of the comparison between Plans A1 and B1 at 1975 cost levels. Annexes E-2 and E-3 show the unescalated cash flow for the two and three dam schemes, respectively, as part of independent system expansion plans A1 and B1. Annexes E-4 to E-18 are summaries for sensitivity tests 1 - 15 listed in Table VIII.1.

8.2.2 SENSITIVITY OF SELECTION TO COST ESCALATION

Curves are shown on Figure VIII.4 corresponding to the series of sensitivity tests applied to determine the effect of cost escalation on plan selection. The large differential exhibited in favor of the two dam development results largely from the effect of the displacement of thermal generation by the large energy potential associated with the Copalar high dam. This effect progressively increases the net differential between plans A1 and B1, as escalation of fuel costs relative to investment dominates the overall economic comparison.

The differential escalation effect may be observed by the disposition of the curves, corresponding to the three main groups of sensitivity tests. The effect is most pronounced when fuel cost escalation proceeds in step with escalation of capital investment on a continuing basis, as demonstrated in sensitivity tests 1-5. When fuel oil costs are assumed to stabilize after 1980, the reduction in the overall differential between alternative plans varies between $7,515,000 (Tests 1 and 6) and $2,011,000 (Tests 5 and 10), with a mean of $4,236,000 (Tests 3 and 8), at the opportunity cost of capital, 12 percent.

Induced oil price reductions following 1985 have a similar effect, in that the differential between alternative plans is further reduced. However, the predominant advantage still rests with Plan A1, with a $18,076,000 differential in favor of the two dam development,applying the lowest set of escalation profiles (Test 15) and a discount rate of 12 percent corresponding to the opportunity cost of capital.

8.2.3 BASIC PLAN SELECTION FOR INDEPENDENT SYSTEM EXPANSION

The two and three dam development schemes, included in expansion Plans A1 and B1, have been subjected to technical and economic analysis at the system level, in order to select the most economic scheme for independent system expansion.

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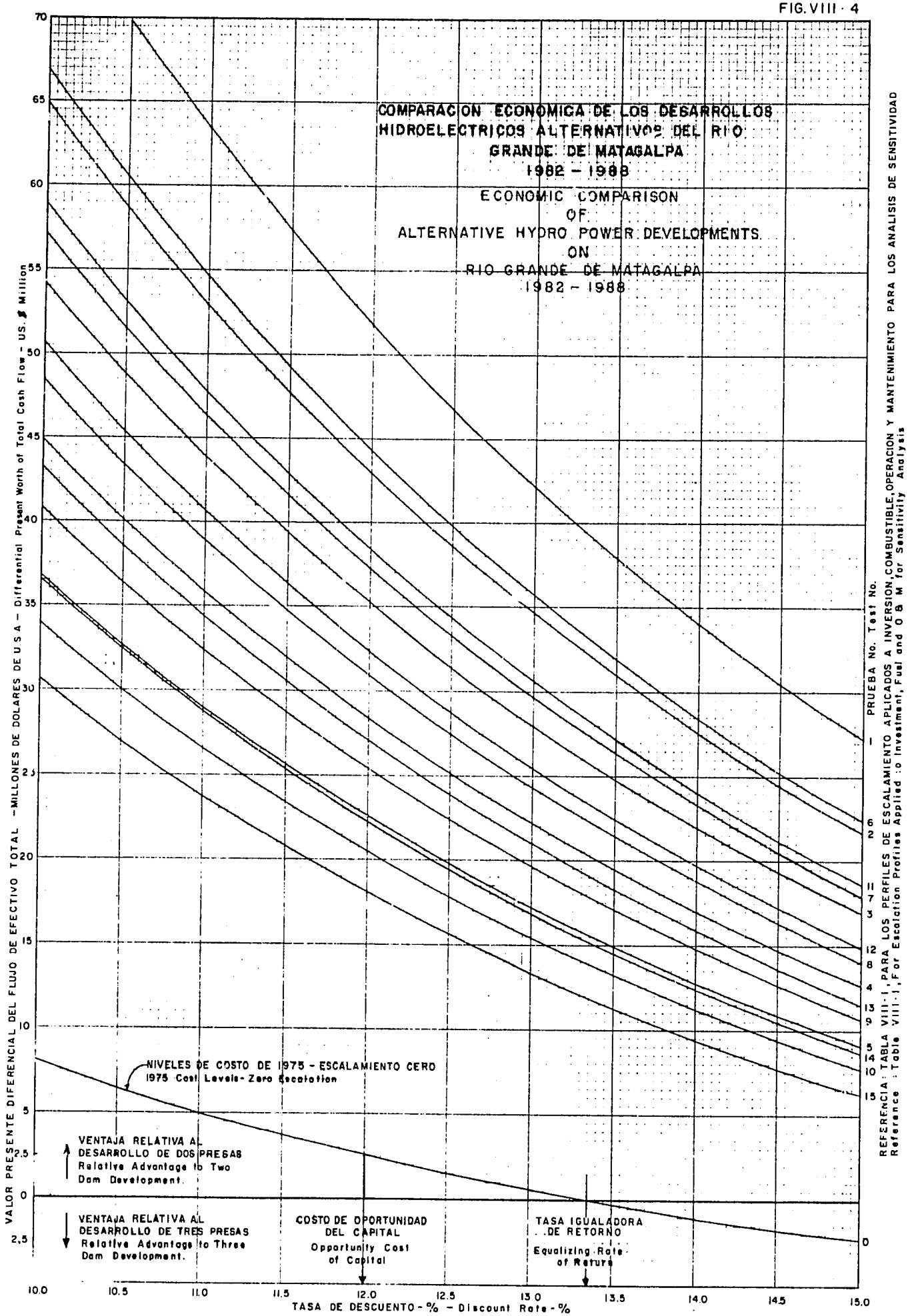
FIG. VIII · 4



As discussed in the two previous sections, the economic evaluation at both 1975 and escalated cost levels, results in a definite economic advantage for the two dam scheme of Plan A1 at the opportunity cost of capital. This means that at the 12 percent discount rate used to compare the economic merits of major infrastructure or development projects in Nicaragua, there is a positive economic advantage to the construction and operation of the high dam at Copalar together with Paso Real. The economic advantage is decisive at 1975 cost levels and the basis for the selection is magnified at escalated cost levels.

As cost escalation is a continuing reality, the economic selection process has to take into account possible future cost trends. In this study certain assumptions have been made relating to cost escalation, as discussed in Section 8.1.3, to enable economic comparisons to be conducted at escalated cost levels. The sensitivity analysis has been made relative to the average escalation profiles used for investment, fuel cost and O & M expenses. These being respectively I/C 3 of Figure VIII.1; F3, F8 and F13 of Figure VIII.2; and O/M 3 of Figure VIII.3. These were combined in sensitivity tests 3, 8 and 13. Upper and lower escalation profiles, associated with each of these average profiles, enable sensitivity analysis to be conducted at plus and minus 1 and 2 percent off-sets to determine the relative extent of the change produced in differential present worth between alternative plans.

The results of the sensitivity tests are summarized as follows:

SENSITIVITY TESTS AT ESCALATED COST LEVELS
(12% Opportunity Cost of Capital)

TEST NO.	OFFSET FROM AVERAGE	DIFFERENTIAL PRESENT WORTH BETWEEN PLANS A1 AND B1	INCREASE (DECREASE)	PERCENTAGE CHANGE
1	+ 2%	$51,732,000	$16,568,000	+ 47%
2	+ 1%	$42,896,000	$ 7,732,000	+ 22%
3	0	$35,164,000	0	0
4	- 1%	$28,416,000	($ 6,748,000)	- 19%
5	- 2%	$22,543,000	($12,621,000)	- 36%
6	+ 2%	$44,217,000	$13,289,000	+ 43%
7	+ 1%	$37,173,000	$ 6,245,000	+ 20%
8	0	$30,928,000	0	0
9	- 1%	$25,404,000	($ 5,524,000)	- 18%
10	- 2%	$20,532,000	($10,396,000)	- 34%
11	+ 2%	$38,325,000	$11,288,000	+ 42%
12	+ 1%	$32,363,000	$ 5,326,000	+ 20%
13	0	$27,037,000	0	0
14	- 1%	$22,292,000	($ 4,745,000)	- 18%
15	- 2%	$18,076,000	($ 8,961,000)	- 33%

It may be concluded that the differential present worth between Plans A1 and B1 is most sensitive to the percentage offsets from average escalation profiles. The differential present worth is less sensitive to the changes caused by alternative long-range trends in fuel cost escalation, due to the discounting effect on future cost streams.

Although the initial OPEC fuel price increase anticipated for the fourth quarter of 1975 is critical to economic analysis of alternative plans, the impact of long-term changes in the rate of fuel cost escalation has little effect on the sensitivity of the differential present worth between alternative plans A1 and B1. This is due mainly to the time period over which discounted cash flow is computed, these changes to escalation profiles being assumed to be effective following 1980 and 1985, respectively.

Over the plus or minus two percent range for escalation profile off-sets, in comparison to continuing fuel cost escalation, the effect of zero fuel cost escalation after 1980, produces a four percent reduction in the differential present worth at the upper end of the range and a two percent reduction at the lower end. The effect of decreasing fuel costs, following 1985, causes an additional one percent reduction at both upper and lower ends of the range.

At the plus or minus one percent range for escalation profile offsets, the effect is less marked, with a two percent reduction in the differential present worth between alternative plans, for zero fuel cost escalation following 1980, at the upper end of the range and a one percent reduction at the lower end. No additional change results from a reduction of fuel costs in the long-range after 1985.

Thus, the selection of basic independent system expansion Plan A1 is assured on the basis of economic analysis at both 1975 and escalated cost levels. The inclusion of the two dam scheme, consisting of the Copalar high dam and Paso Real,is essential to an independent long-range plan for the development of the hydroelectric resources of the Rio Grande de Matagalpa.

8.3 EVALUATION OF CONTINGENCY PLANS FOR SHORT-RANGE EXPANSION

The reasons for the consideration of alternative short-range plant additions to substitute for geothermal plant were discussed in Chapter IV, Section 4.1.5. The economic evaluation of contingency plans has been made in order to alert ENALUF to the relative merits of the alternative solutions compared, so that the basis for in-depth studies will be available for subsequent detailed evaluation if it proves necessary to seriously consider alternative plant additions to substitute for geothermal development at Momotombo.

8.3.1 ADDITIONAL THERMAL CAPACITY AT THE PUERTO SOMOZA PLANT

A third unit could be installed at the Puerto Somoza thermal plant, if the ultimate capacity of the geothermal reservoirs is less than that required to support the entire geothermal plant complement assumed for inclusion in the short-range expansion plan 1979-1981. Present fuel costs and projected escalation make this solution unattractive; however, this solution may be the only long term possibility unless a possible method of accelerating the development of hydro resources is found. The turnkey method of combining engineering design and construction could serve to gain one year on the required schedule for introduction of Copalar Units 1 and 2 in November 1982. This would be of help, if the required alternative would only have to generate the equivalent energy of the third 45 megawatt unit at Momotombo, scheduled for September 1981. System reliability could be preserved by the earlier introduction of hydro units at Copalar in 1981 but the available hydro energy from indigenous resource development is limited and to satisfy total system

energy requirements transfers via interconnections would have to provide relief, beginning in 1982.

The acceleration of Copalar to end-of-year 1981 instead of November 1982 could provide more power than the equivalent of a single 45 megawatt geothermal unit but this required capacity and energy could also be arranged by purchasing additional power from Honduras, beginning in 1982.

However, if alternative base-load capacity were required to substitute for the second geothermal unit at Momotombo, which is scheduled for service by mid-year 1980, the substitution of hydro capacity would be precluded due to lead-time required to bring hydro power on-line. In this case power purchases would provide no relief before 1982 and, in the long-run, other hydro developments would have to be moved forward to substitute for the base-load energy generated by geothermal plant.

So a legitimate situation could arise, in which for reason of various possible exigencies, only 40 to 50 megawatts could be developed at Momotombo by 1980 and an alternative thermal solution would have to be sought. Accordingly, a contingency plan, C1, was devised on the assumption that a third 50 megawatt thermal unit would be required by 1980, for initial service in January 1981.

A cost segregation was made of the current estimates for the two 50 MW units presently under construction at the Puerto Somoza Site, to determine the construction cost of a single unit addition. Allowing for remobilization costs and other increases relevant to design and construction of a third unit at the same site, the estimate for this 50 megawatt plant addition was $15,000,000, or the equivalent of $300 per kilowatt.

This was disbursed over a four year period as follows:

PUERTO SOMOZA UNIT 3 ADDITION
ANNUAL CAPITAL DISBURSEMENTS FOR 50 MW PLANT AND SUBSTATION

	YEAR 1 (1977)	YEAR 2 (1978)	YEAR 3 (1979)	YEAR 4 (1980)
Thermal Plant	$1,200,000	$7,500,000	$4,390,000	$1,045,000
Substation			260,000	605,000
Total	$1,200,000	$7,500,000	$4,650,000	$1,650,000

Certain assumptions were made relating to the unit heat rate, the delivered cost of Bunker C fuel and the annual plant factor of the thermal unit in order to determine the operating costs of the 50 MW thermal unit for the equivalent of the base-load generation of a 45 MW geothermal unit.

The full load heat rate of the Puerto Somoza Units 1 and 2, corresponding to the input-output characteristic of the units used for production costing was 9,370 BTU/kwh. In order to account for decreased efficiency during part-load operation, the average plant heat rate was assumed to be 9,400 BTU/kwh.

The cost of fuel delivered at the plant was assumed to be $11.52 per barrel at 1975 price levels, the same as for Units 1 and 2. As the fuel supply contract for a third unit would entail renegotiation of fuel prices for delivery at the site, this assumption is one of convenience only, as any other would constitute a hypothetical value.

The annual generation of a 45 MW geothermal unit, operating on base-load at an annual plant capacity factor of 89 percent is 350 GWH. This value was assumed for the annual generation of the 50 MW thermal unit, which was the equivalent of an annual plant capacity factor of 80 percent. Assuming a heating value for fuel oil of 140,000 BTU per gallon, the annual fuel cost was calculated to be $6,445,000.

The same fixed and variable components of plant O & M were used for the third 50 MW unit; as were entered for Puerto Somoza Units 1 and 2 in production costing, these being $5.00 per KW and 0.30 mills per kwh. Total annual O & M expenses were calculated to be $355,000 for the generating plant and $43,000 for the associated substation facilities, based on a value of $0.72 per KVA, applicable to a 60 MVA 138/230 kV main transformer.

These values were used for economic comparison with an equivalent diesel plant, in order to determine the relative economic advantage of alternative contingency plans for thermal generation.

8.3.2 DIESEL GENERATOR PLANT INSTALLATION AT MASAYA

The relatively recent design innovations in diesel engine technology have made possible the multiple-unit plant installation of large capacity, high thermal efficiency engines, to realize investment costs per kilowatt of installed capacity and fuel costs, that are comparable to normal thermal plants with ratings between 40 and 100 MW.

As an equivalent base-load plant, to replace a geothermal power installation, the application of large capacity units in multiple formation allows flexibility in both timing of unit placement and normal daily operation to supply base-load on the system. The high thermal efficiency enables low unit heat rates to be obtained for continuous rated units. The added feature of engines designed to use Bunker C fuel, makes the units most attractive to utilize in the event geothermal generation potential is found to be limited.

A plant consisting of four 12.5 MW units was selected for comparison with the single 50 MW thermal unit, the diesel plant being assumed to be located in Masaya, relatively near to the system load center. Fuel was assumed to be delivered by tank truck from Managua, at a delivered cost equal to that paid for Bunker C delivered to the Managua Plant. This cost of $11.65 per barrel at 1975 price levels was assumed to apply to the same grade of fuel used for the third unit at Puerto Somoza, with a heating value of 140,000 BTU per gallon. The net station heat rate of 9,400 BTU/kwh was based on technical data received from the manufacturer of the plant. The resultant annual fuel cost was $6,520,000 based on the equivalent 350 GWH generation of the geothermal plant. Thus, the actual unit price for fuel deliveries constitutes the only factor which would produce a fuel cost differential between the two thermal alternatives, unless special fuel treatment is required for the Masaya Plant.

The cost estimate for the plant was prepared from a quotation received from a manufacturer capable of supplying the entire installation, consisting of four diesel engine-generator units and auxiliaries, switchgear, structural steel housing, overhead crane and cooling tower. The total installed cost was estimated to be $19,000,000, or the equivalent of $380 per kilowatt. A separate estimate was made for the plant substation equipment, including the main transformer and 138 kV position, assuming that the plant would be connected to the 138 kV bus at the Masaya Substation.

No transmission line costs were entered for either the Puerto Somoza Unit 3 or the Diesel Plant at Masaya. The Puerto Somoza thermal plant has adequate line capacity to carry the output of an additional unit and the diesel plant would supply the system over adequate transmission line capacity from the 138 kV substation bus at Masaya.

The annual disbursements for the Masaya plant and substation are as follows:

MASAYA DIESEL PLANT INSTALLATION
ANNUAL CAPITAL DISBURSEMENTS FOR 50 MW PLANT AND SUBSTATION

	YEAR 1 (1978)	YEAR 2 (1979)	YEAR 3 (1980)
Diesel Plant	$1,900,000	$7,600,000	$9,500,000
Substation		$ 190,000	$ 445,000
Total	$1,900,000	$7,790,000	$9,945,000

Diesel plant O & M costs were estimated to be $380,000 annually, based on the manufacturers recommendation of two percent of plant costs. Substation O & M was estimated to be $39,000, based on a value of $0.65 per KVA for a 60 MVA, 13.8/138 kV transformer.

The above costs were used for economic comparison with the 50 MW thermal unit, to assess the relative worth of the second contingency plan for geothermal power plant substitution.

The analysis was conducted over a 29 year period, with capital disbursements in the years 1977 through 1980, followed by a period of constant operation for 25 years, corresponding to the service life of a geothermal plant.

8.3.3 ECONOMIC COMPARISON OF ALTERNATIVE CONTINGENCY PLANS

The results of the economic comparison are given in Appendix E, Annexes E-19 through E-26, with the graphical representation shown on Figure VIII.5 The economic advantage of Plan C1, for the addition of a third 50 MW unit at the Puerto Somoza Plant, is such that no equalizing rate-of-return is possible within a reasonable range of discount rates.

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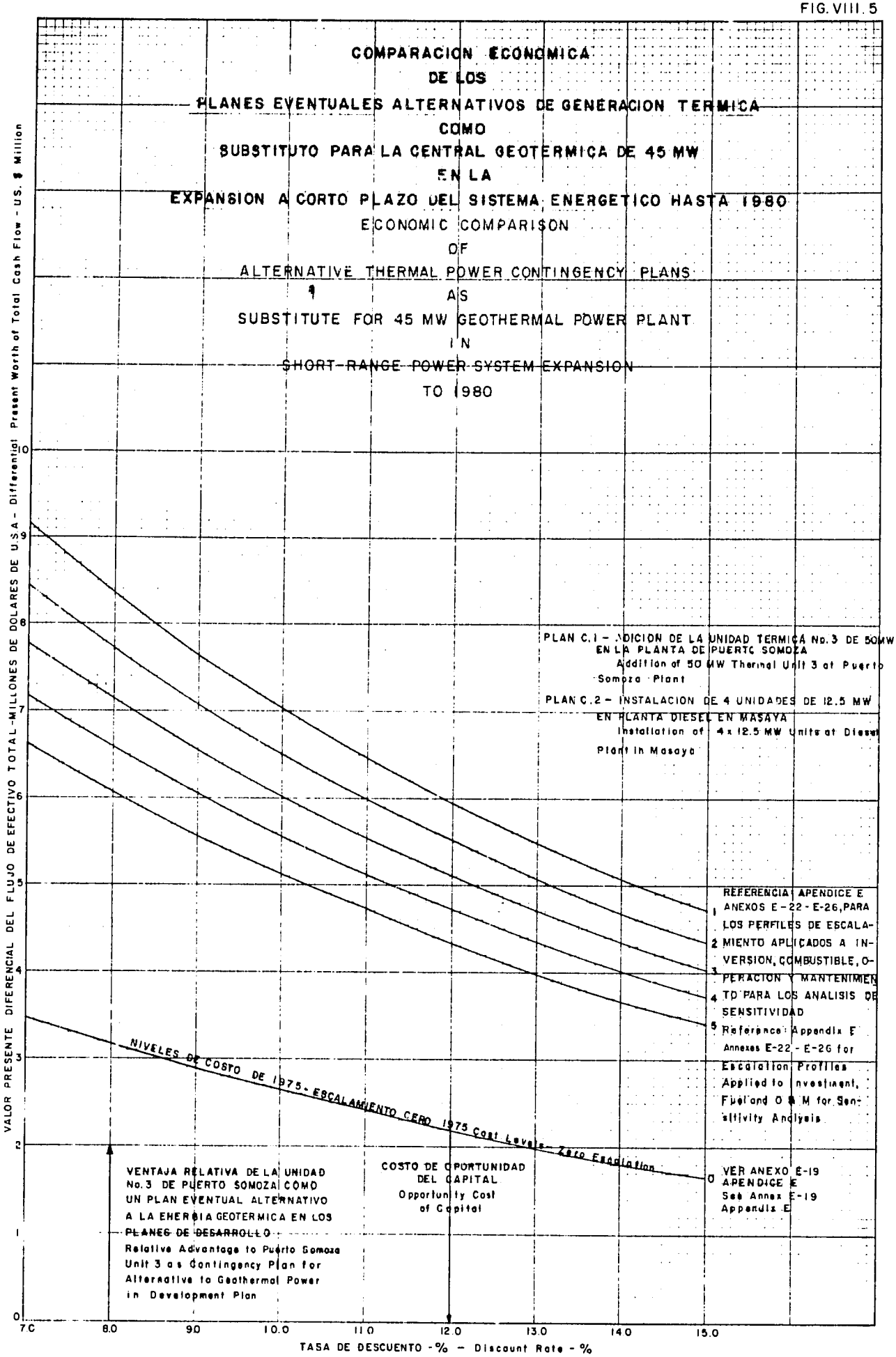
FIG. VIII. 5



At the discount rate corresponding to the 12 percent opportunity cost of capital, used for definitive plan selection, the differential present worth of futu st streams between Plans C1 and C2 is $2,187,000, in favor of Plan C1, in ter 1975 cost levels. This differential represents approximately 5 percent o the total present worth of future costs associated with Plans C1 and C2, the absolute values being $40,640,000 and $42,827,000, respectively.

At escalated cost levels, the relative economic advantage of Plan C1 increases, as may be observed from the curves corresponding to Sensitivity Tests 1-5. The installation of either the 50 MW thermal unit or the equivalent diesel plant was assumed to be required for initial service in 1981 and to simplify the analysis only five fuel escalation profiles were applied, these corresponding to profiles F6-F10 on Figure VIII.2. These were profiles with fixed price controls beginning in 1980, so the analysis for sensitivity tests 1 through 5 was conducted over a range of fuel prices from $17 to $21 per barrel, in steps of $1.00 per barrel. Thus, the curves of Figure VIII.5 corresponding to Tests 1-5 are representative of the effect of $1.00 per barrel increments for the price of fuel over the service life of the geothermal plant replaced, coupled with the escalation profiles for investment costs and O & M expenses shown on Figures VIII.1 and VIII.3.

The mean profile corresponds to Test No.3, with plus or minus one and two percentage offsets corresponding to the curves for Tests 2 and 4, 1 and 5, respectively. The results of the sensitivity tests may be summarized as follows:

THERMAL CONTINGENCY PLAN ANALYSIS AT ESCALATED COST LEVELS
(12% Opportunity Cost of Capital)

TEST NO.	OFFSET FROM MEAN	FUEL PRICE BASE $/BBL	DIFFERENTIAL PRESENT WORTH BETWEEN PLANS C1 AND C2	INCREASE (DECREASE)	PERCENTAGE CHANGE
1	+ 2%	21	$5,972,000	$864,000	+17
2	+ 1%	20	$5,526,000	$418,000	+ 8
3	0	19	$5,108,000	0	
4	- 1%	18	$4,716,000	($392,000)	- 8
5	- 2%	17	$4,349,000	($759,000)	-15

Thus, even with the restricted range of fuel cost escalation, the differential present worth between Plans C1 and C2 is quite sensitive to 1 or 2 percent increases or decreases to mean escalation rates included in profiles.

The economic comparison of the two contingency plans for thermal substitution for geothermal power development results in the apparent choice of an additional 50 MW unit installation at the Puerto Somoza Plant rather than the Masaya Plant.

To qualify the results, it should be understood that plant estimates for Puerto Somoza Unit 3 were based on segregated construction costs and disbursements obtained from accounting records and engineering estimates for a project under construction. In contrast, the estimates for the diesel plant construction cost was based on quotations received from one manufacturer and not from competitive bids for a diesel plant installation. Any future analysis should utilize competitive proposals for plant costs as a basis for economic comparison.