No. 8

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

FEDERAL COMMISSION OF ELECTRICITY,
THE UNITED MEXICAN STATES

FEASIBILITY STUDY
ON
REHABILITATION
OF
MAZATEPEC HYDROELECTRIC POWER STATION

FINAL REPORT
MAIN REPORT

NOVEMBER [illegible]

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NIPPON KOEI CO., LTD.
TOKYO, JAPAN

PREFACE

In response to a request from the Government of the United Mexican States, the Government of Japan decided to conduct a feasibility study on Rehabilitation of Mazatepec Hydro-electric Power Station and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Mexico a study team headed by Mr. Kiyoshi Miyake of Nippon Koei Co., Ltd., five times during the period from August 1992 to October 1993.

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

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

I wish to express my sincere appreciation to the officials concerned of the Government of the United Mexican States for their close cooperation extended to the team.

November 1993

Kensuke Yanagiya
President
Japan International Cooperation Agency

November 1993

Mr. Kensuke Yanagiya
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Sir,

Letter of Transmittal

We are pleased to submit herewith the Final Report of Feasibility Study on Rehabilitation of Mazatepec Hydroelectric Power Station in the United Mexican States.

This Report deals with the formulation of a rehabilitation plan for the Mazatepec Power Station which was built on the Apulco River in 1962, about 170 km northeast of Mexico City. In this Project, it is anticipated that power generation will be affected by sediment problems since the reservoir storage capacity has been depleted by progressive sedimentation and hydraulic equipment has been subjected to sand-abbrasion effect. Based on the study a package of remedial measures is proposed in the Report.

The Report consists of three (3) Volumes, Executive Summary, Main Report and Appendix. Executive Summary presents main outputs of the study. Main Report covers all the study results including analysis of the reservoir sedimentation progress, comparative study for countermeasures, cost estimate, evaluation of the proposed measures. Appendix gives additional and supporting informations and data to Main Report.

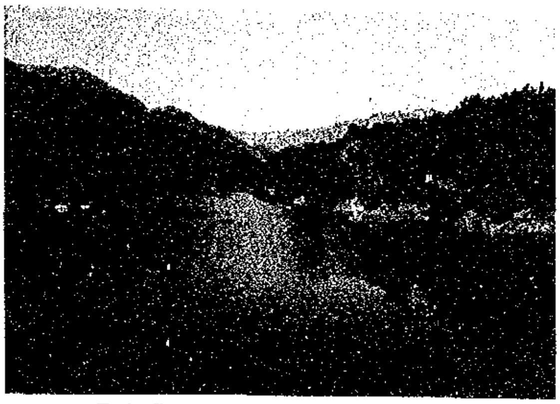
We would like to express out grateful acknowledgment to the personnel of your Agency, your Branch Office at Mexico City, and Embassy of Japan in Mexico, and also to officials and individuals of the Government of Mexico and Federal Commission of Electricity for their assistance and advice extended to the Study Team. We sincerely hope that the results of this study would contribute to the national and regional development of the country.

Yours sincerely,

K. Miyake

Kiyoshi Miyake
Team Leader
Feasibility Study on
Rehabilitation of
Mazatepec Hydroelectric Power Station

P-1 Soledad Dam and Reservoir
(wet month, October 1992)

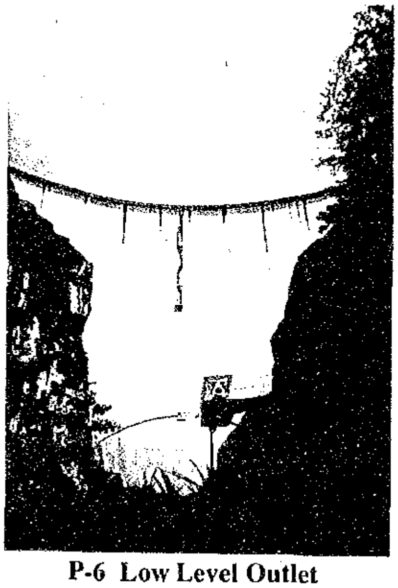


P-2 Soledad Reservoir
(dry month, February 1993)

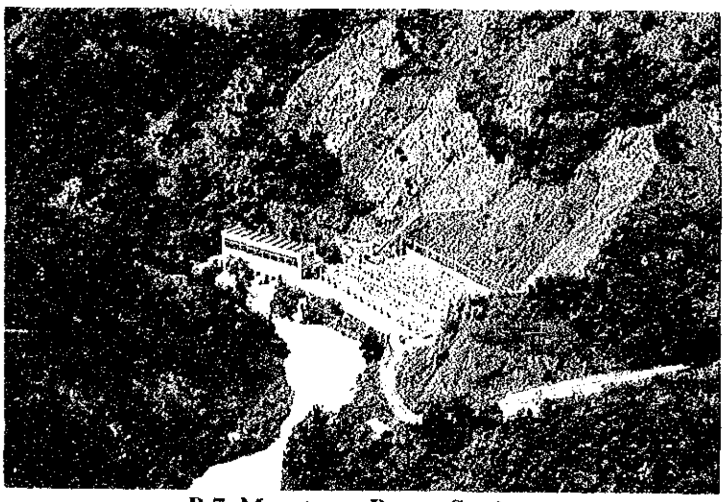
P-3 Soledad Dam

P-4 Spillway

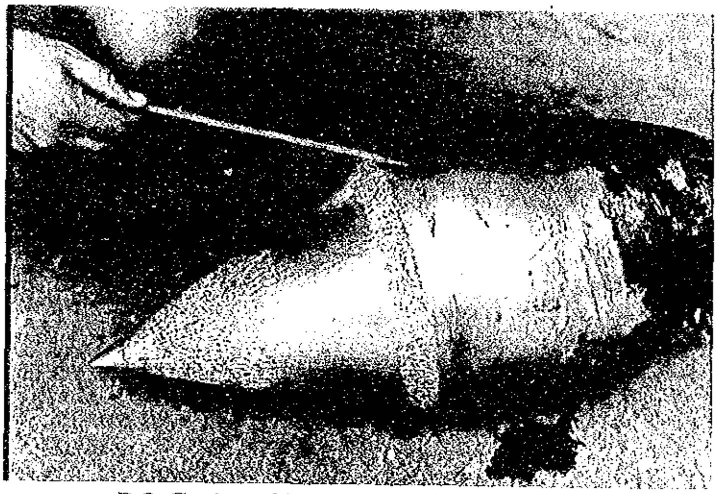
P-5 Spillway Chute



P-6 Low Level Outlet

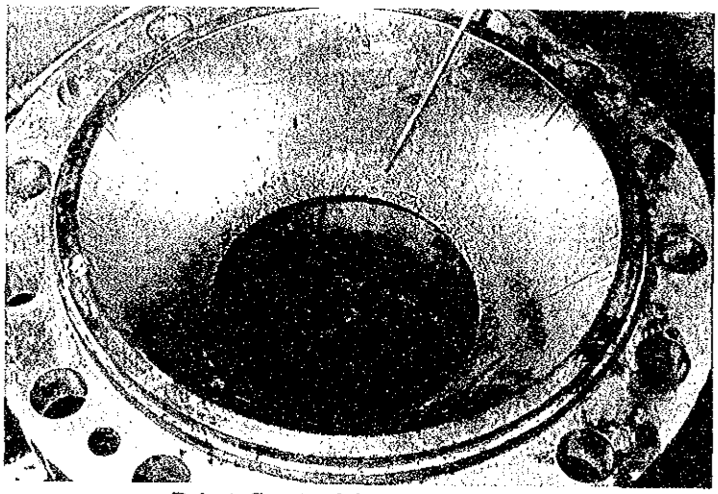


P-7 Mazatepec Power Station



P-8 Cavitated Needle for Needle Valve of 6-jet Pelton Turbine

P-10 Upper Catchment of Rio Xalcomulco (Annual rain fall exceeding 1,000mm)



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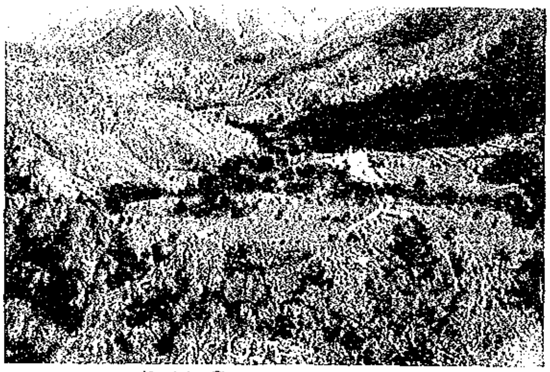

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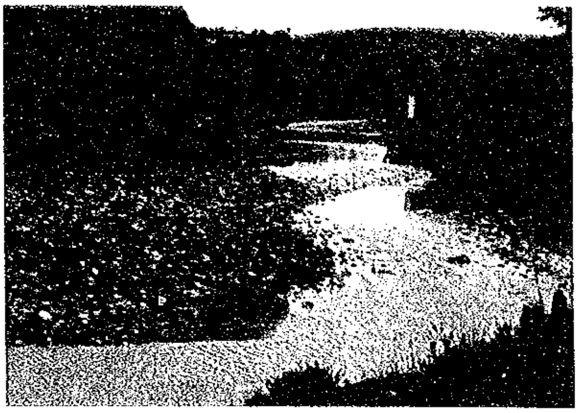

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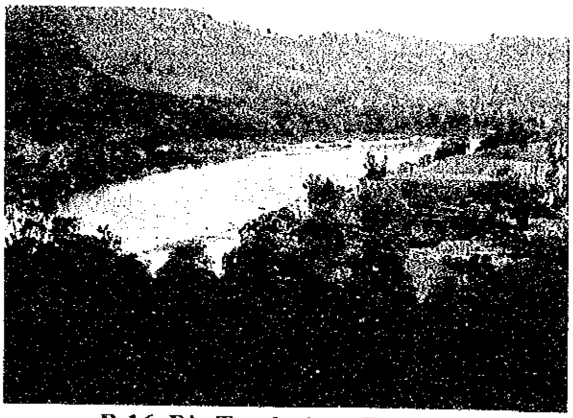

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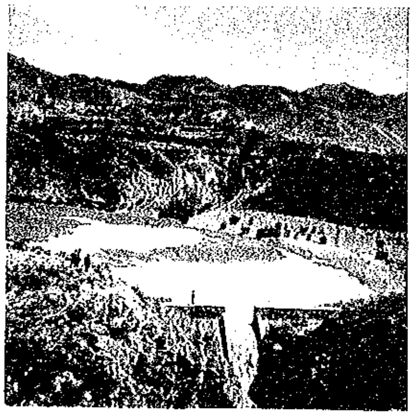
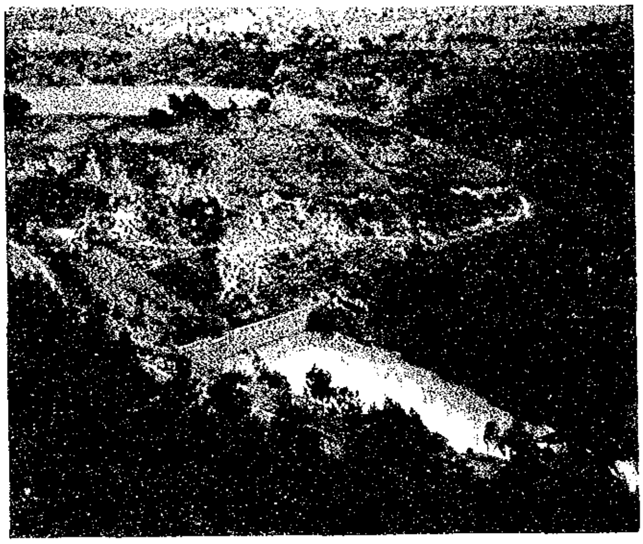
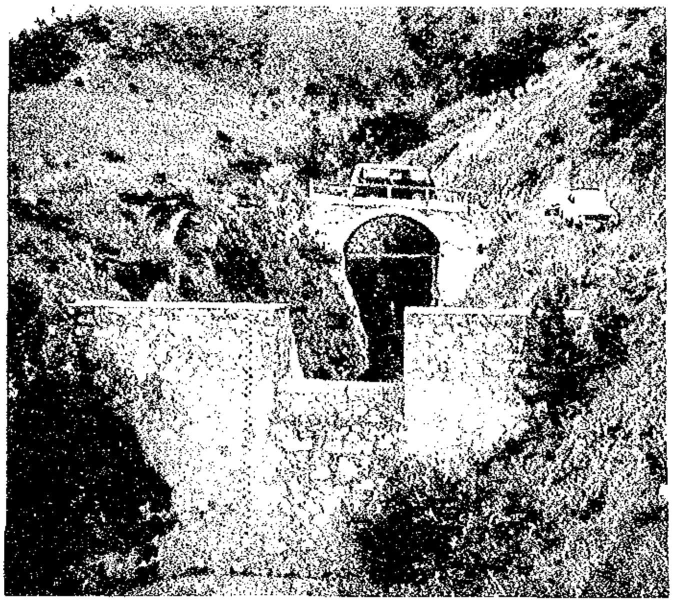


P-26 Checkdam



P-27 Checkdam



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Dam Axis

Flow

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Abbreviations and Units

<u>Organization</u>

JICA	Japan International Cooperation Agency
CFE	Federal Commission of Electricity

<u>Measurement</u>

1) Length

mm	millimeter
cm	centimeter
m	meter
km	kilometer

2) Area

m^2	square meter
ha	hectare = 10,000 m^2
km^2	square kilometer

3) Volume

m^3	cubic meter
mcm	million cubic meter

4) Weight

kg	kilogram
ton	metric ton

5) Time

yr	year
hr	hour
min	minute
s, sec	second

6) Money

US$	US Dollar
NP	Mexican New Peso

7) Electricity

kW	kilowatt
MW	megawatt
kV	kilovolt

8) Other Measures

%	percent
℃	degree centigrade
10^3	thousand
10^6	million

9) Derived Measures

cms	cubic meter per second
kWh	kilowatt hour
GWh	gigawatt hour (x 10^6 kWh)
kVA	kilovolt ampere
MVA	megavolt ampere

Others

El.	Elevation
FSL	Full Supply Level (Normal High Water Level)
MOL	Minimum Operating Level
RCC	Rolled Compacted Concrete
G. S.	Gauging Station
GDP	Gross Domestic Product
PAESE	Program of Energy Saving of Electrical Sector
SIOPE	System of Energy Loss Control
CONAPO	National Commission of Population (Comision Nacional de población)
EN	Net Energy
IBFA	Accumulated Fixed Gross Investment
POB	Population
LF	Load Factor
EJIDO	Group-owned Land System in Mexico
SEMIP	Secretary of Energy, Mines and State Industries
ELC	Electroconsult, Consulting Engineers, Italy
CLFC	Central Lighting Company
PEMEX	Mexican Petroleum Company (Petroleos Mexicanos)

CHAPTER 1

INTRODUCTION

CHAPTER 1 INTRODUCTION

1.1 Background

The Mazatepec Hydroelectric Power Station (hereinafter referred to as the Project) is a hydropower plant with a dam and reservoir which was commissioned for commercial operation in 1962. The Project was developed on the Apulco river about 170 km northeast of Mexico City. The Apulco river originates in East Sierra Madre Mountains and pours into the Gulf of Mexico, and offers favorable sites for hydropower development, being blessed with abundant precipitation, steep topography, sound geological features, etc.

The Project is owned and operated by the Federal Commission of Electricity (Comision Federal de Electricidad, CFE) under Secretary of Energy, Mines and State Industries (SEMIP) of the United Mexican States. The Project was planned to have a single purpose for power generation and its construction was executed by CFE with technical assistance to the arch dam portion from an Italian consultant, ELC.

The Project consists of such structural components as arch dam, spillway, low level outlet, intake, power tunnel, surge tank, penstock, surface-type power house, outdoor switchyard and transmission lines. The powerhouse accommodates 4 units of turbine-generator, each rated at 54.86 MW and 220 MW in total. The plant had a significant role in the power system because at the time when commissioned, the total peak load in Mexico was presumably only a few million kilowatts. Thereafter the Project has continuously made contribution to the national and regional energy supply over 30 years with a high reliable performance.

In several years after operation, however, it revealed that the sedimentation progress in the reservoir showed a much higher rate than planned in the design stage and the effective storage had been decreasing very rapidly. It was feared that power generation could not be realized as scheduled due to decrease of reservoir storage capacity and shortening of the useful life of the hydraulic structures and equipment due to sand abrasion effects. The recent survey by CFE revealed that available effective storage has decreased to 10 million m^3 from 30 million m^3 which was originally planned, though the reservoir operation levels and drawdown range were modified for recent years.

CFE considered that the problems are quite serious and proceeded to take some countermeasures such as construction of check dams for preventing sediment materials from entering the reservoir and forestation and grassing for soil conservation in the upper catchment area and has continued periodical bathymetric surveys of the reservoir to monitor the behavior and progress of sedimentation. The check dams constructed to date numbers 25 in all and the total forested area counts for about 625 ha. These measures were mainly provided during the period of 1976 to 1987 but the implementation has been suspended since 1988 mainly due to financial constraints.

Under the situation, the Government of the United Mexican States made a request for the Government of Japan to undertake a feasibility study on rehabilitation of the Project in 1990. In response to the request, the Government of Japan decided to conduct the study and entrusted it to the Japan International Cooperation Agency (JICA) which is the official agency responsible for implementation of technical cooperation programs of the Government of Japan.

Prior to the feasibility study, the Government of Japan dispatched the mission twice to Mexico; a contact mission for project formation in August, 1991 and a preliminary survey mission to discuss and decide the Scope of Works for the study in February, 1992.

The study was carried out by the JICA Study Team with full cooperation and assistance of CFE and the other agencies concerned in accordance with the Scope of Works agreed between JICA and CFE for the period of August, 1992 through November, 1993. A list of the Study Team members and CFE's counterparts is presented in Table 1.1.

This report is the final report which incorporates all the results of the study conducted by the JICA Study Team.

1.2 JICA Study

1.2.1 Objectives of the Study

The objectives of the study are summarized as follows.

(1) to study countermeasures against sedimentation of Soledad Reservoir and erosion of turbines of Mazatepec Hydroelectric Power Station in consideration of technical, economical and environmental aspects, and

(2) to formulate a rehabilitation plan in order to maintain (or recover to some extent) the function of the power station.

In the Scope of Works agreed between JICA and CFE, it is further noted that regarding the watershed management program which would be quite essential as a long-term measure for soil conservation, the study will be limited to make a review and advice to the past measures having been undertaken by CFE such as fore station and construction of check dams.

1.2.2 Work Progress

The study was carried out in three stages; (l) Basic Study Stage, (2) Detail Study Stage and (3) Preliminary Design Stage. Details are described in the Scope of Works agreed between CFE and JICA on March 3, 1992 and the Inception Report prepared and submitted by the Study Team in August, 1992.

The basic study was commenced by dispatching the Study Team to Mexico for a period of August to October, 1992. Main activities in this period were the discussion on the Inception Report which presented a plan of operation of the study, reconnaissance to the site, power survey, socio-economic survey and identification of possible alternative countermeasures, the results of which were briefed in the Progress Report submitted in December, 1992.

The Detail Study followed the above Basic Study from December, 1992 and continued until March, 1993. Main efforts in the Detail Study Stage were placed on field survey for topography, geology and sediment load which were undertaken by CFE upon the Study Team's request as well as natural and social environmental surveys, and in-depth analysis on (1) sensitivity of reservoir storage volume to energy output and (2) projection of future progress of reservoir sedimentation. The study results were presented in the Interim Report submitted for further discussion in May, 1993.

In the Preliminary Design stage for the period of May to September, 1993, main efforts were made on formulation of an appropriate rehabilitation plan for the reservoir sedimentation based on the previous basic studies, including preparation of preliminary design of proposed structures and their economic justification.

Transfer of technology is also one of the main objectives of the JICA study. Efforts were made by the Study Team to transfer some of technologies related to sediment problems and hydropower development to the CFE's personnel through "on-the-job training" in which counterparts work together with experts for the study. Other than "on-the-job training" mentioned above, seminars were held twice during the field survey period, on June 1 and September 29, 1993. The subjects of the seminars are as follows.

June 1 :
- Relationship between storage capacity and energy production, and available water for sediment flushing
- Reservoir sedimentation
- Problems arising in the other reservoirs in Mexico

September 29 :
- Sediment problems in Japan
- Planning and design of hydro projects considering the control of sediment
- Operation and maintenance considerations at hydroelectric power stations
- Outline of Atexcaco hydropower scheme (a new project near the Mazatepec Project under planning)

JICA also invited three members of the CFE's personnel to Japan in 1993 under the overseas training program to study similar reservoir sedimentation problems and remedial measures taken in Japan.

1.3 Report

The final report of the study consists of three (3) volumes.

Volume 1 is Executive Summary which summarizes the results of the study including the conclusions and recommendations for the rehabilitation program.

Volume 2 is Main Report which presents all the study results and Volume 3 is Appendix to Main Report which includes supporting information and data related to the study.

CHAPTER 2

ELECTRICITY IN MEXICO

CHAPTER 2 ELECTRICITY IN MEXICO

2.1 Overview of Electricity Supply System in Mexico

2.1.1 Power Supply System

The power system in Mexico is composed of the National Interconnected System, Peninsular System, Baja California Norte (North Baja California), Baja California Sur (South Baja California) and a number of other small scale systems which are being operated independently.

Most of the power systems are controlled by the Federal Commission of Electricity (CFE) and are administratively divided into 8 service areas: (1) Central area, (2) Occidental area, (3) Oriental area, (4) Peninsular System, (5) Northeast area, (6) North area, (7) Northwest area and (8) North and South Baja California system. The Central area is partly operated by the Central Lighting Company (CLFC). The principal network of the power system and administrative areas are as shown in Figure 2.1. In the National Interconnected System, the power system covering the northwest area is usually operated independently of the National Interconnected System.

2.1.2 Installed Capacity and Energy Production

The installed capacity of power plant in Mexico has increased as shown in Table 2.1. The installed capacity at the end of 1990 was 25,298 MW, of which 7,805 MW was shared by hydropower plant, 1,200 MW by carbon fired thermal power plant, (coal fired steam), 705 MW by geothermal power plant, 14,913 MW by hydrocarbon fired thermal power plant (oil fired steam, gas turbine and diesel), and 675 MW by the nuclear power plant at Laguna Verde.

In 1990 hydropower plant represents 30.9% of the total capacity, while the hydrocarbon fired thermal plant shared 58.9% and geothermal power plant shared 2.8%. After introducing the operation of four 300 MW units of carbon fired plant in the last decade, its share became 4.7% of the total capacity.

Energy production in Mexico has increased as shown in Table 2.2. In 1990 hydroelectric energy shared 20.4% of the total energy generation, while carbon thermal energy of 6.8%, geothermal energy of 2.6%, and oil fired thermal energy of 65.7%.

Hydroelectric power generation is influenced by availability of water, that is, rainfall;

18,200 GWh in 1987, 20,777 GWh in 1988, 24,199 GWh in 1989 and 23,333 GWh in 1990. Aiming at the rational and effective use of fossil fuel the generation by gas turbine and internal combustion has been limited since 1981, indicating 0.7% as a whole in 1990. In 1990 the generation by oil fired steam thermal plant was 66,915 GWh, which corresponds to 58.5% of the total energy. The combined cycle plant produced 6.5% of the total energy in 1990. In 1990 the export of energy counted for 1,952 GWh and the import was 680 GWh.

In 1990 the consumption of fuel for thermal electric generation was composed of 15.8 millions cubic meters of fuel oil (73.7% on caloric basis for consumption for electrical power generation), 4,057 million cubic meters of gas (16.1%), 3.97 million tons of coal (8.5%) and 0.4 million cubic meters of diesel oil (1.7%). The record of fuel consumption in terms of caloric value since 1974 is summarized in Table 2.3.

2.1.3 Transmission/Distribution Lines and Substations

The total length of transmission and distribution lines was 316,206 km in 1990, excluding feeders of low tension in the distribution division. Out of the CFE's total length of transmission and distribution lines, 2.9% is comprised by 400 kV, 5.3% by 230 kV, 15.9% by 69 kV to 230 kV and 75.9% by 69 kV or lower lines. Table 2.4 shows the increase of transmission and distribution lines.

In 1990 the capacity of transformers at substations reached to 105,197 MVA, including 16,273 MVA operated by CLFC. In 1990 the step-down substations totaled to 54,274 MVA and the step-up substations totaled to 34,650 MVA. Table 2.5 shows the increase of transformer capacity at the substations.

2.1.4 Rural Electrification

Since the electrification program commenced in 1952, 50,370 population centers have been electrified (34,660 villages newly electrified, 8,714 villages expanded and 6,996 population colonies), and 23,290 units of pumps for agricultural irrigation gave benefits to 28,010,288 of inhabitants and to 856,249 hectares of land.

The electrification programs are formulated annually, with coordination between CFE and the state governments, and the distribution divisions of CFE are responsible for executing the program.

In 1990, 1,348,246 habitants who lived in 1,948 villages were electrified. Further, 566 agricultural lands were provided with electric service, which covered 10,542 ha of irrigation areas and 147 public and particular services were also provided with electricity. Table 2.6 outlines the statistics of rural electrification activities since 1974.

2.1.5 Interchange of Energy with Neighboring Countries

Export and import of electrical energy are made between CFE and the electric companies of the States of California, Texas and Arizona of the United States of America and that in Belize.

In September 1986, the 10-year contract became effective for the sale of 220 MW of firm capacity and energy with San Diego Gas & Electric and Southern California Edison. The export of energy is made through two transmission lines of 230 kV between the system of North Baja California and the electric system of California of USA.

There is another interconnection for energy sale between the area of Yucatan Peninsular and the Compania Electrica de Belize, for which the treaty was concluded in 1989. The export of 1 MW of firm capacity is made through the transmission line of 34.5 kV.

In 1990 the export energy reached to 1,946 GWh, of which 1,941 GWh was sent to California and 5 GWh to Belize. For the period 1991 to 1996 CFE plans to export 1,932 GWh of firm energy per year under the contracted unit load factor. The import of energy reached to 575 GWh in 1990, of which 516 GWh was sent to the Baja California System, 56 GWh to the North System, 1 GWh to the Northeast and 2 GWh to the Northwest. From these figures on import and export, the balance in 1990 was in favor of CFE as 1,371 GWh.

In 1991, import was expected to be 405 GWh, of which 171 GWh would be sent to the Baja California System when the maximum power demand would occur during the summer time, 232 GWh to the North System and 2 GWh to the Northwest System.

2.2 Power Market

2.2.1 Present Status of Power Market

The annual average increasing rate of energy in the last decade was 6.3%, while the population of the country increased at 2.5% annually on average. In 1990, the gross power generation reached to about 115,000 GWh, showing an increase by 3.9% from that in 1989. The total energy sales counted for 94,069 GWh, consisting of the domestic sales of 92,123 GWh and the export of 1,946 GWh. The difference between the gross generation and energy sold is attributable to the energy use for the station's own services, the losses in the transmission and distribution systems, illicit use of energy and the lag-time in the invoice circulation. Tables 2.7, 2.8 and 2.9 show the growths of energy consumption, number of consumers and unit consumption of energy by sector for the period of 1974 to 1990.

The annual increase rate in 1990 was forecast at 6.5%, but it was not attained mainly because the increase of self-supply services in PEMEX and the abundant rainfall over the irrigation area during the year. It is forecasted that the energy demand will reach to 160,354 GWh in 1995, which means an average increase rate of 6.9% during the period from 1990 to 1995.

The maximum power demand in the National Interconnected System was 18,049 MW in 1990, and it is expected to increase to 24,829 MW by the end of 1995. The southern area of the Interconnected System shares 62% of the maximum demand and the northern area by 30%. The south interconnected system will grow by 4,661 MW for the five years from 1990 to 1995, the north interconnected system by 2,119 MW and the independent systems will increase by 868 MW.

Typical daily load curves in the National Interconnected System and in the Oriental area are shown in Figure 2.2.

2.2.2 Price of Electricity

In 1990 the Federal Government authorized to adjust the unit price of electricity with a strategy of improvement of financial situation of the electric sector to compensate cost of power supply for the increasing registration. The adjustments are intended to rationalize the subsidies granted in the tariff of the electrical sector.

These adjustments were executed on March 17, May 29, July 10 and November 13. Among these adjustments due care is made to the restructuring of tariffs applicable to the hot climate areas during summer time and the creation of Tariff 1D. The adjustments influence to the Tariff 4 service for the so called "Molinas de Nixtamal y Tortillerias" mill for producing maize pan, and the so called "Pago del a Usario" for pumping water for irrigation use.

The energy sales price is set lower than the cost for producing electricity, the rate showing 0.81 in 1990 and the total subsidy to the consumers of the electrical sector reached to 2.8 million New Pesos, which was nearly equal to 50% of the total investment of the sector in this period. The tariffs of residential services and pumping for irrigation use was lower than the cost, whose price/cost index is nearly 0.4 and 0.2 respectively.

The average sales price in 1990 including export and tax was 150.44 pesos/kWh (N. Peso 0.150/kWh). This figure includes a net increase of 161% to the price of 116.95 Pesos/kWh in 1989.

2.2.3 Save of Energy and Reduction of Losses

In the framework of "National Plan of Development" and through the priority of actions established in the "National Program of Energy Modernization", the "Program of Energy Save of Electrical Sector (PAESE)" is established. The actions contemplated in the PAESE are related with many internal aspects, especially in power plants, networks of transmission and distribution and local administrations, as well as external aspects.

For the internal measures, actions are taken aiming at full use of fuel of the country's own product, and improvement of thermal power plants are intended by reducing loss of calories and increasing the combustion efficiency. With regard to the networks of transmission and distribution, the "System of Energy Loss Control (SIOPE)" is organized. The measures are to use fluorescent lamps in place of incandescent lamps for domestic and commercial use, and actions to save energy are taken in self-service shops, hotels, governmental offices, municipal services, agricultural sectors, etc.

In 1989 and 1990, the application of the hourly tariff system resulted in reduction in the maximum demand in the National Interconnected System in an order of 500 MW. By applying this type of tariff arrangement to Tariff 12 and majority of Tariff 8 services, it is expected that the maximum system demand could be reduced by 500 to 800 MW and this would make it possible to increase the load factor of the system.

2.3 Demand Forecast

2.3.1 Factors Affecting to the Demand

The economic development and population increase are two important factors to determine the power and energy demands. The former is related with the volume and type of production and the principal source of energy consumption. The population increase directly determines a rate of expansion of electricity production sources.

The energy consumption had been increased at a relatively high rate for the decade of 1980 to 1990, while the decade is characterized as the sluggish economic period, and the domestic energy demand excluding export had increased at an annual average growth rate of 5.9%. Figure 2.3 shows historical trends of the domestic energy sales and the gross domestic product (GDP), in which the electrical demand always increased at a higher rate than that of the economic growth.

This phenomenon is observed in the countries where economic recession does not affect much to the growth rate of electricity. This is mainly due to the fact that electricity demand depends more on the population increase than the economic activities, especially as seen in developing countries. Further in the countries whose electrification has not been completed, there are a number of social factors which stimulate the expansion of electric sector, even in the period of economic depression. In Mexico it is estimated that about 87% of population is benefited with the electric energy services.

Other factors which influence to the energy demand are climatic change, though it does not affect for a long duration, and change of technology that determines more over a long period of time. The adjustment of electricity price would give an inverse effect to energy consumption.

2.3.2 Economic Scenario and Population Growth

In the demand forecast by CFE, three economic scenarios are elaborated, which are related with the growth rate of GDP. It is assumed that the GDP in 1991 increases between 3.0% and 4.5%; from 1992 to 1994 between 5.3% and 6.0%, and from 1995 to 2000 between 4.5% and 5.5% as shown below.

Growth Rate of GDP (%) in Economic Scenarios 1991 - 2000

Period	Low	Medium	High
1991	3.00	3.80	4.50
1992 - 1994	5.30	5.65	6.00
1995 - 2000	4.50	5.00	5.50
Average	4.59	5.08	5.55

For forecasting the future energy demand, reference is made not only to the growing speed of economy, but also to the productive capacity in a given period. According to the experience, another economic indicator, the fixed gross investment of economic development or la Inversion Bruta Fija (IBF) is used, which demonstrates its explanatory capacity for electricity demand. In the year 2000 it is expected that the IBF reaches to 23.5% of GDP in the medium economic scenario.

Regarding the population, the average scenario of CONAPO (El Consejo Nacional de Poblacion) is used, which assumes an average annual growth rate of 2.1% for the next decade.

2.3.3 Forecast up to Year 2000

Based on three economic scenarios and the population growth based on the average scenario of CONAPO, the energy demand until the year 2000 is forecasted by CFE. The results for the medium scenario of economic development are shown below in sectorwise.

Sales of Energy by Sector (GWh)

Sector	1962	1970	1980	1990	2000
Residential	1,419	3,582	10,038	20,605	43,090
Industrial	4,162	11,795	28,744	52,213	107,153
Commercial	1,508	3,253	5,821	8,265	14,601
Agriculture	621	1,349	3,746	6,707	12,059
Services	668	1,580	3,677	4,549	8,604
Total	8,378	21,559	52,026	92,339	185,507

Remarks: Demand for export is excluded.

The average annual growth rates for the past 10 year period is shown below. As it can be seen, with exception of the agriculture sector, the rates of increase for the period (1990 - 2000) are set higher than those for the last decade (1980 - 1990).

Average Annual Increase Rate of Energy by Sector (%)

Sector	1962-1970	1970-1980	1980-1990	1990-2000
Residential	12.3	10.9	7.4	7.7
Industrial	13.9	9.3	6.2	7.5
Commercial	10.1	6.0	3.6	5.9
Agriculture	10.2	10.8	6.0	6.0
Services	11.4	8.8	2.2	6.6
Total	12.5	9.2	5.9	7.2

A relation between energy demand and GDP, derived as a quotient of the rates of increase, is known as an elasticity. The elasticities are presented below and the high elasticity is seen in the decade of 1980-1990.

Elasticity of Energy Demand to GDP by Sector (%)

Sector	1962-1970	1970-1980	1980-1990	1990-2000
Residential	1.7	1.6	5.2	1.5
Industrial	2.0	1.4	4.3	1.5
Commercial	1.4	0.9	2.5	1.2
Agriculture	1.4	1.6	4.2	1.2
Services	1.6	1.3	1.5	1.3
Total	1.8	1.4	4.1	1.4

The elasticities for the period of 1990 - 2000 will have the same value to those for the decade 1970 - 1980. On the other hand, it is expected that both the industrial and residential sectors would enjoy the most dynamic growth as shown below.

Composition of Electric Market by Sector (%)

Sector	1962	1970	1980	1990	2000
Residential	16.6	16.6	19.3	22.3	23.2
Industrial	49.7	54.7	55.2	56.5	57.8
Commercial	18.0	15.1	11.2	9.0	7.9
Agriculture	7.4	6.3	7.2	7.3	6.5
Services	8.0	7.3	7.1	4.9	4.6
Total	100.0	100.0	100.0	100.0	100.0

Remarks: Demand for export is excluded.

In the forecast model, the net energy (EN) is a function of gross domestic product (GDP), the accumulated fixed gross investment (IBFA) and the population (POB). The GDP represents the growth rate of the economic activities, the IBFA measures the asset which helps the economy for realizing its duty, and the POB indicates the number of population. The model is statistically verified acceptable as shown in Figure 2.4, in which the energy forecast is compared with the actual values. Once the model is established, the net energy can be forecast using the projected economic variables and population.

The gross energy is obtained by adding estimated station use energy to the net energy, and the salable energy is derived from the subtraction of the estimated losses.

Table 2.10 presents the historical trend of energy demand for the period of 1970 to 1990. Table 2.11 and Figure 2.5 present the projected values of gross and net energies as well as salable energy for each of the three economic scenarios. It must be considered that a model of econometric type may include an error of natural (aleatoria; uncertainty). In Figure 2.5, the demand forecasts with a band of 80% reliability are also shown.

It is also necessary to review the development of electrical market from a geographical aspect, which will permit to optimize the location and size of power stations, substations and transmission and distribution lines. The study of development of regional electrical market for the period 1991-2000 is based on the annual review on the programming of electrical system.

Six areas of the continental territories are interconnected and partly the Peninsular of Yucatan is interconnected through a line of 230 kV transmission line from the National Interconnected System but the peninsular of Baja California is isolated from the main national network. In the forecast the country is electrically divided into 109 zones and 13 small isolated systems, seven of which receive imported energy. For each of these zones the historical data, such as sales and consumption of electrical energy, demands, etc., are counted for. Individual bulk consumers which use much electricity are duly taken into account. In the forecast the data of 279 important loads are referred to.

2.3.4 Balance of Power and Energy

The power and energy demand is monitored in the frame work of mid-term power generation plan covering 2 to 4 years, taking into account the difference between the actual power and energy demands and those previously forecasted.

In the mid-term power generation plan of CFE, the nature of power and energy balance is analyzed, dividing the daily duration time into five zones: peak time zone of 1 hour, quasi-peak time zone of 3 hours, middle time zone of 11 hours, quasi-off-peak time zone of 7 hours and off-peak time zone of 2 hours.

In the power balance under the mid-term power generation plan, the forecast is elaborated monthly for each area, since Mexico has a very wide area of diverse climatic conditions, different economic activities, different population and population growth, etc., and the demand in the entire country is obtained as an aggregate sum of the respective demands. The power generation plan is elaborated with the aid of computer under the concept of economic despatching of power and energy, taking into account the maximum utilization of nuclear power, hydropower, geothermal power and minimum expenditure of fuel consumption.

Table 2.12 presents the power balance of the national interconnected system in 1993 on monthly basis. Here, power plants are classified into 13 categories, according to the type and size of generating sources in consideration of the respective operating characteristics, efficiency, availability, etc. The peak demand is expected to occur in May with one hour energy output of 17,509 MWh/hour. The difference of peak demand among the months is not so significant in the National Interconnected System since the lowest peak in January would be 16,486 MWh/ hour, 94.2% of the annual maximum peak. The load factor of each month varies from 73.9% in December to 81.4% in June and the annual load factor is estimated at 76.1% for the annual gross energy production of 116,785 GWh.

Figure 2.6 shows an average load duration curve of the National Interconnected System in May, 1993 with load sharing by generating source. Usually the base loads are born by nuclear, geothermal, coal fired thermal, major oil fired thermal plants and some of minor scale hydro plants, and the peak load and variable portion of load are covered by gas turbine and major hydropower plants including the Grijarva hydropower systems located in the southern part of the Interconnected System.

2.4 Power Development Program

2.4.1 Development Program and Investment

In 1990 CFE established the power development program to initiate the construction of six power plants of 2,728 MW in total, but only the construction of hydropower plant of 280 MW at Zimapan was commenced. The major part of the program was not completed due to delay in construction works under private financing. However, these works are expected to complete before the termination of Six Year Plan.

It is noted that the commercial operation of the first nuclear unit at Laguna Verde with the unit capacity of 675 MW and unit No. 9 of the Los Azufras geothermal plant electric of 5 MW was commenced in 1990, following the energy diversification policy.

With regard to the transmission and distribution works, the progress was made by increasing the installed capacity by 1,812 km-circuit and 1,867 kVA.

2.4.2 Construction Works Completed in 1990

In 1990 the installed capacity increased by 680 MW with two units; one was a 5 MW unit at the Boca Pozos Azufres geothermal power plant and the other was the first unit of 675 MW of the Laguna Verde nuclear power plant. There are a number of power plants under preparation for test in 1991, and the total output of 1,180 MW became available as shown in Table 2.13.

In 1990 the transmission line of 1,724 km in total length was completed and the capacity of transformer increased by 1,649 MVA as shown in Table 2.14.

2.4.3 Works under Construction

The power plants under construction are summarized in Table 2.15, of which a total installed capacity of 2,060 MW is expected to be completed by the end of 1991, 700 MW in 1992, 700 MW in 1993, 675 MW in 1994 and 1,240 MW in 1995.

CHAPTER 3

MAZATEPEC HYDROELECTRIC POWER PROJECT

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3.1 Outline of the Project Facilities

Mazatepec Hydroelectric Power Project situates on the midstream reach of the Apulco River as shown in Figure 3.1. The Apulco River originates in the mountains of around EL. 3,000 m and pours into the Gulf of Mexico. The project site is about 170 km northeast of Mexico City or about 130 km north of Puebla. The dam and power plant are located on the densely vegetated steep and narrow gorge, which is quite conspicuous as contrasted with the very less vegetated area on the upstream basin.

The Project has a power plant of surface type which accommodates four units of 54.86 MW turbines-generator. This plant is integrated in the National Interconnected System with the high voltage transmission lines which extend to the substations at Zogac, Jalacingo and Poza Rica II. The Project has produced 500 to 800 million kWh of energy annually with the total installed capacity of 220 MW.

The Project has a reservoir called Vaso La Soledad which is created by a concrete arch dam of 92 m in height and 1,220 m in length including gravity dam sections on its both sides. Soledad Reservoir receives water not only from its own catchment of the Apulco River but also through a transbasin diversion from the Xiucayucan River. The total catchment area of the reservoir is 1,830 km^2, including the area for the diversion scheme.

The outline layout of the project facilities is shown in Figure 3.2. The plans and sections of the dam, spillway, intake, waterway and power house are given in Figures 3.3 to 3.9.

Details of the project facilities and their operation and maintenance are presented in Appendix A. The salient features of the Project are summarized below.

(l) Catchment and runoff:

Catchment area (Apulco River including Sontalaco)	:	1,460 km^2
Catchment area (Xiucayucan River and tributaries)	:	370 km^2
Total		1,830 km^2

Mean river runoff (Apulco River)	:	8.8 m^3/sec
Mean river runoff (Sontalaco River)	:	1.3 m^3/sec
Mean river runoff (Xiucayucan River))	:	8.1 m^3/sec
Total		18.2 m^3/sec

(2) Reservoir:

Normal high water level	:	EL. 804.5 m (EL. 798.4 m)
Minimum water level	:	EL. 797.5 m (EL. 775.0 m)
Drawdown	:	7 m (23.4 m)
Reservoir area	:	Approx. 1.8 km^2 (at NHWL)
Flood WL	:	EL. 805.0 m (PMF)
Effective storage	:	10 x 10^6 m^3 (30 x 10^6 m^3)
Gross storage	:	18 x 10^6 m^3 (47 x 10^6 m^3)

* Figures in ( ) were based on the original design.

(3) Tailwater:

Center of Pelton turbine	:	EL. 295.3 m

(4) Dam:

Type	:	Concrete arch combined with buttress dams on the both sides
Length	:	1,220 m (210 m for arch dam section)
Crest elevation	:	EL. 806.5 m
Top of parapet wall	:	EL. 808.05 m
Foundation elevation	:	Approx. EL. 715 m
Height	:	92 m

(5) Spillway:

Type	:	Gated chute with flip bucket
Ogee crest elevation	:	EL. 789.5 m
Chute width	:	71 m on ogee crest
Design discharge	:	6,835 m^3/sec at water level of EL. 805 m
Gate	:	15.0 m H x 11.2m W x 5 nos.

(6) Low-Level Outlet:

Type	:	Howell Bunger Valve
Diameter	:	1.88 m

	Elevation	: EL. 750.0m
	Assumed max. discharge	: 73 m^3/s
(7)	Power intake:	
	Type	: Inclined concrete structure
	Elevation of intake sill	: EL. 768.76 m
(8)	Headrace tunnel (Tunnel No. 2)	
	Type	: Pressure tunnel of circular section
	Inside diameter	: 4.0 m
	Length	: 6,570 m
(9)	Surge Tank	
	Type	: Steel shaft
	Top elevation of tank	: EL. 821.30 m
(10)	Penstock	
	Diameter	: 4.0 m to 1.6 m
	Length	: 270 m to 347 m
(11)	Power house:	
	Type	: Surface type
	Length	: 78.9 m
	Width	: 34.0 m
	Height	: 34.4 m
	Elevation of turbine CL	: EL. 295.3 m
(12)	Turbine/Generator:	
	Number of units	: 4
	Turbine (Pelton)	: 54.86 MW (maximum output)
	Generator	: 58.0 MVA (rated)
	Max. turbine discharge	: 13.8 m^3/sec x 4 (= 55.2 m^3/sec)
	Rated net head	: 480 m
	Rated speed	: 360 rpm
	Frequency	: 60 Hz
	Inlet valve	: Spherical valve of 1.5 m dia.
	Overhead traveling crane	: 95/20 ton
	Emergency service turbine generator	: 510 HP, 1,500 rpm

(13) Outdoor Switchyard:

Main transformer	:	20 MVA x 13 nos.
Length	:	140 m
Width	:	90 m

3.2 Performance and Role of Mazatepec Power Station

3.2.1 Operation Performance

Mazatepec Power Station belongs to the Oriental Area, of which peak demand counted for about 3,000 MW in 1991, while the total demand in the National Interconnected System over the country was about 16,500 MW. The single line diagram for the Station is given in Figure 3.10.

Mazatepec Power Station is provided with the installed capacity of 220 MW, which corresponds to about 7 percent of the system peak demand in the Oriental Area, and about 1.3% of the peak demand in the National Interconnected System.

As a hydropower station with a regulating pond (reservoir), it is operated to meet peak load in principle. The plant is rated to generate power to its full output of 220 MW at any operating level of the regulating pond (reservoir).

However, as the inflow pattern to the reservoir "La Soledad" in the rainy season is distinctly different from that in the dry season, and this has affected to the operation pattern of the Mazatepec Power Station. Figure 3.11 shows the typical daily operating mode of the plant in wet and dry seasons in 1992. Figures 3.12 shows the monthly mean outputs of hourly operation in March and October, 1991 respectively.

In the rainy season lasting from June to November, the Mazatepec Power Station is operated so as to utilize the inflow to maximum extent. So whenever there is abundant rainfall in the upstream basin or there is any sign that the reservoir water level may rise, such exceeding EL. 800.0 m, the full output of 220 MW for the 24 hour continuous operation is ordered and this operation is more likely to occur in September and October.

On the other hand in the dry season from December to May, Mazatepec Power Station is operated to make a balance adjustment between supply and demand for the whole 24 hours in the National Interconnected System. According to the output of centralized economic despatching system, which supervises the balance of power generation and changing demand ever offsetting from the forecast, Mazatepec Power Station takes the role not only to operate in the limited peak hours in the evening, but also in any duration of hours, that is, as the result of economic despatching, off-peak hours like early morning or other time zone than the evening peak of 20 hour to 22 hour. The daily economic despatching system controls the power station output in the National Interconnected System for a week long duration, in which Mazatepec Power Station is intended to be fully utilized as hydropower plant.

Another major role assigned to Mazatepec Power Station is to regulate the voltage of 230 kV transmission lines. There are three single-circuit transmission lines, which connects Mazatepec Power Station to the Poza Rica thermal power station, Jalacingo and Zocac Substations with relatively long transmission lines.

Mazatepec Power Station is operated continuously, whether it takes loads or not, and under no-load operation it conducts the condenser operation by using four generators, especially in late night and early morning hours to absorb redundant reactive power flow to keep the operating voltage of the 230 kV system in the range from 235 kV to 240 kV.

The power flow in the transmission lines connected with Mazatepec Power Station always changes, depending on output of generators of Mazatepec Power Station and the time, hour, season, etc., but generally the power flow takes place from the Poza Rica thermal power station to Mazatepec Power Station and thence to Zocac and Jalacingo Substations. Figure 3.13 shows typical flow pattern of the 230 kV system connected with Mazatepec Power Station, when it is operated under full load and no-load respectively.

3.2.2 Energy Production Record

The energy production of Mazatepec Power Station since it started the commercial operation in 1962 is summarized in Table 3.1.

The annual energy production varies from year to year depending on availability of reservoir inflow. According to the record, the energy production varied between the lowest production of 449 GWh per year in 1963 which corresponds to the annual mean output of 51.3 MW, or 23.3% of plant factor and the highest production of 904 GWh in 1981, similarly corresponding to the annual mean output of 103.3 MW, or 47% of plant factor.

As the sedimentation problem had become a critical issue for the operation of power generation, the operation range of Soledad Reservoir was changed in 1980 from EL. 798.4 m to EL. 804.5m, to avoid floating dust and sands from entering the waterway and running turbines. According to the data, there is no conspicuous difference in the amount of mean energy production between the decade of 1971-1980 and that of 1981-1990.

3.2.3 Inflow and Energy Production

The annual production rate of energy depends much on the available inflow into the reservoir. This relationship is given in Figure 3.14.

In order to investigate any historical trend between the energy production and the inflow, a double mass curve is prepared as given in Figure 3.15. As seen in Figure 3.15, the mass curve appears to be almost on a straight line with the same gradient throughout the period. As far as this mass curve is concerned, therefore, no appreciable indication is found on the energy decrease due to the progressive loss of the reservoir capacity.

The inflow should be used to its maximum extent for energy production and the spillout discharge should be minimized as low as practicable. Figure 3.16 shows a relationship between the inflow and spillout discharge in the past. It is learned from Figure 3.16 that the spillout discharge volume became relatively larger where the annual inflow exceeded 600 million cum. However, no influence by reservoir sedimentation is observed for the spillout volume, since the spillout occurred in the earlier stage of operation as well as in the recent years.

3.2.4 Reservoir Water Level and Inflow and Outflow Discharges

The past reservoir water levels for the period of 1976 to 1990 are recorded in Figures 3.17 and 3.18. The figures indicate that the minimum operating level was raised in and after 1982.

The records on inflow and outflow are given in Table 3.2. The water levels in 1990 and 1991 are compared with the inflow discharge and energy output as shown in Figure 3.19. The power plant appears to operate principally as a run-of-river plant, that is, the outflow is almost equal to the inflow.

3.2.5 Operation during Flood Time

A communication network which aims at estimating flood inflow and proper operation of the reservoir during flood time is established among the hydrological stations and Mazatepec Power Station. The following information and data are collected for reservoir operation and power generation.

- Water levels and discharges at Buenos Aires, Sontalaco and Canal Tunnel No. 1
- Rainfall and evaporation rate at La Soledad
- Reservoir level and storage

The hydrological stations are linked each other by radio. Water levels and discharges at two remote stations, Buenos Aires and Sontalaco, are transmitted to the office near Canal Tunnel No. 1 and they are integrated with those at Canal Tunnel No. 1 and with meteorological information obtained at the La Soledad station. The data collected at Canal Tunnel No. 1 are sent to the dam office which is connected with Mazatepec Power Station by telephone. The dam office sends the meteoro-hydrological data to Mazatepec Power Station together with reservoir water levels measured near the office. The communication is periodically made by the CFE staffs stationed at the hydrological stations and office with the following time interval.

Dry season (1 Nov. - 31 May)	:	18:00 in a day
Flood season (1 Jun. - 31 Oct.)	:	every 2 hours during 6:00 to 18:00 in a day
In case of flood anticipated	:	every 2 hours during a full day (24 hours)

The flood inflow is estimated at Mazatepec Power Station based on the above information. Flood runoff from the Xiucayucan River is regulated by gate at the Atexcaco Diversion weir. Release from the spillway of Soledad Reservoir is subjected to the dam and reservoir operation rule which specifies the procedures to be taken.

The high water level of Soledad Reservoir is controlled as follows.

From June 1 to Oct. 15	:	EL. 803.0 m
From Oct. 16 to May 31	:	EL. 804.5 m

The storage volume between the design flood water level at EL. 805.0 m and the water level at EL. 803.0 m is about 5.8 mcm in 1962 and about 5.0 mcm in 1992. This storage volume is considered as flood control space. However, the flood control space is too small to control flood inflows such as the maximum daily inflow volume of 27.8 mcm for the 1989 flood and that of 31.6 mcm for the 1989 flood. Figure 3.20 shows the daily reservoir inflow and outflow (power plant discharge + spillway release) for the 1988 and 1989 floods. The outflow volume is nearly equal to the inflow volume on daily basis for these floods.

The inflow, outflow and reservoir level during the 1989 flood are illustrated in Figure 3.21.

3.3 Emerging Problems

3.3.1 Sedimentation in Soledad Reservoir

Soledad Reservoir is about five kilometers long, measured along center line and the surface area estimated based on the 1992 survey is about 186.4 hectares. Figures 3.22 shows the configuration of the reservoir.

Over the period of time after the Project came into operation, sedimentation has occurred in the reservoir, and a fear arose that normal power generation would be affected. Then, the reservoir operating levels have been modified from time to time. The reservoir operating levels which were initially set and are currently used are as follows.

	Maximum operating level	Minimum operating level
Original design	EL. 798.40m	EL. 775.00 m
Current operation	EL. 804.50 m	EL. 797.50 m

CFE has estimated the loss of effective storage periodically by reconnaissance type or detailed reservoir sedimentation surveys. Table 3.3 shows the elevation-surface area-capacity data in 1962,1977,1988, and 1992 estimated by CFE. The data are taken from the published elevation-area- capacity curves and may slightly differ from the actual surveyed data. Reconnaissance type surveys made in other years also offer the same information, though they should be regarded as approximation. The change of the storage curve is shown in Figure 3.23.

Based on these data, the active storage available between the reservoir water levels of EL. 775.0 m and EL. 798.4 m (minimum and maximum operating levels in 1962) was about 30.238 mcm in 1962. Based on the 1992 survey, this storage has been reduced to 9.152 mcm.

Table 3.4 indicates that the total sediment deposited in the reservoir up to EL. 804.5 m in 1992 is about 40.355 mcm. Of this, a deposit of about 23.232 mcm has occurred above EL. 775 m. Sediment deposits between EL. 775.0 m and EL. 804.5 m are estimated as follows.

Sediment deposits (mcm)

Year	Deposit	Year	Deposit
1972	7.800	1982	14.773
1978	10.316	1983	14.796
1979	12.319	1990	17.940
1980	12.737		

The sediment surveys on which these data are based could not be obtained except for the year 1990. The 1990 value is less than that shown in Table 3.3 (about 21.71 mcm).

The reservoir bed profile data were available for the years 1962,1977,1990 and 1992 as shown in Table 3.5. These data are plotted on Figure 3.24. The profiles start from the non-overflow section of the arch dam. The reservoir bed elevations indicated by the 1990 and 1992 profiles are higher than the inverts of low level outlet (EL. 750.0 m) and power intake (EL. 768.76 m). These profiles also show a progressive movement of coarse deposits toward downstream.

CFE has been monitoring build-up of sediment near the intake area. A detailed survey of the area was undertaken in 1990 and then in 1992. The 1992 survey lines are shown on Figure 3.25. A cross section identified on Figure 3.25 is plotted on Figure 3.26 using the data from both the 1990 and 1992 surveys (Table 3.6). These cross sectional profiles indicate that the sediment elevation near the intake (about 40 meters from the intake) is about 772 meters. Within a distance of 40 meters the elevation drops to EL. 768.76 m (crest of the intake). This pattern of sediment deposition is very likely to carry coarse sediment into the intake, if not now, in near future.

3.3.2 Sand Abrasion Effect to Hydromechanical Equipment

There are four, 6-jet, vertical-shaft Pelton turbines rated at 74,600 metric hp (54.86 MW) under 480 meter net head, a rated synchronous speed of 360 rpm (corresponding to 60 Hz), and a rated flow of 13.8 m^3/s. All four turbines were manufactured by Neyrpic, France, and placed in operation from 1962 to 1964. The turbines have the following features:

- 22 runner buckets and a crown form a cast, integral runner made of 13% Cr stainless steel;
- sleeve-type guide bearing with self pumping action;
- automatic grease lubrication system.

The turbines have operated continuously since they were placed in operation except for maintenance, overhaul and frequency changeover periods. The units are normally used to control system frequency, for block load operation (during the rainy season from July to October, the turbines operate at full load), and for synchronous condenser operation.. Units 1 and 2 are alternatively used to provide station services, and therefore should exhibit greater wear than units 3 and 4.

The runners are inspected during the annual inspections and have not been replaced or repaired in 30 years; fatigue is clearly not a problem for this runner design. It was reported that the runners of all units show little cavitation damage and give the appearance of very little erosion. However, in 1993, a bucket profile template made form the spare runner and offered up to the runner buckets of unit 3 showed that considerable erosion had in fact taken place. In the worst bucket of unit 3, 9.5 mm of wear was reported. This was confirmed during the inspection in May 1993. The needles and nozzles have to be repaired at regular intervals as they suffer severe cavitation damage. New needles have an average life of 4 - 5 years. Repaired needles have an average life from 1-1/2 to 2-1/2 years. After two repairs the parent metal deteriorates sufficiently to render further repairs inadvisable.

The sediment passing through the turbines is very fine silt containing virtually no sand. However, in order to avoid passing silt through the turbines, which seriously erodes the needles and nozzles, the minimum operating level has been currently raised to EL. 797.5.

3.4 Countermeasures for Sediment Problems Undertaken by CFE

3.4.1 Survey of Reservoir Sedimentation

CFE initiated the reservoir sedimentation survey program in 1972 and conducted the surveys periodically. The surveys appear to have been made generally on a reconnaissance level except the 1992 survey which was done on a detailed level. According to CFE, the 1992 survey is most reliable while the others are indicative of sediment progression in the reservoir. The 1992 survey indicates that the reservoir has lost 40.4 mcm of storage capacity of the original capacity of 58.8 mcm over the 30-year period.

The 1992 field survey and office procedures were reviewed and discussed with CFE. The procedures adopted provided a reasonably accurate estimate of revised storage capacity.

Generally, suspended sediment and bed material samples are taken as an essential component of reservoir sedimentation survey. However, these data were not collected in a proper manner. Direct computations of sediment accumulation using changes in the reservoir bed levels were not made.

Reservoir bed elevations (contour lines) based on the sedimentation surveys made in 1977, 1988 and 1990, and the computed elevation-area capacity data were also available. The 1990 survey was of considerable detail near the intake area. Most of range lines used in this survey were different than those used in 1992. Similarly, the range lines used in 1977 were different. It appears that CFE selected new range lines for each survey. General practice is to fix the range lines permanently not only for a reasonable accuracy but also for comparison with the previous surveys.

3.4.2 Soil Conservation Measures

Various soil conservation measures have been implemented in the basin in the past, with varying degrees of success. Contour farming is practiced in some areas, and in some locations this is accompanied by the establishment of rows of maguey or other drought resistant vegetation at intervals of 10 to 20 meters to retard runoff down the slope.

Between the years 1976 to 1988, CFE also conducted a program of watershed management in the area. This multifaceted effort included the reforestation of eroded slopes, the development of terraces and ditches to intercept and retard the flow of water, the development of rock walls (muros secos) to intercept runoff and silt in drainageways (barrancas), and the construction of 25 check dams to act as silt retention basins on tributaries of the Rio Apulco. Generally, these watershed management activities were concentrated in the area between Ocotzingo and a little west of Tlajamulco, with very little activity in the basin upstream of Tlajamulco.

Check Dams: The 25 check dams, Presas de Mamposteria, were constructed between 1976 and 1987. They are located on tributaries to the Rio Apulco, usually close to the discharge of the tributary to the river. Check dam No. 1, furthest downstream, is located on Bca. de Morelos at Sta. Ines Morelos. Except for four dams located upstream in the vicinity of Sta. Maria Coyoltepec, the check dams extend upstream in the Apulco Valley to No. 18, Presa Nopala, just downstream of Tlajamulco.

The dams have a total drainage area of 450.6 km^2 or about 32 percent of the basin of the Rio Apulco upstream of the Buenos Aires G.S. Some of the sediment storage areas were completely filled in as little as one year. Other check dams, particularly many of those downstream from Zautla, still have considerable storage area available. These check dams and their effectiveness in retarding sediment from entering the Rio Apulco are described further in the following sub-section 3.4.3.

Terracing (Terrezas Forestales): From 1981 through 1987 a series of terraces were constructed by bulldozers moving along the contour on slopes that ranged from 5° to 25°. The terraces were approximately 4 meters wide and were constructed at 15 to 20 meter intervals down the slope. In all, approximately 43,100 linear meters of terrace were constructed during the five years 1981, 1982, 1984, 1986, and 1987 at a cost of approximately US$80,000. It is estimated that erosion was retarded on a little over 100 hectares of the basin by this work, or approximately 20 hectares per year at a cost of approximately US$800 per hectare. The first year, 1981, covered the most area, 39.7 hectares.

Rock Walls (Muros Secos): A second method utilized to retard runoff, particularly in natural shallow drainages (barrancas) down the slopes, was the construction of rock walls (Muros secos) at intervals across the barrancas. Like the terraces, these walls retard the runoff flow and cause the sediment carried with it to be deposited. During the eight years from 1980 to 1987, a total of 5,019 walls were constructed in 156 barrancas in the area between Comaltepec and Tlajamulco.

Drain Ditches (Zanja and Bordo): A third watershed management technique implemented during the years 1980 to 1987 was the construction of ditches along the contour, with the earth placed along the downslope side of the ditch. Like the previous methods, the objective was to retard the flow of runoff down the slope and, particularly with this technique, to facilitate infiltration of the water into the soil. These features were frequently located on slopes of 15° to 30° that were subject to cultivation, usually maize (corn), frijol (beans), trigo (wheat), or cebada (barley). The soils tend to be very sandy and erode easily when cultivated.

The ditches initially were 40 x 40 cm in cross section, and this was eventually increased to 60 x 60 cm. Maintenance was required to keep them cleaned out. Maguey was frequently planted at intervals along the border to further stabilize the soil. In all, approximately 255,000 linear meters of Zanja and Bordo were constructed in 19 communities in the basin affecting approximately 640 hectares. Average cost of these facilities was approximately US$0.20 per linear meter for a total cost of US$51,000 or US$80 per hectare. Like the terraces, it takes approximately 400 linear meters of Zanja and Bordo to improve one hectare of land.

Reforestation: In addition to the above work, a program of reforestation in the basin was also carried out between 1980 and 1987. A total of almost 450,000 trees were planted at a cost of about US$0.85 per tree, but the total coverage was relatively small (approx. 625 ha) because of the large number of plants required to treat one hectare (about 720 per hectare at a cost of US$610 per hectare). Three basic groups of plants used for reforestation were maguey or century plant, fruit trees (frutales), and forest species as shown below.

BASIC GROUPS OF PLANTS FOR REFORESTATION (No.)

Year	Maguey	Frutal	Forestal	Total
1980	12,000	5,101		17,101
1981		3,163		3,163
1982		32,057	44,216	76,273
1983		14,242	18,013	32,255
1984	2,000	4,144	54,041	60,185
1985	470	8,350	47,661	56,481
1986	5,669	4,238	69,519	79,426
1987		6,446	116,864	123,310
Total	20,139	77,741	350,314	448,194

3.4.3 Check Dam

Apparently, based on the 1972 and 1977 reservoir surveys, CFE planned to construct sand arresting dams (check dams) in the upper catchment area of the Rio Apulco, which produced major portion of the sediment entering Soledad Reservoir. The check dams were constructed during the period from 1976 to 1987. The monitoring of the dams to check the sediment deposition was initiated in 1980. Figure 3.27 shows the locations of the check dams.

Table 3.7 shows the number of dams constructed during 1976-87, drainage area controlled by each dam, year of construction and the storage capacity at spillway crest. Also given are the sediment volume monitored during 1980-87 and status of filling.

The total area controlled by the dams is about 450. 6 km^2 compared to an area of about 1,405 km^2 of the Rio Apulco at Buenos Aires and about 1,140 km^2 at the confluence with the Rio Zitlalcuautla. Thus the check dams control about 40 percent of the area above the confluence of Apulco and Zitlalcuautla and about 32 percent of the area above Buenos Aires. The total capacity of the dams was about 1.34 mcm.

As indicated in Table 3.7, some of the dams were filled in about one to four years. The data on monitoring the available capacities are not consistent because in some early years no deposition is shown and then a dam is reported to be full in one or two years. Tenanpulco No. 3 Dam, constructed in 1977-78 is reported to about 92 percent full in about six years, and the remaining 8 percent is reported full in 1987, after about three years. The rainfall pattern during this period does not support this type of pattern, the other factors being unknown. However, based on these data, it is apparent that small size dams were filled up rapidly, while the relatively large ones sustained for a few years more.

To evaluate the effect of check dams on the sediment inflows in Soledad Reservoir, the monthly rainfall at two stations in the vicinity of the check dams, monthly flows and monthly sediment discharges at Buenos Aires are plotted on Figure 3.28. During the active functioning of the dams, the rainfall was relatively low. The sediment discharge pattern does not show significant decrease. However, it is also not conclusive that there was no decrease in sediment transport at Buenos Aires. This is because that at Buenos Aires, the transport of coarse material is not properly measured and the check dams only trapped the coarse material as seen during field reconnaissance.

Erosion rates were computed based on the depositions of sediment behind the check dams. The calculations are also given in Table 3.8. The trap efficiency of each dam was estimated using the Churchill's trap efficiency curve (Details are given in Chapter 6). The curve is considered suitable for small reservoir, flood retarding structures, semi-dry reservoirs and settling basins. Therefore, its application for the check dams was judged to be appropriate.

A review of Table 3.8 indicates that the erosion rates from small areas are generally high. This is true because in case of small areas, the sediment is measured near the source while for larger area, the sediment deposition occurs as the sediment moves to a downstream location. However, the erosion rates, in general are on low side. This may be due to some errors in monitoring the volume of deposit at a dam or the trap efficiencies may have been over-estimated. Judging from the types of topography, land use, geology and soils above these dams, an erosion rate of about 2 mm per year would be appropriate.

The erosion rate for the whole basin above Soledad Reservoir was estimated using the reservoir sediment deposit rate and trap efficiencies for various periods during the sedimentation process. The estimated rate is about 1.4 mm per year as discussed in Chapter 6.

An erosion rate of 1.4 mm per year is not very much different from the rates estimated for the areas above the dams. The area below the confluence of Rio Apulco and Rio Zitlalcuautla is covered with good forest and sediment contribution may be very small. The basin above Rio Zitlalcuautla has a moderate forest cover. However, sheet erosion of soft tuff is evident at many places. The river water is clear. The sediment is mostly silt and sand, compared to large quantity of clay and silt carried by Rio Apulco.

3.4.4 Sediment Flushing through Low Level Outlet

The low level outlet is located in the center of the arch dam with a centerline elevation at 750.0 m, which consists of a steel conduit, gate valve, and Howell Bunger valve. Currently the level of sediment in the reservoir is estimated at EL. 775 m. The intake of the outlet is therefore buried under about 25 m of sediment. The outlet has not been operated since 1985 or for about 7 years.

The reason for providing the low level outlet is not known, but probably to control the impounding rate of the reservoir level in initial filling or to release a maintenance flow in the river. However, for a short period previous to 1985 the outlet was used for flushing sediment from the reservoir. Use of the outlet for this purpose was stopped for the following reasons:

- The discharge capacity of the valve for flushing sediment was found to be too low to adequately flush the amount of sediments that were being deposited.

- The intake drew in trash and the operators were concerned that eventually they would not be able to close the Howell Bunger valve.

- A possible fear arose that the discharge could hit the abutment and severe vibration of the valve would occur.

Because of these reasons, CFE decided to abandon operation of the low level outlet in 1985.

3.4.5 Sediment Flushing through Spillway

Use of the spillway for flushing sediment out of the reservoir has been employed by operating personnel. It was found to be somewhat effective in sluicing local material deposits from the reservoir within the immediate vicinity of the spillway area. However, it was not found effective in sluicing sediment deposits from the intake and low level outlet areas. The primary reason for this is the small island which is located adjacent to the left side of the spillway and which reaches a maximum elevation of 810 m. This island presents a natural barrier which restricts movement of the sediment from one side to the other. Also, the spillway is located at a considerable distance from the intake area, about 350 m, which would further inhibit the movement of sediment from this area.

3.4.6 Dredging of Reservoir Sediment

In addition to the sand conservation and prevention works in the upstream reaches, CFE tried to remove sediment materials by mechanical method in and around the power intake site of Soledad Reservoir.

The CFE's plan was to dredge the sediment materials by using a sand pump mounted on the pontoon and spoil them in the river gorge just downstream of the spillway flip bucket through discharge pipe. The principal dimensions of the dredging work are as follows.