at a suitable time when the value of their kW generation can be favorably evaluated as the peak supply source. In contrast to the total power demand of approximately 960 MW in the ENEE power system in 2010, El Cajón is a large hydroelectric power plant which has the regulating capacity of 292 MW. From this point of view, it has been regarded that the development of Naranjito and Sico II before 2010 would be too early.

Sico I is a site of which development is related to Sico II, and it is deemed appropriate that this site not be developed before 2010.

El Cajón Hydroelectric Power Plant has a reservoir with an effective storage capacity of 4,200 x 10^6 m^3, and the existing units are being operated at a plant factor of 52%.

The discharge of this power plant can be regulated with the reservoir on an annual basis by means of the existing units. Therefore, no additional energy generation can be expected even after the additional units are installed. In other words, the feasibility of this Amplification Project depends on whether it is implemented at the proper timing when only kW supply capability is required in balancing the demand and supply of the power system.

As discussed before, there are sufficient peak regulating power supply sources until 2010, and what is required to be developed in the near future is the base supply power source that deals with the kWh demand increase.

Agua de la Reina Hydroelectric Project is being planned for a site which is located approximately 3 km downstream of El Cajón Hydroelectric Power Plant, and this project can not be evaluated as economically competitive if it is considered as a single project. However, this project could function in such a manner that it levels the discharge of El Cajón Power Plant, or in other words, as the "re-regulating pondage" of El Cajón.

Currently, El Cajón Power Plant functions as a base and peak supply power source, and consequently, the fluctuation of its discharge is not so large. However, it is anticipated that the fluctuation of discharge will be increased in future as a peak supply capability increases. Therefore, the need for the development of Agua de la Reina Project will increase, in view of assuring safety for the people living along the downstream of the river, and utilizing the river bed for agriculture.

ENEE recognizes the need for development of the project, and it is now studying the timing of development.

In the past operation of El Cajón Hydroelectric Power Plant, some overflows from the reservoir have been recorded. However, it has been assumed that there will be no waste spill of reservoir in future as the reservoir operation is improved, and it is assumed in this study that no increase in the secondary energy will be realized by the El Cajón Amplification Project. The records of past overflows from the Reservoir are shown in **Fig. 5-3**.

It was assumed that Cañaveral and Rio Lindo Hydroelectric Power Plants are serial plants utilizing the water of the Yojoa Lake, and these plants will continue to operate at fixed loads, or as base supply power sources, as they are today.

(2) Gas Turbine Power Plant

ENEE has decided to commission a gas turbine power plant at Toncontin, Tegucigalps in 1994.

This decision has been made to deal with the urgent need for electric power demand in the near future. The gas turbine power plant may be operated for a long time to deal with the increase of energy demand, until the next new base supply power source is developed. However, in terms of general economy, it is not advantageous to operate gas turbine power plants at plant factor exceeding 30%, and the JICA Study Team decided in its study not to develop new gas turbine power plants, because sufficient peak supply capacity will be provided.

(3) Diesel Thermal Power Plant

ENEE intends to develop diesel thermal power plants, following the development of gas turbine power plants. The unit capacity is 20 MW, and it is intended to develop as many units as required in terms of demand/supply balance.

The diesel thermal power plants will be operated at high plant factor as base supply power source. In this study, the plant factor of these power plants has been assumed to be 70%. Although it is expected that large capacity thermal units, having superior economy, will be introduced in future as the base supply capability. The appropriate unit capacity of these thermal power plants would be 75 MW, considering the unit capacity of El Cajón units, and the timing of introduction of such thermal units will be after 2000. That is, it is expected that the diesel thermal power plants will share the role of base supply power source for the period between 1995 and 2000.

(4) Oil-Fired Thermal Power Plant, Coal-Fired Thermal Power Plant and Combined Cycle Thermal Power Plant

The oil-fired thermal power plants, coal-fired thermal power plants, and combined cycle thermal power plants are conceivable as large capacity base supply sources.

Out of these types, the combined cycle thermal power plant would be selected from the point of view of realizing higher economy by means of the advantage of size, higher thermal efficiency by means of combining gas turbines and steam turbines, and the advantage of development by stages.

This type of thermal power plant is excluded from the study for the reason that the application of relatively small units, 75 to 90 MW in unit capacity, would not be necessarily advantageous.

When comparing the oil-fired thermal and coal-fired thermal, as large a unit capacity as possible is desirable for a coal-fired thermal, because of abundant preparatory works such as procurement of the coal which must be imported, and the development of the infrastructure. Specifically, it has been assumed that the first coal-fired thermal project will consist of two, 90 MW units, and it will be commissioned after 2008, when the unit capacity of 90 MW roughly corresponds to 10% of the peak demand. In other words, it has been assumed that the base load will be supplied by oil-fired thermals for the period between 2001 and 2007.

The unit capacity of the oil-fired thermals would be 75 MW, considering the unit capacity of El Cajón Power Plant.

5.3.3 General Conditions for Study

(1) Power and Energy

The unit capacity of the power supply sources to be developed in future was assumed to be 50 MW for a gas turbine unit, 20 MW for diesel thermal units, 75 MW for oil-fired thermal units, 90 MW for coal-fired thermal units, 57 MW for Agua de la Reina, and 73 MW for El Cajón units respectively. The firm power and the firm energy to be used in demand/supply balance study were determined by the following.

Firm Power: The firm power was calculated based on the station-service power ratio which is generally adopted.

Firm Energy :	The firm energy was calculated based on the station-service energy consumption and the annual plant factor which are generally adopted. The values for Agua de la Reina Power Plant were quoted from the Case of Sin Tunnel in the Feasibility Study Report. The firm energy of the amplification units of El Cajón was assumed to be zero.

(2) Although there are many basic concepts concerning the definition of the reserve capacity, the following rules are generally used in determination of the reserve capacity in power systems of which size is up to 1,000 MW or so.

1) The sum of the unit capacities of the largest unit and the second largest unit in the power system is defined as the reserve capacity.

2) The largest unit capacity plus the 10% of the peak load of the power system is defined as the reserve capacity.

3) 15 to 30% of the peak load of the power system is defined as the reserve capacity.

According to the three definitions above, the size of the reserve capacity in this study is the largest by definition 1), and decreases in the order of 2), 3).

Since the maximum unit capacity in the power system of ENEE is large, being 73 MW, the reserve capacity values as defined by 1) and 2) become large, and not favorable in terms of economy. Therefore, the Study Team adopted definition 3), and its value was calculated to be "15%", in view of the fact that the existing generating facilities are mostly composed of hydroelectric power plants.

In determining the reserve capacity, the reduction of the supply capability due to the scheduled inspection of generating units as well as faults, were considered.

(a) Reduction of Supply Capability Due to Scheduled Maintenance

A thermal unit has to be shut down for a considerable time period for inspection. The reserve capacity was studied based on the assumption that thermal units are shut down for periodical inspection once in 2 years, and for a period of 1.5 months, while the projected monthly peak demands are low. The calculation result indicated that at least 12% or more reserve capacity ratio can be maintained throughout a year. In view of this calculation result, the definition of the reserve capacity of 15%, is appropriate.

(b) Reduction of Supply Capability Due to Faults

Forced shutdown of generating facilities, extending to long periods due to faults, would happen for both hydroelectric and thermal generating units.

However, since the objective of this study is to establish the timing, within the time period from 1992 to 2010, when the amplification of El Cajón Power Plant is required, the Study Team assumed that a forced shutdown of power supply facilities in that period did not occur.

Based on this assumption, the size of the reserve capacity was defined as 15% of the peak load.

(3) Interest Rate and Depreciation Period of Facilities

These values were defined as below upon consultation with ENEE.

Interest Rate: 12%

Depreciation Period:

Gas turbine units;	15 years.
Oil-fired thermal units and coal-fired units;	25 years.
Diesel units;	20 years.
Hydroelectric units;	50 years.

(4) Construction Unit Cost

The unit construction cost of thermal units was estimated based on the actual prices in recent projects, and that of hydroelectric units was quoted from the feasibility study report.

Gas turbine:	50 MW;	US$750/kW
Diesel:	20 MW;	US$1,500/kW
Oil-fired thermal;	75 MW;	US$1,200/kW
Coal-fired thermal;	90 MW;	US$1,750/kW
Agua de la Reina;	57 MW;	US$3,750/kW
El Cajón Amplification	73 MW;	US$750/kW

(5) Operation/Maintenance Cost

The operation/maintenance cost was calculated by multiplying the construction cost with the following rates, which are commonly used in the feasibility study level.

Gas turbine:	4.5%
Diesel, oil-fired thermal and coal-fired thermal:	5.0%
Hydroelectric:	3.0%

(6) Fuel Cost

The fuel cost contains various factors that affect the fuel price. In particular, large uncertainty is contained in the escalation rate by which the fuel cost is changed in future.

In this study, the following values assumed in the recent feasibility studies have been adopted, and calculations were performed for the cases in which these values were increased by 50% and 100% for the purpose of sensitivity analysis.

(Unit: US$/ton)

	Fuel	Base Case	50% Up	100% Up
Gas Turbine	Diesel Oil	239	358	478
Diesel Power	Bunker-C	151	226	300
Oil-fired Thermal	Bunker-C	151	226	300
Coal-fired Thermal	Coal	49	73	98

5.3.4 Case Studies of Power Development Plans

The following three cases were formulated as the power development plans for ENEE for the period of 1992 to 2010, by taking into account the conditions assumed in Paragraphs **5.3.1** through **5.3.3**.

Case 1: The case in which the development of Agua de la Reina is implemented at a later time.
(The timing of the development of Agua de la Reina is delayed as much as possible.)

Case 2: The development of Agua de la Reina is implemented at an early time.

Case 3: Power development is implemented by means of diesel thermal plants only.

In formulating the plans, the demand/supply balance of each year had been met. These development plans are illustrated in **Table 5-4** and **Fig. 5-4~6.**

In each development plan, it was assumed that El Cajón #5 and #6 are installed when only the kW supply capability became short.

5.3.5 Economic Comparison and Sensitivity Analysis

In the economic comparison studies, the present values of the annual cost of each power plant to be newly developed in each year from the commissioning of the plant to year 2010 were calculated, and the sums of these values were compared.

The result obtained by this study was as presented below.

Case	Present Value of Annual Expenses (Million US$)
Case 1	521
Case 2	563
Case 3	514

To compare Case 1 and Case 2, there is a difference of around 8%. This difference was caused by the timing of the commissioning of Agua de la Reina Hydroelectric Project, and also by the fact that the large capacity oil-fired thermal power plant was commissioned as early as possible in Case 1. That is, Agua de la Reina Hydroelectric Project has low economic value, and its contribution to the demand/supply balance is smaller than those of other supply sources. For these reasons, there is no advantage in developing this Project at an early time.

Consequently, it can be said that it is desirable to develop Agua de la Reina Hydroelectric Project at as late a time as possible.

Comparing Case 1 and Case 3, the difference in ratio is approximately 1%, and these two cases are almost equal in terms of economy. However, Case 3 has been formulated to optimize a very detailed demand/supply balance, which is not realistic in reference to the diversification of supply sources and fuels when the size of the power system grows to 1,000 MW class. This case has the meaning of providing the base of comparison for other cases.

In view of these facts, it can be said that Case 1 is most desirable in terms of economy.

(2) Sensitivity Analysis of Discount Rate

The discount rate has been assumed to be 12% in this study. At the same time, the present values of annual costs, similarly to Paragraph (1), were compared by assuming ±3% of variation of the discount rate which might reflect the changes in economic activity of the country.

Discount Rate (%)	**Present Value of Annual Cost (Million US$)**		
	Case 1	**Case 2**	**Case 3**
15	409	443	403
12 (base case)	521	563	514
9	675	722	653

These calculation results indicate that the economic superiority between 3 cases does not change, as in the base case.

(3) Sensitivity Analysis of Fuel Cost

The fuel cost is one of the most influential factors that affect the economy. In this study, the present values of annual cost of new power projects were compared by increasing the fuel price, which has been fixed in the base case, by 50% and 100% for all fuels.

Fuel Price (US$/ton)	Present Value of Annual Cost (Million US$)		
	Case 1	Case 2	Case 3
Base Case	521	563	514
50% Up	640	678	627
100% Up	684	719	664

The calculation results indicate that the economic superiority between 3 cases in the basic case, is unchanged by the increase in the fuel price.

In other words, the new hydroelectric power project considered in this Study is only Agua de la Reina Hydroelectric Project, and the effect of this project on the result of this Study is minor.

In addition, it can be said that, even if the fuel price is increased by 100%, the unit generating costs of the diesel thermal plants, oil-fired thermals and coal-fired thermals remain at the level of 10 to 11.5 ¢/kWh, and in view of the unit generating costs of other hydroelectric projects that are more expensive the economic advantage can not be expected for some time by the commissioning of hydroelectric projects such as Naranjito and Sico II.

5.3.6 Timing of Amplification of El Cajón Power Plant

Based on the studies referred to in the preceding sections, the timing of the Amplification of El Cajón Power Plant is given as below.

	#5	#6
Case 1	2002	2006
Case 2	2004	2009
Case 3	2001	2006

That is, it has been verified that it is desirable to commission #5 in early 2000's, and #6 in late 2000's. Therefore, the timing of commissioning of #7 and #8 falls after 2010.

The JICA Study Team concluded that it would be appropriate, both technically and economically, to implement the civil works of Amplification Project for 2 units or for 4 units simultaneously.

Concerning the generating facilities, however, the simultaneous commissioning of #5 and #6 will only result in possession of excessive reserve capacity for several years, which is not economical.

It is technically feasible to install additional generating units at a later time by providing a bulkhead in the powerhouse on the penstock side and by shutting off water at upper section of the draft tubes on the tailrace side. For this reason, it was decided to plan to commission #5 and #6 when they are required by the demand/supply balance.

Table 5-1 Basic Data for Demand Forecast

GDP. Population = Data of IMF

Year	GDP (Lempiras)		Energy (Generation)		Population		GDP/Capita		Energy/Capita	
	(Million)	Rate(%)	(GWh)	Rate(%)	(Thousand)	Rate(%)	Lempiras	Rate(%)	(KWh)	Rate(%)
1975	2,248	6.3	510.5	11.2	3,090	3.3	728	3.0	165	7.1
1976	2,696	19.9	560.3	9.8	3,200	3.6	843	15.8	175	6.1
1977	3,339	23.8	650.0	16.0	3,320	3.8	1,006	19.3	196	12.0
1978	3,798	13.7	691.4	6.4	3,440	3.6	1,104	9.7	201	2.6
1979	4,425	16.5	781.2	13.0	3,560	3.5	1,243	12.6	219	9.0
1980	5,085	15.0	899.2	15.1	3,670	3.7	1,379	10.9	245	11.9
1981	5,553	9.1	979.0	8.9	3,820	3.5	1,454	5.4	256	4.5
1982	5,762	3.8	1,037.1	5.9	3,960	3.7	1,455	-	262	2.3
1983	6,035	4.7	1,125.1	8.5	4,090	3.3	1,476	1.4	275	5.0
1984	6,462	7.1	1,183.7	5.2	4,230	3.4	1,528	3.5	280	1.8
1985	7,008	8.4	1,383.8	16.9	4,370	3.3	1,604	5.0	317	13.2
1986	7,596	8.4	1,459.6	5.5	4,510	3.2	1,684	4.9	324	2.2
1987	8,128	7.0	1,783.4	22.2	4,660	3.3	1,744	3.6	383	18.2
1988	8,937	9.9	1,938.9	8.7	4,800	3.0	1,862	6.8	404	5.5
1989	9,816	9.8	2,028.3	4.6	4,950	3.1	1,983	6.5	410	1.5
1990	11,923	21.5	1,972.0	-2.8	5,110	3.2	2,333	17.7	386	-5.9

Table 5-2 Energy Demand Forecast by ENEE

Year	High Case			Middle Case			Low Case		
	Energy	Power	L.f.	Energy	Power	L.f.	Energy	Power	L.f.
	(GWh)	(MW)	(%)	(GWh)	(MW)	(%)	(GWh)	(MW)	(%)
1991	2,105.9	381.6	63.0	2,058.6	385.3	61.0	1,917.9	358.9	61.0
1992	2,374.5	430.3	63.0	2,191.8	410.2	61.0	2,023.8	378.7	61.0
1993	2,583.1	467.3	63.1	2,267.4	417.5	62.0	2,107.1	388.0	62.0
1994	2,686.8	485.3	63.2	2,298.0	419.7	62.5	2,166.9	395.8	62.5
1995	2,808.0	506.4	63.3	2,379.3	431.1	63.0	2,261.7	409.8	63.0
1996	2,933.9	528.3	63.4	2,463.9	443.6	63.4	2,352.5	423.6	63.4
1997	3,065.5	551.1	63.5	2,565.8	461.3	63.5	2,449.7	440.4	63.5
1998	3,202.6	574.8	63.6	2,712.7	486.9	63.6	2,580.8	463.2	63.6
1999	3,366.2	603.2	63.7	2,874.1	515.1	63.7	2,719.4	487.3	63.7
2000	3,539.0	633.2	63.8	3,047.1	545.2	63.8	2,866.2	512.8	63.8
2001	3,720.2	664.6	63.9	3,232.2	577.4	63.9	3,021.4	539.8	63.9
2002	3,911.4	696.6	64.1	3,427.4	610.4	64.1	3,184.7	567.2	64.1
2003	4,112.6	730.1	64.3	3,636.7	645.6	64.3	3,358.6	596.3	64.3
2004	4,325.9	765.6	64.5	3,858.3	682.8	64.5	3,541.6	626.8	64.5
2005	4,556.9	804.0	64.7	4,094.8	722.5	64.7	3,736.2	659.2	64.7
2006	4,800.8	843.1	65.0	4,350.7	764.1	65.0	3,941.2	692.2	65.0
2007	5,060.0	885.9	65.2	4,620.5	809.0	65.2	4,157.9	728.0	65.2
2008	5,338.4	931.8	65.4	4,907.0	856.5	65.4	4,386.6	765.7	65.4
2009	5,632.0	980.1	65.6	5,211.2	906.8	65.6	4,627.8	805.3	65.6
2010	5,941.7	1,032.4	65.7	5,534.3	961.6	65.7	4,882.3	848.3	65.7

Table 5-3 Power Stations Existing and Planned by ENEE

EMPRESA NACIONAL DE ENERGIA ELECTRICA
Dirección de Planificación y Control de Proyectos

DESCRIPCION DE CARACTERISTICAS DE LAS CENTRALES
3 DE NOVIEMBRE DE 1992

		NOMBRE	POTENCIA		ENERGIA/AÑO		AÑO PUESTA
		DE	(MW)		(GWh)		/DISPONIBLE
		CENTRALES	INSTALADA	FIRME	FIRME	MEDIA	
EXISTENTE	HIDRO	CAÑAVERAL	28.5	26.7	186	216	1964
		RIO LINDO	80.0	73.1	571	624	1971/79
		EL NISPERO	22.5	21.8	34	67	1982
		EL CAJÓN	292.0	271.6	1,183	1,387	1985
			(423.0)	(393.2)	(1,974)		
	TERMICA	LA CEIBA	26.6	21.0	fp 0.7	128	1974
		I ALSTHOM	30.0	24.0	fp 0.7	147	1980
		II SULZER	30.0	24.0	fp 0.7	147	1984
			(86.6)	(69.0)		(422)	
		GRAN TOTAL	509.6	462.2	2,335		
FUTURA	HIDRO	AGUA DE LA REINA	57.7	57.0	223	255	flexible
				(tentativo)			
	TERMICA	TURBO GAS A1	50.0	47.5	fp 0.4	166	1994
		TURBO GAS A2	50.0	47.5	fp 0.4	166	flexible
		DIESEL LENTA A1	40.0	38.0	fp 0.7	233	flexible
		DIESEL LENTA A2	40.0	38.0	fp 0.7	233	flexible

Table 5-4 Demand and Supply Balance

Year	Demand			Case 1					Case 2					Case 3				
				Late Development of La Reina					Early Development of La Reina					Development by Diesel				
	Power (MW)	Required Power (MW)	Energy (GWh)	Power Station	Firm		Available		Power Station	Firm		Available		Power Station	Firm		Available	
					(GWh)	(MW)	(GWh)	(MW)		(GWh)	(MW)	(GWh)	(MW)		(GWh)	(MW)	(GWh)	(MW)
1990	364.7	419	1,917					462					462					462
91	385.3	443	2,059					462					462					462
92	410.2	472	2,192				2,362	462				2,362	462				2,362	462
93	417.5	480	2,267				2,362	462				2,362	462				2,362	462
94	419.7	483	2,298	GTI (50)	172	47	2,534	509	GT1 (50)	172	47	2,534	509	GT1 (50)	172	47	2,534	509
95	431.1	496	2,379				2,534	509				2,534	509				2,534	509
96	443.6	510	2,464	D1 (20)	120	19	2,654	528	D1 (20)	120	19	2,654	528	D1 (20)	120	19	2,654	528
97	461.3	530	2,566	D2 (20)	120	19	2,774	547	D2 (20)	120	19	2,774	547	D2 (20)	120	19	2,774	547
98	486.9	560	2,713	D3 (20)	120	19	2,894	566	D3 (20)	120	19	2,894	566	D3 (20)	120	19	2,894	566
99	515.1	592	2,874	D4 (60)	360	57	3,126	602	D4 (60)	360	57	3,126	602	D4 (60)	360	57	3,126	602
2000	545.2	627	3,047	B1 (75)	432	70	3,558	672	D5 (40)	240	38	3,366	640	D5 (40)	240	38	3,366	640
01	577.4	664	3,232				3,558	672	La Reina (57)	223	57	3,589	697	El Cajón #5 (73)	–	68	3,366	708
02	610.4	702	3,427	El Cajón #5 (73)	–	68	3,558	740	B1 (75)	432	70	4,021	767	D6 (20)	120	19	3,486	727
03	645.6	742	3,637	B2 (75)	432	70	3,990	810				4,021	767	D7 (40)	240	38	3,726	765
04	682.8	785	3,858				3,990	810	El Cajón #5 (73)	–	68	4,021	835	D8 (40)	240	38	3,966	803
05	722.5	831	4,095	B3 (75)	432	70	4,275	856	B2 (75)	432	70	4,306	881	D9 (40)	240	38	4,206	841
06	764.1	879	4,351	El Cajón #6 (73)	–	68	4,275	924	B3 (75)	432	70	4,738	951	D10 (60) El Cajón #6 (73)	360 –	57 68	4,419	942
07	809.0	930	4,621	B4 (75)	432	70	4,707	994				4,738	951	D11 (40)	240	38	4,659	980
08	856.5	985	4,907	La Reina (57)	223	57	4,930	1,051	B4 (75)	432	70	5,170	1,021	D12 (40)	240	38	4,899	1,018
09	906.8	1,043	5,211	C1 (90)	508	83	5,291	1,063	El Cajón #6 (73) C1 (90)	– 508	68 83	5,359	1,101	La Reina (57) D13 (80)	223 480	57 76	5,283	1,080
2010	961.6	1,106	5,534	C2 (90)	508	83	5,627	1,146	C2 (90)	508	83	5,867	1,174	D14 (40)	240	38	5,523	1,114

To be retired
la Ceiba in 1999
Cortes I in 2005
Cortes II
GT1 } in 2009

Table 5-5 Conditions for Calculation

		Gas Turbine	Diesel Thermal	Bunker Thermal	Coal Thermal
Unit Output	(MW)	50	20	75	90
Firm Power	(MW)	57	19	70	83
Plant Factor	(%)	40	70	70	70
Station Service	(%)	2	2	6	8
Available Energy	(GWh)	172	120	432	508
Fuel		Diesel Oil	Bunker C	Bunker C	Coal
Calorific Power	(kcal/kg)	10,200	9,900	9,900	6,000
Efficiency	(gen./send. %)	30/30	40/38	36/34	35/32.5
Consumed Factor	(kcal/kWh)	2,867	2,263	2,529	2,646
Fuel Cost	($/ton)	239	151	151	49
Fuel Cost	($/kWh)	0.0672	0.0345	0.0386	0.0216
Variable Cost	(M$/year)	11.56	4.14	16.68	10.97
Life	(Year)	15	20	25	25
Construction Cost	($/kW)	750	1,500	1,200	1,750
Capital Cost	($/kW)	110.11	200.82	153.00	223.13
O&M Cost	(%)	4.5	5	5	5
O&M Cost	($/kW)	33.75	75.00	60.00	87.50
Fixed Cost	($/kW)	143.86	275.82	213.00	310.63
Fixed Cost	(M$/year)	7.19	5.52	15.98	27.96
Annual Cost	(M$/year)	18.75	9.66	32.66	38.93
Averaged Unit Cost	(¢/kWh)	@10.90	@8.05	@7.56	@7.66

Table 5-6 Construction Cost

(Unit: M$)

Case 1 (Late Development of Agua de la Reina)		Case 2 (Early Development of Agua de la Reina)		Case 3 (Development by Diesel Thermal)	
GT1 (50)	37.5	GT1 (50)	37.5	GT1 (50)	37.5
D1 (20)	30	D1 (20)	30	D1 (20)	30
D2 (20)	30	D2 (20)	30	D2 (20)	30
D3 (20)	30	D3 (20)	30	D3 (20)	30
D4 (60)	90	D4 (60)	90	D4 (60)	90
B1 (75)	90	D5 (40)	60	D5 (40)	60
El Cajón #5 (73)	73	Agua de la Reina (57)	214.5	El Cajón #5 (73)	73
B2 (75)	90			D6 (20)	30
B3 (75)	90	B1 (75)	90	D7 (40)	60
El Cajón #6 (73)	36	El Cajón #5 (73)	73	D8 (40)	60
B4 (75)	90	B2 (75)	90	D9 (40)	60
Agua de la Reina (57)	214.5	B3 (75)	90	D10 (60)	90
		B4 (75)	90	El Cajón #6 (73)	36
C1 (90)	157.5	El Cajón #6 (73)	36	D11 (40)	60
C2 (90)	157.5	C1	157.5	D12 (40)	60
		C2	157.5	Agua de la Reina (57)	214.5
				D13 (80)	120
				D14 (40)	60
	1,216		1,276		1,201

Table 5-7 Present Value of Annual Cost

	Case 1 Late Development of La Reina					Case 2 Early Development of La Reina					Case 3 Development by Diesel Thermal				
	P.S.	Installed Capacity (MW)	Annual Cost (M$)	PV at Commissioning Year (M$)	PV at 1992 (M$)	P.S.	Installed Capacity (MW)	Annual Cost (M$)	PV at Commissioning Year (M$)	PV at 1992 (M$)	P.S.	Installed Capacity (MW)	Annual Cost (M$)	PV at Commissioning Year (M$)	PV at 1992 (M$)
1991															
92															
93															
94	GT1	50	18.75	133.50	106.43	GT1	50	18.75	133.50	106.43	GT1	50	18.75	133.50	106.43
95															
96	D1	20	9.66	65.80	41.82	D1	20	9.66	65.80	41.82	D1	20	9.66	65.80	41.82
97	D2	20	9.66	64.02	36.33	D2	20	9.66	64.02	36.33	D2	20	9.66	64.02	36.33
98	D3	20	9.66	62.05	31.44	D3	20	9.66	62.05	31.44	D3	20	9.66	62.05	31.44
99	D4	60	28.98	179.52	81.21	D4	60	28.98	179.52	81.21	D4	60	28.98	179.52	81.21
2000	B1	75	32.66	193.93	78.32	D5	40	19.32	119.68	48.34	D5	40	19.32	114.72	46.33
01						La Reina	57	32.15	181.65	65.50	El Cajón #5	73	11.05	62.43	22.51
02	El Cajón #5	73	11.05	58.87	18.95	B1	75	32.66	174.01	56.03	D6	20	9.66	51.47	16.57
03	B2	75	32.66	162.25	46.64						D7	40	19.32	95.98	27.59
04						El Cajón #5	73	11.05	50.43	12.94	D8	40	19.32	88.17	22.63
05	B3	75	32.66	134.25	30.77	B2	75	32.66	134.25	30.77	D9	40	19.32	79.42	18.20
06	El Cajón #6	73	5.53	19.93	4.08	B3	75	32.66	117.72	24.09	D10 El Cajón #6	60 73	28.98 5.53	104.45 19.93	21.37 4.08
07	B4	75	32.66	99.21	18.13						D11	40	19.32	58.69	10.72
08	La Reina	57	32.15	77.21	12.59	B4	75	32.66	78.43	12.79	D12	40	19.32	46.40	7.57
09	C1	90	38.93	65.81	9.58	C1 El Cajón #6	90 73	38.93 5.53	65.81 9.35	9.58 1.36	D13 La Reina	80 57	38.64 32.15	65.32 54.35	9.51 7.92
2010	C2	90	38.93	34.76	4.52	C2	90	38.93	34.76	4.52	D14	40	19.32	17.25	2.24
Tota 1		853			520.81		893			563.15		833			514.47
	GT1	50				GT1	50				GT1	50			
	E.C.	146				E.C.	46				E.C.	146			
	L.R.	57				L.R.	57				L.R.	57			
	B+C	480				B+C	480				D	560			
	D	120				D	160								

Table 5-8 Planned Hydro-Power Projects

		Agua de la Reina	El Cajón Amplification	Naranjito	Sico II
Installed Capacity	MW	57.7	73x2	136	201
Firm Energy	GWh	223.8	-	332	391.1
Average Energy	GWh	255.6	-	541	487.9
Construction Cost	M$	214.5 (W/O IDC)	109 (W/IDC)	448 (W/O IDC)	568.6 (W/O IDC)
Life	Year	50	50	50	50
Fixed Cost	M$	25.73	13.28	53.95	68.47
O&M Cost	M$	6.42	3.30	13.44	17.06
Annual Cost	M$	32.15	16.58	67.39	85.53
Unit Cost	¢/kWh	@12.6	-	@12.5	@17.5

Table 5-9 Sensitivity Analysis

	Disc. Rate (%)	Fixed Cost (M$)	Variable Cost (M$)	Annual Cost (M$)	Unit Price (¢/kWh)	Fuel Cost ($\ton)	Fixed Cost (M$)	Fuel Cost (M$)	Annual Cost (M$)	Unit Price (¢/kWh)
GT (50 MW)	15	8.10	11.56	19.66	@11.43	478	7.19	23.12	30.31	@17.62
	12	7.19		18.75	@10.90	358		17.31	24.50	@14.24
	9	6.34		17.90	@10.41	239		11.56	18.75	@10.90
D (75MW)	15	6.29	4.14	10.43	@8.69	300	5.52	8.23	13.75	@11.46
	12	5.52		9.66	@8.05	226		6.20	11.72	@9.77
	9	4.79		8.93	@9.44	151		4.14	9.66	@8.05
B (75MW)	15	18.42	16.68	35.10	@8.13	300	15.98	33.09	49.07	@11.36
	12	15.98		32.66	@7.56	226		24.93	40.91	@9.47
	9	13.66		30.34	@7.02	151		16.68	32.66	@7.56
C (90MW)	15	32.30	10.97	43.27	@8.52	98	27.96	21.95	49.91	@9.82
	12	27.96		38.93	@7.66	73		16.36	44.32	@8.72
	9	23.91		34.88	@6.87	49		10.97	38.92	@7.66
Agua de la Reina (57MW)	15	32.09	6.42	38.51	@17.27					
	12	25.73		32.15	@14.42					
	9	20.49		25.91	@11.62					
El Cajón (146MW)	15	16.50	3.30	19.86	-					
	12	13.28		16.58	-					
	9	10.06		13.36	-					

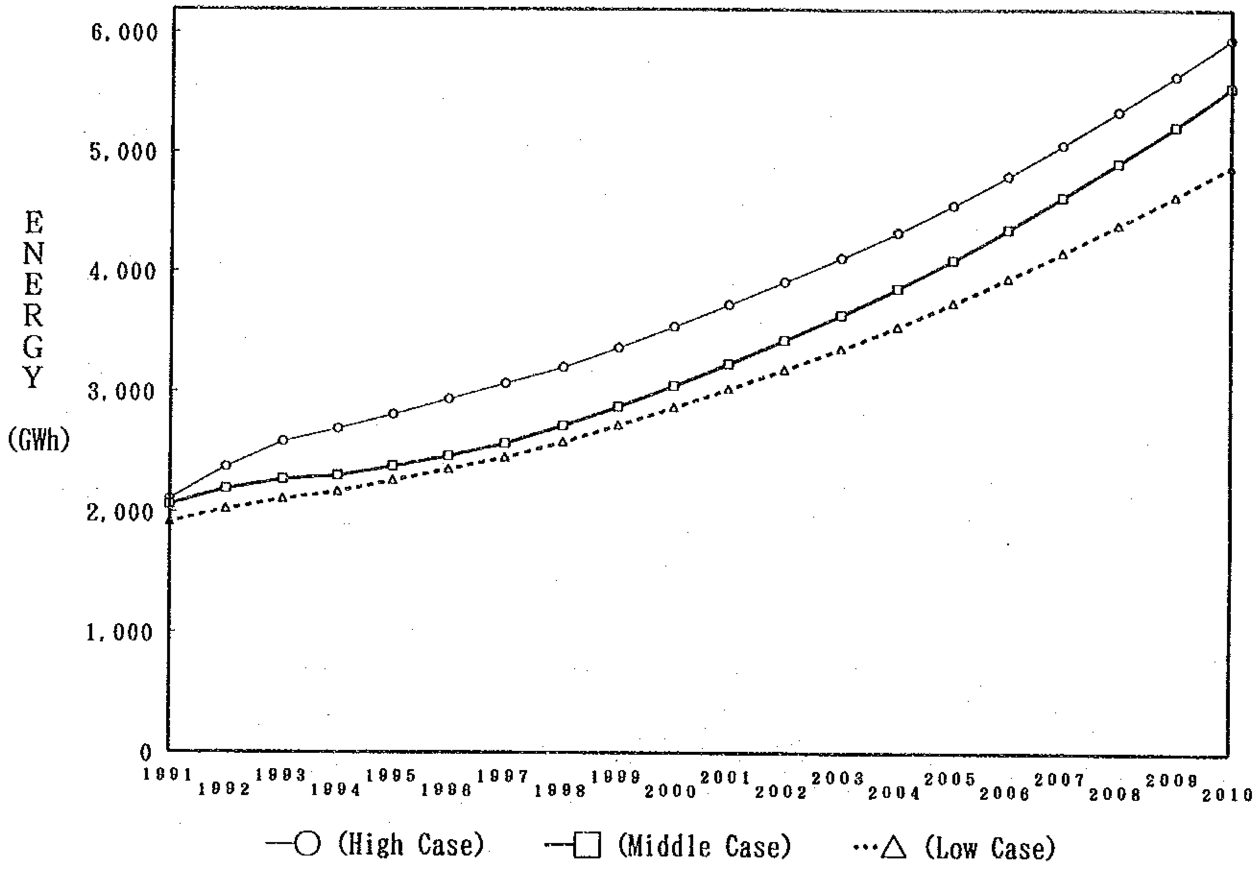

Figure 5-1 Energy Demand Forecast by ENEE

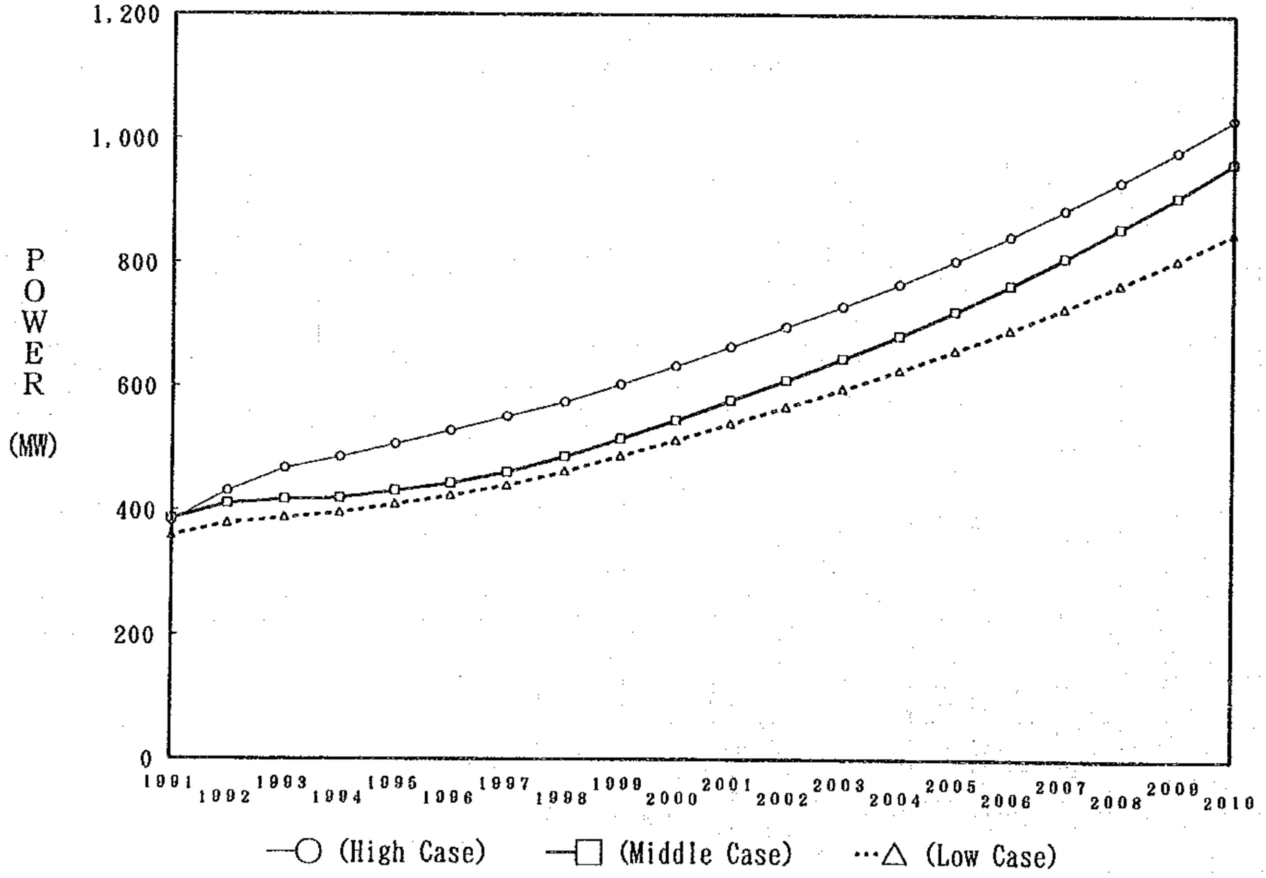

Figure 5-2 Power Demand Forecast by ENEE

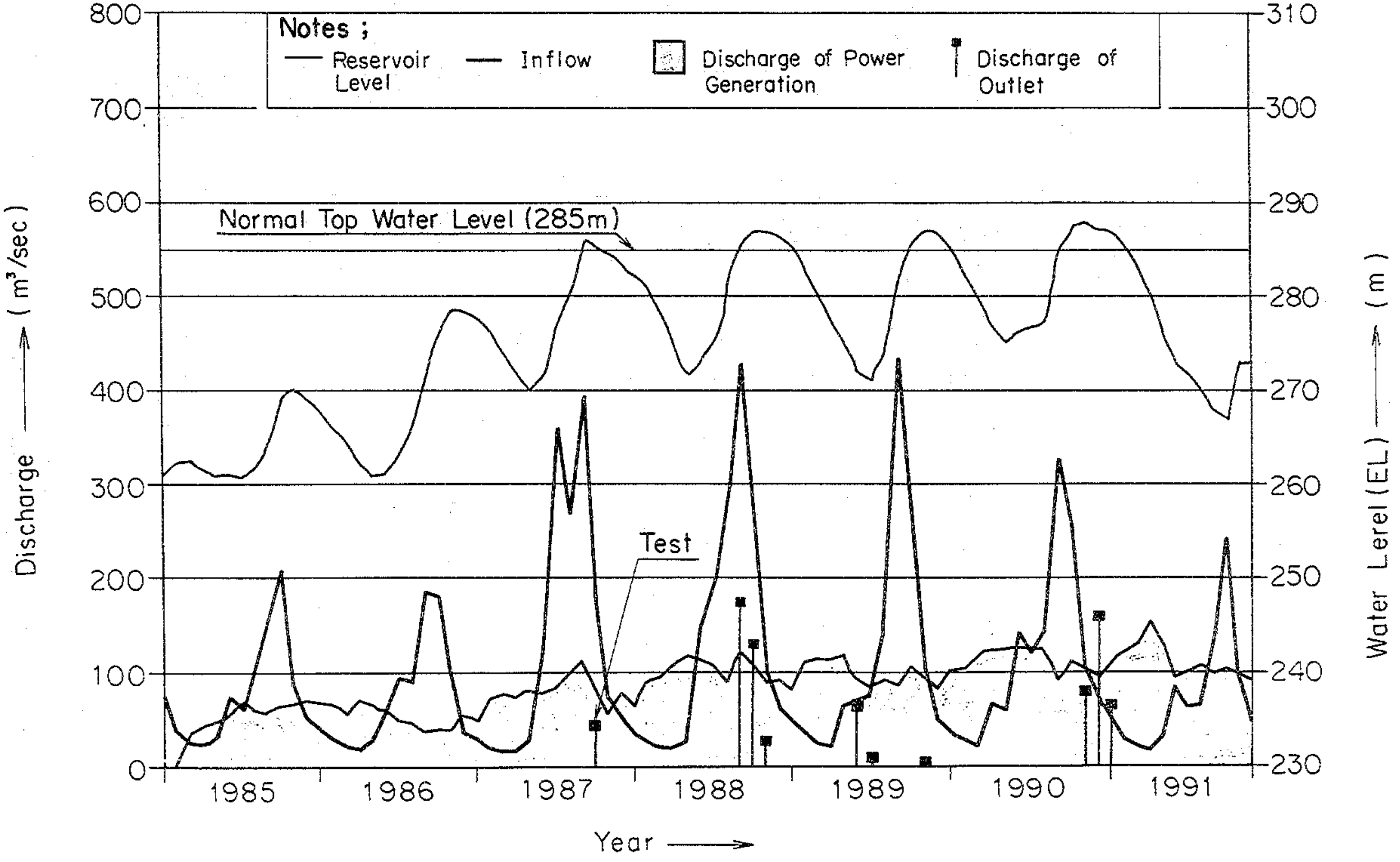

Figure 5-3 Past Records of Reservoir Operation

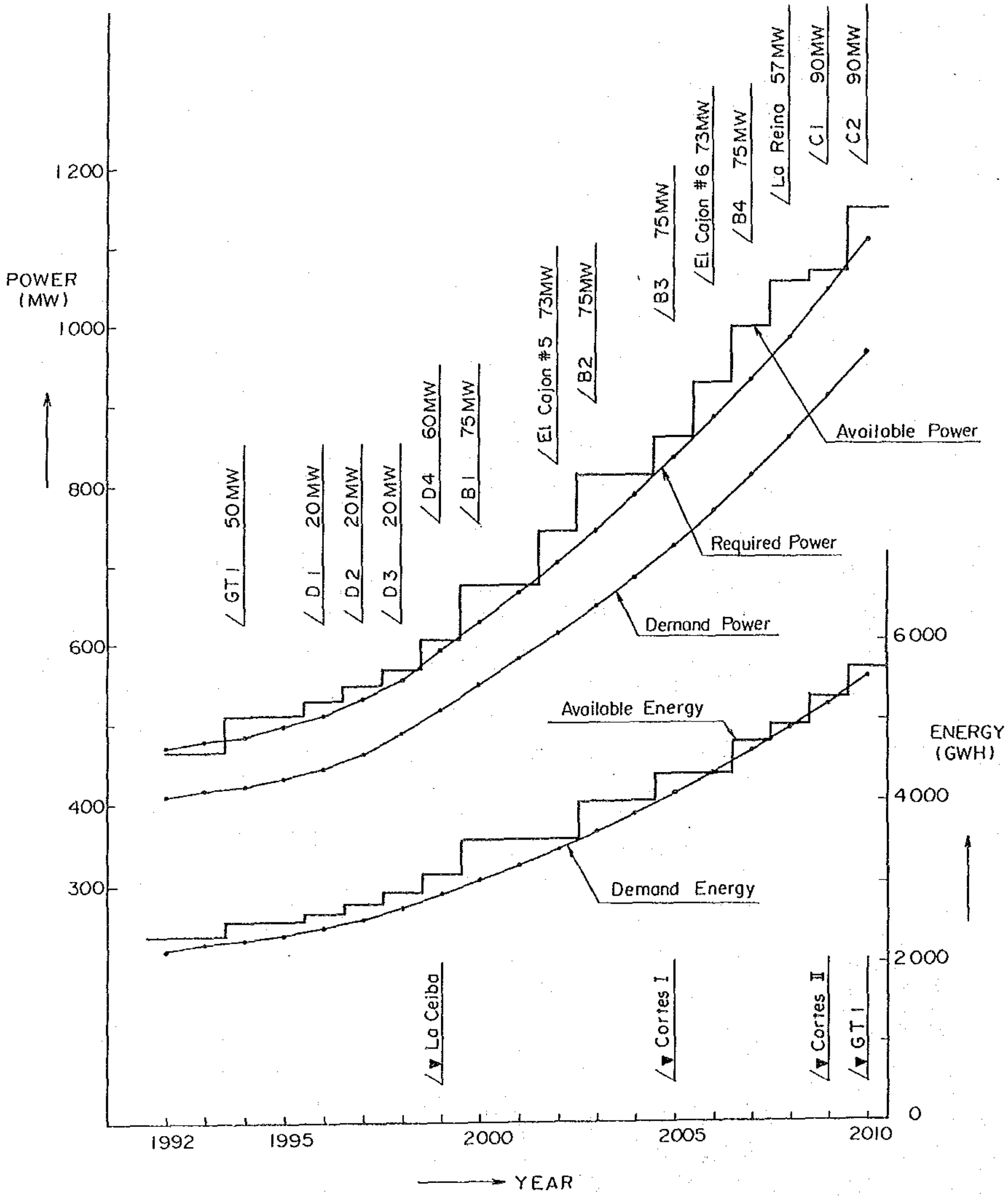

Figure 5-4 Demand and Supply Case 1 (1/3)

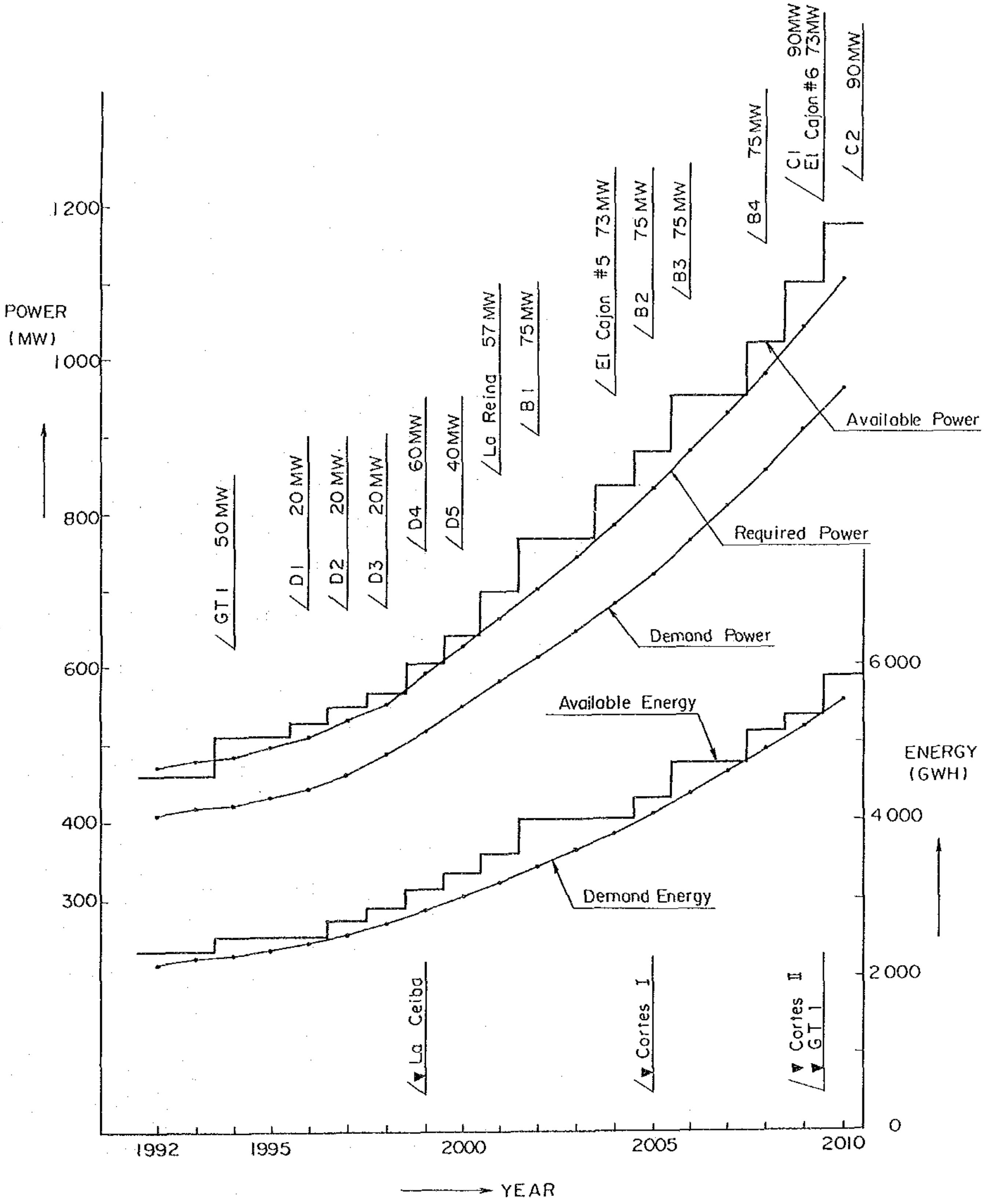

Figure 5-5 Demand and Supply Case 2 (2/3)

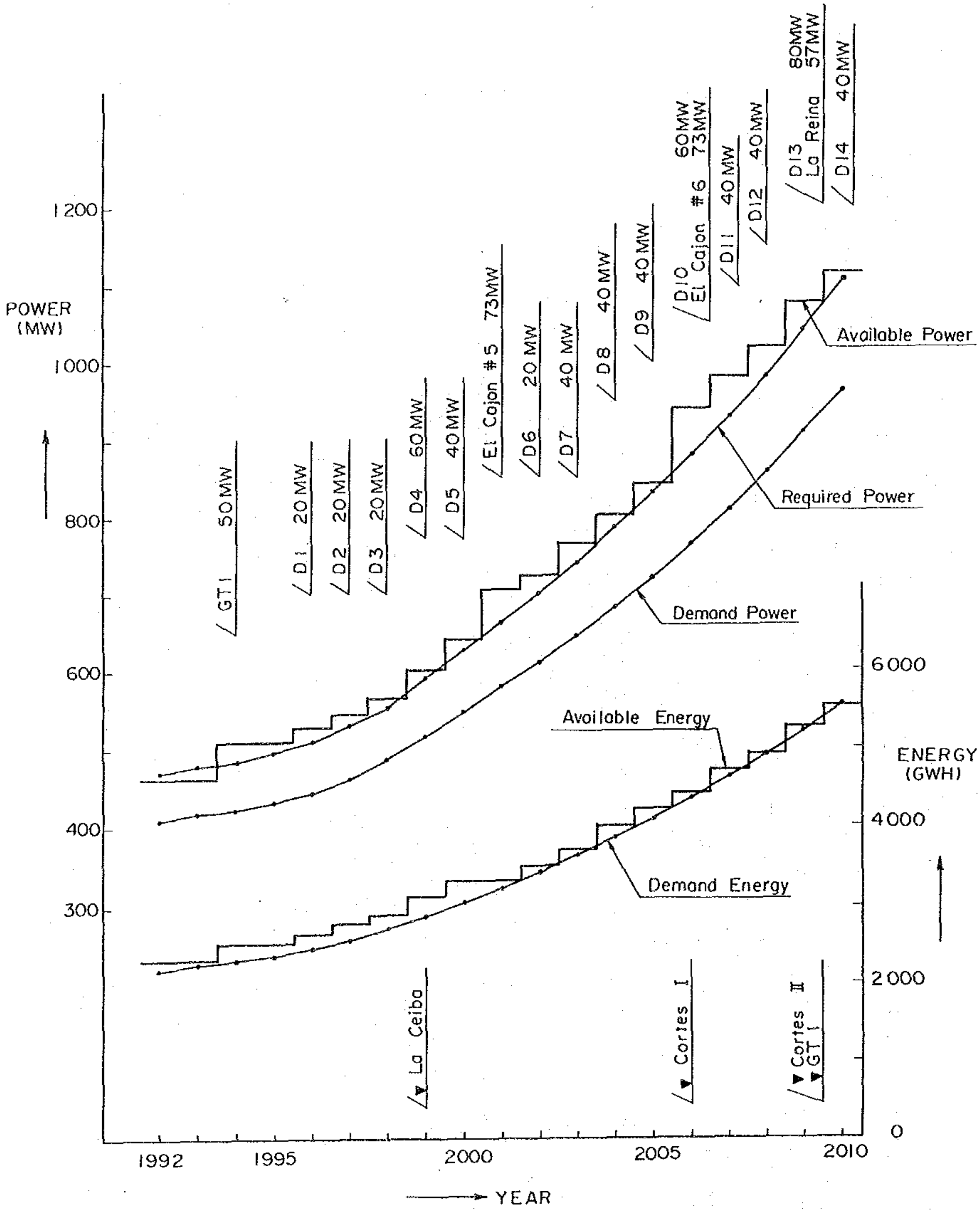

Figure 5-6 Demand and Supply Case 3 (3/3)

Chapter 6 METEOROLOGY AND HYDROLOGY

Chapter 6

METEOROLOGY AND HYDROLOGY

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Chapter 6 METEOROLOGY AND HYDROLOGY

6.1 Outline of Meteorology and Hydrology

6.1.1 General Description

Honduras is located at the isthmus of Central America, and its length in the east-west direction is greater than the distance between its north and south borders. It is located in the area between 13 and 16 degrees north latitude and for almost half of the year receives the effects of cold fronts and cold air system that originate in the northern and northeastern part of the North American continent as well as at the North Pole. For the remaining period, it receives the effects of the Tropical Convergence Zone and the tropical waves within the trade wind that originate in the equatorial and the tropical zone and the Bermuda High influence during a short period.

The El Cajón Dam site is located at the confluence of the Humuya and Sulaco Rivers. The Humuya and Sulaco Rivers are two major tributaries of the Comayagua River, which is itself part of the Ulua River system that flows into the Atlantic Ocean. The Humuya River originates at El. 1,400 to 1,500 m in the mountains to the west of Honduras' capital city of Tegucigalpa. From there, it flows north into the plains where the city of Comayagua is located and continues northward into a valley.

The Sulaco River originates at around El. 1,000 m in the mountains at the northern part of Tegucigalpa, which borders the Choluteca River system that flows into the Pacific Ocean. While shaping the valley, the Sulaco River flows north and then turns west, later joining up with the Humuya River.

Along the way, the two rivers flow almost parallel to each other and proceed northward. The two river basins are separated at El. 1,000 to 2,000 m by a mountain range. The average elevation of the El Cajón basin is about 900 m. The catchment area at the El Cajón Dam is 8,220 km^2. Of that, the Humuya River accounts for 3,620 km^2 and the Sulaco River, 4,600 km^2.

6.1.2 Climate and River Runoff Data

Fig. 6-1 shows the location of each runoff gauging station, and **Fig. 6-2** shows observation period at each station. The El Cajón reservoir has 15 working runoff gauging stations. Among those, five are administered by ENEE and 10 by DSHC (Departmento de Servicios Hidrológicos y Climatológicos). Six of these gauging stations, namely those at Lagunetas, Piedra Parada, Los Naranjos, El Sarro, Los Encuentros and Siale, were established by the Swiss consulting company, Motor-Columbus, in order to complete a feasibility study for the El Cajón Project. This study was conducted from 1970 to 1971. Of the four gauging stations shown in the chart, El Cajón, Piedra Parada, Los Naranjos and Agua Blanca are submerged in the reservoir as a result of the construction of the El Cajón Dam. The Lagunetas gauging station is to be moved to the proposed Remolino Dam Site at upstream site between January and March, 1993 because sediment prevents observation.

Fig. 6-3, shows the location of each meteorological gauging station, and **Table 6-1** shows observation items and observation period. There are 30 working meteorological gauging stations in the river basin. Among those, 4 are controlled by SMN (Servicio Meteorológico Nacional), 13 are managed by ENEE and 13 are managed by DSHC. Only hyetometers have been set up at most of the stations. There are few self-recording hyetometers; most are the cylinder type. For the cylinder type hyetometer, observation personnel take measurements at 7:00 a.m. every day. Of these weather observation stations, those at Esquias, Las Flores, Marale, San Ignacio, Sulaco and Vallecillo were established by the Swiss consulting firm, Motor-Columbus after a feasibility study for the El Cajón Project.

Also shown in **Fig. 6-3** is the isohyetal map of annual precipitation. The precipitation trend in the river basin shows that the most rain falls in the area of Yojoa Lake in the northwestern part of the basin and along the border between the Humuya and Sulaco river basins where they border the mountains.

The meteorological gauging stations are arranged with good balance within the river basin so that it is not difficult to understand the pattern of rainfall in the area.

6.1.3 Site Survey of Hydrometeorological Gauging Stations

On the occasion of the first site survey, the weather observation stations at San Jeronimo and El Cajón, as well as the El Jicaro gauging station, were surveyed. The area around the weather observation stations has been cleared of trees and shrubs, so there are no obstacles to observation. Also, at the gauging stations, from observation well, and staff gauge, trash and dead leaves are picked up to make observation easy. The observation device is also well maintained.

The results of the local surveys for meteorological observation and hydrological observation are entrusted to private citizens and the results are mailed to the ENEE head office once a month.

6.1.4 Climate and Hydrology

The country of Honduras contains both tropical and sub-tropical zones. The climate consists both of tropical rain forest and tropical savanna.

(1) Precipitation

The Humuya and Sulaco River basins are located in the highlands at the central part of the country, where much rain falls.

The rainy season lasts for six months from May through October. The rainiest months are June and September except the North Atlantic Zone where the rainiest months are October to December and its least rainy months are April and May. The least rainy months are February and March. Average annual rainfall in the mountain foothills is 1,600 mm. In addition, annual precipitation at the mountain's summit and on its windward slope is close to 2,000 mm.

In the area of the reservoir, the northeast part of Yojoa Lake receives the most rain, with an annual precipitation that reaches approximately 3,200 mm. **Table 6-2** shows monthly precipitation at all meteorological gauging stations in the basin, and **Fig 6-4** shows the annual change in monthly precipitation at El Cajón, Santa Elena which is the rainiest in the basin and Playitas gauging stations which is the least rainy. The average yearly rainfall is approximately 1,400 mm, and looking at the variation in annual rainfall by month, the rainy season, which lasts from May through October, is clearly differentiated from the dry season, which goes from November through April.

(2) Temperature

Table 6-3 shows monthly average temperature at all meteorological gauging stations in the basin, and **Fig. 6-5** shows the annual change in monthly average temperature at El Cajón and Tegucigalpa gauging stations.

The average annual temperature at the El Cajón station is 26°C. As shown in **Fig. 6-5**, Honduras experiences little seasonal variation in temperature because it lies in tropical and subtropical zones. From 1981 to 1991, the average annual values indicate that the temperature difference between the coldest months, namely December and January, and the warmest months, April and May, is 4 to 5 °C.

(3) Evaporation

Table 6-3 shows monthly evaporation at all meteorological gauging stations in the basin, and **Fig. 6-6** shows the annual change in monthly evaporation at El Cajón gauging station. In general, the trend shows a higher volume of evaporation from evaporation pan than from the surface of lakes and rivers. Evaporation from the surface of the reservoir is calculated by using the pan coefficient. At this gauging station, a value of 0.7 was adopted for the coefficient. This is the average of 0.6 and 0.8, the coefficient's range for a Class A pan.

From **Table 6-5**, evaporation from the reservoir over an 11-year period averaged about 1,780 mm. Converting the average annual evaporation at full water level to discharge, the following formula is used:

Annual evaporation converted to discharge

$$= 1.78 \times 94 \times 1{,}000^2 \times 0.7/365/86{,}400$$

$$= 3.71\ (m^3/sec)$$

The resulting value is fairly large, approximately 3.7 m^3/sec, which is equal to 3.4% of annual average runoff from 1970 to 1983, 108 m^3/sec. In the calculation of energy generation stated in **Chapter 9**, therefore, the evaporation volume from the reservoir has been considered carefully.

(4) Hydrology

The Humuya and Sulaco Rivers cut a deep valley in the vicinity of the El Cajón Dam. **Table 6-5** shows monthly average runoff at El Cajón runoff gauging station. The annual discharge from 1966 to 1984 at El Cajón gauging station is 106.9 m^3/sec, which equals 1.249 m^3/sec per 100 km^2 of catchment area. However, about 40% of that is discharged during the latter half of the wet season, in September and October.

Since the El Cajón runoff gauging station began operating in 1966, the largest flood occurred in September, 1974 when Hurricane Fifi struck Honduras. The maximum discharge at that time was estimated to be 3,600 m^3/sec.

6.2 River Runoff

6.2.1 Outline

Data on the daily discharge at the El Cajón Dam, specifically that at the El Cajón runoff gauging station located directly downstream of the dam, has been provided for 19 years, from 1966 to 1984. This is the data that are used as a basis.

6.2.2 Examination of River Runoff Data

In order to verify the discharge data for the El Cajón gauging station, the correlation was investigated between the daily discharge data recorded at the nearby gauging stations at Lagunetas, El Sarro and Guacamaya, which, have gathered daily discharge data over a relativelylong period of time. The inspection results, based on double mass curve, are shown in **Fig. 6-7 ~ 9**. There is a relatively high correlation in daily runoff among the three runoff gauging stations. As a result, the adequacy of the discharge recordings at each runoff gauging station was verified. **Fig. 6-10 ~ 12** show the result of regression analysis using monthly average runoff among the three runoff gauging stations.

6.2.3 Compensation of River Runoff Data

The compensation of missing daily river runoff data at the El Cajón runoff gauging station was done by using the data near the station.

From the results of regression analysis shown in 6.2.2, runoff data at Lagunetas gauging station were adopted because they had the largest coefficient of correlation.

Missing daily runoff data at El Cajón runoff gauging station were compensated using daily runoff data for 13 years from 1970 to 1983. Compensation calculation was divided into two parts; dry season from

December to May and wet season from June to November. The calculations for both periods are shown below.

Dry season: $Q_E = 0.47 \times Q_L + 6.99$

Rainy season: $Q_E = 0.86 \times Q_L - 9.96$

where Q_E: Daily discharge at the El Cajón runoff gauging station

Q_L: Daily discharge at the Lagunetas runoff gauging station

Fig. 6-13 shows correlation of daily runoff data in both dry and wet seasons and **Table 6-6** shows the average compensated runoff by month for the period 1970 to 1982.

Monthly average runoff for 50 years is estimated with Matalas' data generation based on Marcov chain for compensated daily runoff from 1970 to 1982. Average runoff for 50 years is estimated to be 109.5 m^3/sec. Estimation results are shown in **Table 6-7** and trend of annual average runoff in **Fig. 6-14.**

The feasibility study conducted by the Swiss consulting firm, Motor-Columbus, is based on river runoff data collected for 6 years between 1966 and 1971. Using Monte Carlo simulation with standard deviation and skewness of river runoff data, Motor-Columbus estimated the monthly runoff over a period of 50 years. According to their results, the average monthly discharge over 50 years at the El Cajón runoff gauging station is 140.8 m^3/sec. After that, they updated the feasibility study and they estimated the monthly average runoff over a period of 50 years with the same method by adding runoff data observed in the period after the feasibility study was conducted. The monthly average runoff for 50 years is estimated to be 110.3 m^3/sec, which is smaller than the value of the feasibility study because 1972 and 1973 were dry years. Monthly average runoff for 50 years, 109.5 m^3/sec, using compensated runoff data over the 13-year period from 1970 to 1982 is almost the same as the value of 110.3 m^3/sec estimated by Motor-Columbus.

6.3 Flood Analysis

6.3.1 Outline

This feasibility study is not for a project to construct a new hydroelectric power plant but for an amplification project of the existing power plant. The study does not involve reconstruction of the existing dam. Therefore, only review of analysis method in the existing study is mentioned in this section. Flood discharge is not newly calculated.

The flood discharge at the El Cajón gauging station in September, 1974 where Hurricane Fifi hit Honduras, was not recorded, because the self-recording water level meter was submerged. Thus, in the feasibility study conducted by the German consulting firm, International GmbH, flood discharge was indirectly calculated by discharge analysis based on rainfall data. Rainfall intensity distribution and hydrograph are shown in **Fig. 6-15**.

6.3.2 Probable Flood

In the feasibility study carried out by the Swiss consulting company, Motor-Columbus, they could not gather enough data with sufficient observation period in order to calculate probable flood. Therefore, a unit hydrograph was drawn up based on rainfall data and the probable flood discharge was calculated.

This study was based on the hypothesis that the 1,000-year rainfall probability at the gauging stations, at Agua Caliente, Comayagua, El Cajón, El Coyolar and Talanga in the basin, is calculated using the PMP (Probable Maximum Precipitation) with respect to 72 hours of continuous rainfall over the entire basin. Regarding the calculated precipitation, a unit hydrograph was drawn and the flood discharge was calculated taking into consideration the delay in discharge resulting from vegetation and the decrease in discharge due to perviousness and evapotranspiration. According to distribution of rainfall intensity shown in **Fig. 6-15**, a heavy rain continues for 72 hours. The estimation of 72 hours of continuous rainfall by Motor-Columbus is considered to be correct.

After that, in a feasibility study conducted by the German consulting firm, International GmbH, the PMP is calculated for 96 hours of continuous rainfall over the entire basin based on rainfall distribution by Hurricane "Fifi".

6.3.3 Probable Maximum Flood Discharge

In the Motor-Columbus feasibility study, a probable maximum flood of 17,300 m^3/sec was calculated based on the probable flood over a 1,000-year period. This study took into consideration the coefficient related to probability and statistics according to the Russian standard.

After that, they updated the study and estimated a probable maximum flood of 22,800 m^3/sec based on the Hurricane "Fifi" in 1974. However, the Consulting Board reviewed it to 14,300 m^3/sec.

According to the feasibility study by the German consulting firm, International GmbH, they estimated probable maximum flood of 14,600 m^3/-sec based on PMP.

Table 6-1 Measurement Period of Meteorological Data

Station		Latitude	Longitude	Elev. (m)	Measurement Period				
					Precipitation	Temperature	Evaporation	R. Humidity	Dew Point
Tegucigalpa	SMN	14°03'31"N	87°13'10"W	1,000	1938-91	1951-90	--	1944-90	--
El Cajon	ENEE	15°01'02"N	87°45'19"W	250	1965-91	1981-91	1981-91	1981-91	1981-91
Victoria	DSHC	14°56'07"N	87°23'22"W	360	1966-89	1968-89	1968-89	1970-89	1983-89
El Taladro*	DSHC	14°27'00"N	87°43'00"W	630	1958-70	1959-71	1958-69	--	--
Flores	DSHC	14°17'30"N	87°34'06"W	620	1944-89	1958-89	1957-89	1974-89	1983-89
Lamani	SMN	14°09'00"N	87°37'00"W	650	1956-89	--	--	--	--
El Coyolar	DSHC	14°19'00"N	87°30'39"W	800	1958-89	1963-89	1958-89	1972-89	1983-89
Comayagua*	SMN	14°25'00"N	87°34'00"W	579	1943-74	1956-71	--	--	--
Agua Caliente	SMN	14°40'00"N	87°18'00"W	555	1954-89	--	--	--	--
Santa Clara	DSHC	14°26'38"N	87°17'00"W	740	1967-89	1967-89	1967-89	1971-89	1983-89
Talanga	SMN	14°23'00"N	87°06'00"W	806	1952-70	--	--	--	--
El Horno*	DSHC	14°24'00"N	87°28'00"W	1,500	1969-74	--	--	--	--
La Paz*	SMN	14°19'00"N	87°40'30"W	667	1943-56	--	--	--	--
Pito Solo	ENEE	14°46'30"N	88°00'42"W	660	1956-91	--	--	--	--
La Ermita	DSHC	14°28'00"N	87°04'05"W	760	1969-89	1969-89	1970-89	1969-89	1983-89
Agua Caliente	DSHC	14°40'39"N	87°17'25"W	560	1969-89	1969-89	1970-89	1969-89	1983-89
Playitas	DSHC	14°25'25"N	87°42'06"W	595	1970-90	1970-89	1970-89	1970-89	1983-89
Santa Elena	ENEE	14°53'34"N	87°55'15"W	640	1966-91	1971-91	1971-91	1971-91	1971-91
Yure	ENEE	14°58'34"N	87°44'23"W	300	1971-84	1971-84	1971-84	1971-84	1971-84
San Jeronimo	ENEE	14°37'33"N	87°36'15"W	440	1971-90	1971-91	1971-91	1971-91	1971-91
San Nicolas	DSHC	14°42'51"N	87°20'30"W	600	1968-89	--	--	--	--
Las Botijas	DSHC	14°21'49"N	87°24'55"W	1,480	1969-89	--	--	--	--
La Laguna	DSHC	14°25'00"N	87°45'22"W	1,180	1970-89	--	--	--	--
Portillo de la Mora	DSHC	14°25'05"N	87°46'02"W	1,380	1970-89	--	--	--	--
Tutule	DSHC	14°14'00"N	87°51'00"W	1,060	1969-77	--	--	--	--

Table 6-2 Monthly Precipitation in El Cajon Dam Basin

(unit : mm)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
TEGUCIGALPA TONCONTIN	8.5	5.4	9.2	34.5	146.1	158.3	82.4	91.2	178.4	124.7	39.2	12.8	891
EL CAJON	34.0	29.8	17.2	32.2	117.9	234.2	225.6	220.3	240.3	140.5	74.4	55.1	1,421
VICTORIA	17.5	16.2	14.9	47.4	158.6	208.1	169.3	192.8	232.1	154.8	52.1	22.8	1,287
EL TALADRO	8.1	16.8	10.4	26.8	147.5	161.6	115.0	108.6	230.1	109.9	26.9	16.8	978
FLORES	2.8	6.8	8.2	33.0	130.1	173.0	103.5	132.4	175.3	100.7	22.0	6.9	895
LAMANI	8.9	11.0	9.9	39.4	170.1	253.7	167.9	181.3	323.5	171.4	33.8	9.5	1,380
EL COYOLAR	3.3	6.5	7.9	39.2	138.6	180.8	70.7	102.7	188.2	126.3	36.6	10.0	911
COMAYAGUA	10.0	10.8	18.7	33.5	109.5	175.1	120.0	160.3	196.8	143.8	38.5	16.1	1,033
AGUA CALIENTE	23.5	17.2	21.4	44.7	152.2	216.0	166.8	149.2	203.8	162.2	61.7	30.5	1,249
SANTA CLARA	25.7	22.7	20.9	59.7	158.0	214.0	122.9	149.9	205.8	221.1	76.5	47.6	1,325
TALANGA	28.6	16.5	20.9	62.0	182.6	149.5	105.0	83.8	149.4	141.5	76.3	49.8	1,066
EL HORNO	7.7	7.7	0.9	42.1	121.0	117.8	89.7	144.6	203.4	197.3	66.7	13.7	1,013
LA PAZ	4.1	7.0	3.0	25.8	120.6	188.4	153.4	118.3	206.4	124.8	29.0	8.8	989
PITO SOLO	168.1	93.7	70.0	89.0	202.0	363.3	418.2	458.6	427.7	387.9	230.4	179.6	3,089
LA ERMITA	16.5	14.7	16.7	40.6	125.7	135.0	80.3	103.3	158.6	171.8	65.7	30.9	960
AGUA CALIENTE	14.6	11.1	17.7	52.2	166.9	227.2	168.4	169.8	212.3	157.8	53.7	26.0	1,278
PLAYITAS	9.4	6.4	6.4	44.8	105.0	162.2	102.1	121.2	180.4	105.0	35.4	13.1	891
SANTA ELENA	119.0	93.7	70.6	107.6	213.7	440.3	378.5	463.4	439.1	333.8	196.6	175.4	3,032
YURE	26.3	31.4	7.7	32.9	147.5	256.6	217.6	263.8	215.2	136.9	65.8	36.8	1,438
SAN JERONIMO	28.2	22.2	13.0	56.7	172.2	231.0	182.1	236.8	307.9	243.3	83.1	41.7	1,618
SAN NICOLAS	20.9	16.0	12.9	66.0	173.8	251.5	194.7	185.1	238.8	169.4	50.9	21.6	1,402
LAS BOTIJAS	54.1	18.5	13.2	44.9	169.9	170.1	129.3	136.2	188.7	151.6	73.3	60.7	1,210
LA LAGUNA	23.7	8.8	7.9	50.7	149.3	196.7	149.5	172.3	193.7	165.7	47.3	30.4	1,196
PORTILLO DE LA MORA	56.2	44.8	20.8	54.8	186.1	292.8	258.2	231.5	307.1	217.4	122.5	86.9	1,879
TUTULE	26.2	22.7	4.5	60.2	210.3	264.6	143.7	176.6	252.6	196.7	73.2	38.7	1,470
SULACO	10.0	9.1	8.8	44.7	123.9	181.9	148.3	162.1	187.2	126.6	47.2	15.3	1,065
VALLECILLO	46.6	21.1	39.0	101.6	203.3	266.8	222.5	268.2	320.4	271.0	101.2	65.2	1,927
ESQUIAS	21.0	13.2	11.7	47.9	161.9	248.2	205.5	200.2	254.4	146.2	58.9	24.1	1,393
SAN IGNACIO	23.6	17.1	12.8	31.7	123.0	142.8	114.6	128.0	176.3	206.3	66.1	40.6	1,083
MARALE	14.7	12.2	11.1	34.9	118.7	179.9	152.2	151.6	225.1	134.0	51.2	22.2	1,108
PALMITAL	189.0	84.5	47.2	114.2	237.1	395.2	372.3	374.2	387.6	299.7	202.2	208.5	2,912
SANTA FE DE TEGUCIGALPITA	56.3	29.8	30.7	43.9	156.7	334.3	316.2	319.4	305.9	220.1	122.2	64.8	2,000
TALANGA	22.9	29.9	21.7	33.1	146.0	156.9	117.1	98.0	167.7	137.5	55.5	43.0	1.029
PUEBLO NUEVO	46.7	20.5	7.6	45.3	127.4	370.4	320.0	292.2	289.0	205.0	122.2	46.7	1.893

Table 6-3 Monthly Average Temperature in El Cajon Dam Basin

(unit : ℃)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Avg.
TEGUCIGALPA TONCONTIN	19.4	20.3	22.0	23.3	23.4	22.5	22.0	22.3	22.1	21.4	20.3	19.5	21.5
EL CAJON	24.1	25.2	27.2	28.5	29.2	27.9	26.6	26.8	27.0	25.6	24.8	24.4	26.4
VICTORIA	23.4	24.4	27.1	28.3	28.7	27.1	26.3	26.4	26.3	25.4	24.2	23.3	25.9
EL TALADRO	23.1	23.8	25.2	26.3	26.6	25.5	25.4	25.4	25.0	23.7	23.1	22.5	24.6
FLORES	22.2	23.1	24.8	25.8	25.9	25.0	24.8	24.9	24.5	23.9	22.9	22.4	24.2
EL COYOLAR	21.4	22.5	24.6	25.7	25.7	24.4	24.4	24.5	23.7	22.8	21.9	21.2	23.6
COMAYAGUA	22.2	22.7	24.4	25.6	26.6	25.4	25.3	25.7	25.2	24.8	23.5	23.3	24.5
SANTA CLARA	20.9	22.0	24.0	25.4	25.4	24.1	23.7	23.7	23.5	22.8	21.7	20.7	23.2
LA ERMITA	20.8	22.0	24.3	25.7	26.0	24.4	23.6	24.0	23.9	23.1	22.0	20.9	23.4
AGUA CALIENTE	22.8	23.7	26.1	27.3	27.5	25.9	25.0	25.2	25.3	24.4	23.6	22.7	25.0
PLAYITAS	22.7	23.8	26.1	27.1	27.1	26.0	25.4	25.5	25.0	24.2	23.3	22.9	24.9
SANTA ELENA	19.7	20.5	22.3	23.4	24.3	23.5	22.8	22.8	23.1	21.7	20.6	19.9	22.0
YURE	24.6	25.4	27.9	29.2	29.7	28.3	27.2	27.3	27.5	26.5	25.5	24.8	27.0
SAN JERONIMO	22.6	23.5	25.7	27.3	27.6	26.6	25.6	25.9	25.8	24.8	24.1	22.9	25.2
VALLECILLO	19.5	18.5	20.9	23.0	23.6	22.8	22.2	22.6	22.3	21.4	21.2	18.9	21.4
MARALE	22.2	22.3	24.2	26.5	26.2	25.3	24.5	24.8	24.8	23.3	23.0	21.1	24.0

Table 6-4 Monthly Evaporation in El Cajon Dam Basin

(unit : mm)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
EL CAJON	102	131	186	193	202	171	157	165	146	123	103	98	1,778
VICTORIA	97	108	169	176	179	140	132	138	108	98	82	85	1,513
EL TALADRO	132	146	198	193	188	161	147	173	130	119	123	103	1,813
FLORES	149	177	228	215	183	143	158	160	133	132	118	137	1,933
EL COYOLAR	135	146	202	193	169	130	156	151	119	108	103	114	1,726
SANTA CLARA	89	110	169	172	160	121	117	124	115	110	85	76	1,449
LA ERMITA	129	148	217	229	198	158	149	157	145	129	109	114	1,882
AGUA CALIENTE	94	113	175	178	170	131	124	127	115	100	84	78	1,490
PLAYITAS	149	167	229	223	205	145	163	167	138	127	114	130	1,955
SANTA ELENA	86	99	143	144	144	145	146	148	141	110	82	80	1,468
YURE	117	142	204	195	192	160	159	162	139	132	106	110	1,819
SAN JERONIMO	112	138	203	192	182	161	139	144	129	109	93	94	1,696
VALLECILLO	80	77	160	168	147	110	120	150	110	97	85	70	1,374
MARALE	105	124	207	218	210	172	162	187	153	119	105	114	1,877

Table 6-5 Monthly Average Runoff in El Cajon Dam Basin

(unit : m3/sec)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Avg
LAS HIGUERAS	1.34	1.10	0.87	1.21	5.98	20.82	9.57	11.20	26.62	24.91	6.57	2.26	9.37
LA ENCANTADA	4.11	2.90	2.15	2.45	11.64	33.93	20.05	25.02	61.09	44.63	20.10	6.22	19.52
EL CAJON	38.86	29.59	24.03	22.60	52.81	174.10	131.20	146.66	265.04	296.56	145.77	58.33	115.46
GUACAMAYA	9.30	6.72	4.74	4.85	12.37	59.40	36.32	43.85	91.06	75.81	30.84	14.76	32.50
LAGUNETAS	68.98	62.02	52.62	44.33	65.74	168.06	138.15	172.51	234.31	240.24	119.62	94.14	121.73
PIEDRA PARADA	14.27	10.08	6.81	6.94	19.76	84.68	46.25	65.55	81.39	111.76	33.46	23.00	42.00
LAS VEGAS	2.11	1.60	1.25	1.03	1.26	3.78	4.54	5.09	10.49	7.38	5.15	3.13	3.90
SANTA CLARA	0.70	0.54	0.42	0.36	0.57	1.93	1.68	1.57	2.30	2.84	1.38	1.30	1.30
EL SARRO	16.13	12.64	9.96	11.83	22.10	78.67	55.86	63.36	114.91	103.01	42.53	24.04	46.25
LOS NARANJOS	21.35	16.99	12.62	12.58	24.36	72.35	55.67	68.09	126.94	157.78	88.56	30.46	57.31
SIALE	1.43	1.19	0.95	1.35	5.03	5.38	3.02	3.97	7.76	9.81	4.21	1.91	3.83
EL JICARO	16.12	12.38	9.15	8.50	17.55	49.07	68.64	77.24	106.35	70.07	41.35	21.81	41.52
AGUA CALIENTE	9.69	7.77	6.10	6.45	12.25	42.02	29.99	33.72	55.43	65.31	29.34	14.59	26.05
LOS ENCUENTROS	11.30	8.51	6.08	8.06	16.65	48.21	35.12	40.28	66.15	88.75	37.48	18.00	32.05
EL DESMONTE	0.89	0.74	0.60	0.57	0.58	1.84	1.34	1.31	2.07	2.03	1.58	1.23	1.23
AGUA BLANCA	3.42	3.40	2.30	2.17	3.25	6.45	7.29	11.85	10.91	12.23	4.83	5.12	6.10
SAN NICOLAS	0.72	0.66	0.61	0.58	1.29	5.98	5.08	6.03	8.66	7.02	2.09	1.03	3.31
TALANGUITA	0.42	0.29	0.19	0.15	0.72	3.84	0.99	1.68	8.84	5.13	1.69	0.77	2.06
MARAGUA	2.73	2.34	1.34	0.97	1.77	4.82	10.53	13.76	16.73	14.82	8.38	4.98	6.93

Table 6-6 Monthly Average Runoff at El Cajon Gauging Station
Compensated by Daily Runoff at Lagunetas Gauging Station

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Avg.
1970	42.84	39.68	30.49	27.98	36.41	99.43	261.55	351.11	429.30	410.48	178.87	90.81	166.58
1971	54.00	37.82	25.57	21.07	37.69	53.79	69.10	174.66	235.40	254.65	86.68	45.51	91.33
1972	32.08	25.36	20.21	21.55	34.89	51.11	52.57	108.81	150.82	218.45	78.69	41.52	69.67
1973	28.35	25.83	17.53	18.50	50.26	109.67	101.27	115.98	149.13	203.45	76.62	36.54	77.76
1974	26.62	20.73	18.43	19.27	41.05	87.59	105.05	115.61	475.33	343.94	73.46	35.56	113.55
1975	29.45	22.89	17.71	14.24	23.19	76.61	23.71	47.55	363.16	378.42	395.93	75.72	122.38
1976	54.50	39.88	24.11	31.49	36.26	471.30	141.46	121.69	120.55	224.54	94.55	74.63	119.58
1977	41.42	32.19	23.71	21.97	48.86	220.36	81.61	107.54	106.55	79.81	74.87	43.61	73.54
1978	34.40	31.09	20.86	20.95	56.15	102.69	175.62	136.83	210.32	161.15	80.49	67.35	91.49
1979	35.75	24.40	21.30	29.23	40.49	235.50	196.72	197.22	296.17	382.00	125.39	60.77	137.08
1980	39.45	27.11	21.69	20.55	25.98	179.36	119.90	131.26	225.39	208.54	146.71	57.04	100.25
1981	37.29	30.78	23.16	18.99	19.85	239.23	161.04	354.01	440.42	228.73	87.65	56.65	141.48
1982	36.03	28.32	23.97	18.99	80.02	197.54	123.32	143.83	183.31	199.09	101.20	55.60	99.27
Avg	37.86	29.70	22.21	21.91	40.85	163.40	124.07	162.01	260.45	253.33	123.16	57.02	108.00

Table 6-7 Synthetic Monthly Average Runoff at El Cajon Gauging Station

(unit : m3/sec)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Avg.
1	41.57	31.28	20.96	23.39	8.49	240.29	53.48	74.33	384.96	281.64	252.23	65.81	123.20
2	40.73	36.10	21.93	19.61	33.01	148.72	225.84	176.88	248.03	178.78	103.89	60.04	107.80
3	35.59	31.43	24.81	28.31	61.41	265.20	92.56	202.49	304.11	210.88	108.30	56.55	118.47
4	37.35	25.30	18.19	22.05	37.83	324.74	217.19	227.42	208.87	283.77	124.08	40.14	130.58
5	28.29	25.18	20.50	29.81	37.26	37.39	81.72	160.87	101.93	177.40	71.45	39.80	67.63
6	29.02	22.50	20.22	26.49	28.32	90.96	136.61	112.43	251.01	241.73	25.94	58.50	86.98
7	38.42	32.98	24.81	19.82	35.89	45.12	55.59	115.00	325.52	226.63	114.67	62.09	91.38
8	36.28	37.86	23.88	22.86	51.44	103.21	74.06	85.68	203.29	241.25	66.76	78.37	85.41
9	45.54	35.71	26.68	23.82	34.49	117.23	66.14	131.68	195.96	241.05	155.65	43.70	93.14
10	32.36	24.15	21.18	17.59	62.53	246.31	60.47	162.26	240.84	216.65	165.97	53.64	108.66
11	36.74	27.50	21.13	21.41	27.49	192.58	182.24	178.54	323.34	301.14	151.35	56.17	126.64
12	36.09	28.72	23.28	23.62	46.92	183.00	211.24	271.46	266.65	270.07	115.19	44.87	126.76
13	30.45	28.60	22.91	22.39	53.36	98.04	159.28	123.62	513.33	295.33	244.92	57.25	137.46
14	37.56	26.21	22.69	24.51	51.85	126.83	133.68	152.89	148.40	292.52	94.07	47.14	96.53
15	30.48	24.81	17.42	22.46	60.36	105.64	117.23	106.17	144.84	257.72	88.43	72.52	87.34
16	44.72	32.24	21.66	18.82	33.02	73.19	112.70	33.63	217.43	177.51	72.21	46.43	73.63
17	31.96	23.79	17.50	14.50	27.18	154.72	65.76	30.77	199.25	283.77	139.41	66.60	87.93
18	44.96	33.03	25.97	23.22	66.46	13.58	136.38	117.47	265.76	220.82	148.89	82.72	98.27
19	51.10	38.83	26.97	27.31	21.69	181.79	132.63	103.53	313.62	231.97	103.46	70.79	108.64
20	45.00	35.92	25.97	31.30	47.52	166.45	49.79	45.76	88.62	145.49	67.97	64.38	67.85
21	43.83	35.28	23.77	31.64	53.87	235.75	166.55	350.52	410.08	310.87	212.57	38.97	159.48
22	28.88	21.82	19.35	14.95	23.98	192.53	86.53	92.41	156.31	113.82	3.23	39.33	66.10
23	28.35	22.19	11.71	9.78	42.32	257.90	58.98	81.62	91.79	168.60	118.35	63.52	79.59
24	38.26	31.15	21.75	17.60	40.34	305.46	209.47	247.00	311.87	258.48	184.14	48.09	142.80
25	31.41	28.04	24.78	28.49	53.18	30.25	32.49	14.12	208.04	274.00	171.15	57.50	79.45
26	40.67	29.36	23.33	28.79	67.86	389.57	212.44	283.71	343.92	298.80	141.36	69.85	160.81
27	44.70	33.42	20.87	28.10	22.11	67.69	66.53	78.99	297.55	303.22	137.89	72.13	97.77
28	44.68	32.75	20.75	19.66	33.23	109.46	92.60	138.65	160.59	148.28	65.77	20.65	73.92
29	19.81	14.62	13.86	17.75	33.04	174.29	90.78	95.56	234.52	246.61	91.32	44.26	89.70
30	31.88	23.70	19.94	22.52	72.29	118.12	235.77	205.01	215.60	215.38	42.27	45.89	104.03
31	28.25	21.27	18.48	18.88	63.33	443.99	197.87	232.56	255.07	232.02	223.30	57.18	149.35
32	39.35	31.41	25.57	18.33	20.43	83.08	224.74	254.87	296.12	282.46	55.61	52.95	115.41
33	31.62	25.21	17.57	17.52	46.56	43.66	160.47	200.67	257.76	263.38	170.87	41.28	106.38
34	31.04	19.15	20.93	18.69	29.60	103.99	64.16	158.14	156.95	177.77	42.85	37.71	71.75
35	30.02	23.61	15.27	15.58	66.98	236.01	191.27	237.89	320.90	380.74	223.12	76.87	151.52
36	46.64	33.68	24.87	22.86	27.49	66.56	81.39	128.50	224.02	294.27	292.57	87.13	110.83
37	53.15	46.86	29.09	28.78	26.51	188.92	181.59	298.51	313.71	252.53	61.48	58.97	128.34
38	34.30	25.39	20.42	15.11	39.27	40.73	39.48	130.07	426.01	493.06	265.08	65.89	132.90
39	38.96	29.20	20.71	19.66	11.22	280.56	89.92	115.35	359.93	263.27	5.53	57.77	107.68
40	36.79	29.81	24.90	32.34	40.92	122.53	120.29	162.93	404.78	348.03	193.59	55.01	130.99
41	40.85	33.16	26.27	17.82	28.38	117.67	111.93	201.29	218.29	339.11	217.22	59.78	117.65
42	38.21	25.77	21.22	16.06	64.18	93.02	101.81	207.12	205.20	295.59	106.47	60.16	102.90
43	39.23	31.93	25.35	26.27	41.07	192.93	164.42	186.16	249.91	294.39	168.81	57.99	123.20
44	38.25	31.78	20.67	21.95	31.85	424.67	223.64	148.45	220.40	135.95	67.79	37.29	116.89
45	26.37	23.04	18.41	17.02	28.92	224.54	104.62	105.10	279.18	283.29	206.15	58.55	114.60
46	41.18	34.09	25.18	21.21	67.45	102.25	82.37	66.68	151.00	177.90	42.41	25.37	69.76
47	24.16	23.47	20.64	27.34	13.99	371.58	94.44	200.63	283.29	289.63	238.09	61.02	137.36
48	41.78	37.83	24.05	22.11	50.53	271.32	198.63	205.59	236.20	199.87	83.55	59.46	119.24
49	40.17	38.06	22.32	25.56	36.67	129.18	134.65	192.04	376.03	373.22	140.84	48.10	129.74
50	34.55	27.70	22.63	21.67	58.00	194.46	152.36	217.03	487.88	364.57	224.29	92.22	158.11
Avg	36.83	29.34	21.87	22.15	41.24	170.55	126.74	157.00	261.97	257.10	132.25	56.37	109.45

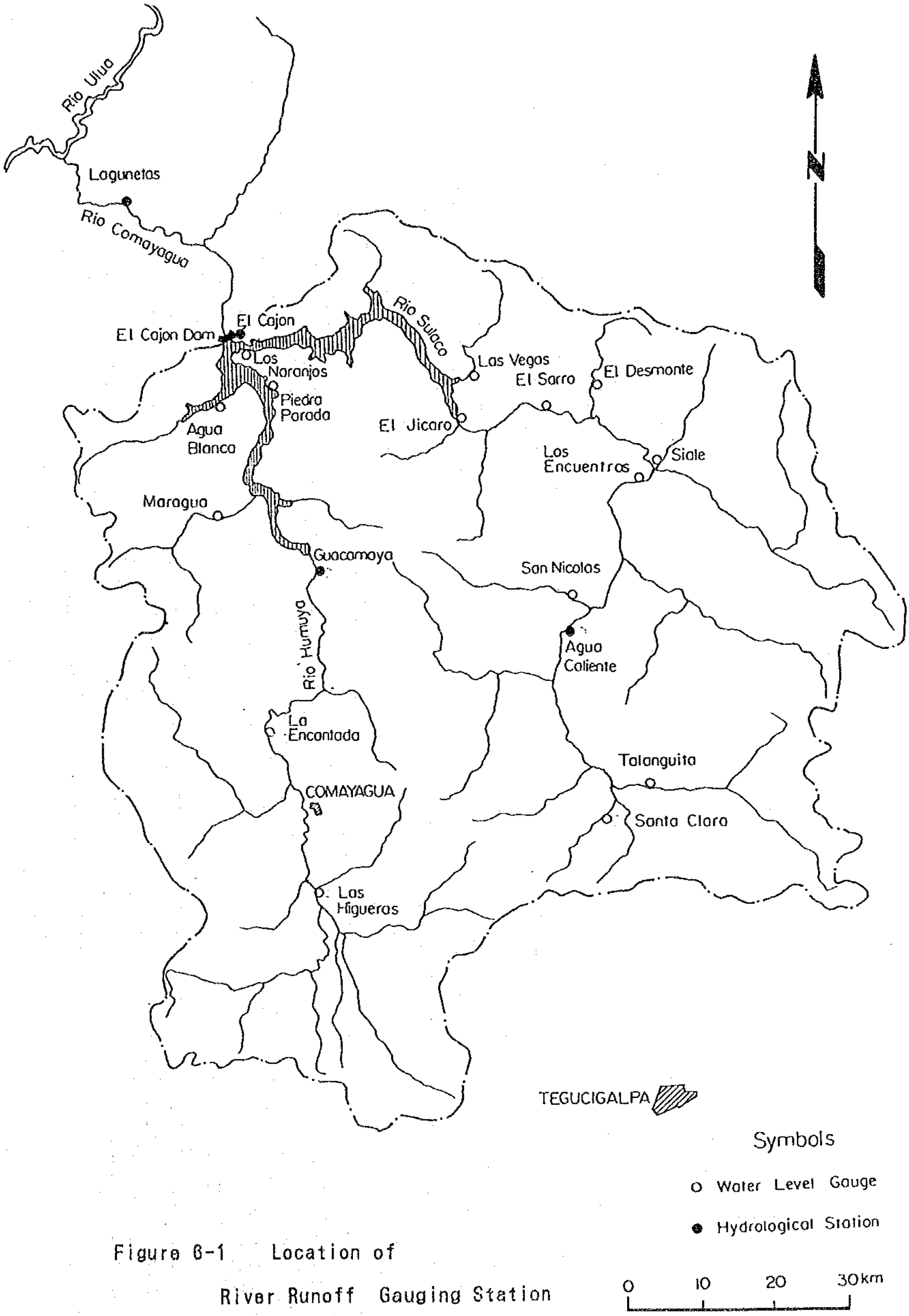

Figure 6-1 Location of River Runoff Gauging Station

Station		Latitude	Longitude	Elev. (m)	CA (km^2)	Year																																				
						1954	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Las Higueras	DSHC	14°20'06"N	87°38'04"W	580	1,147		—	—	—	—	—	4				12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8		
La Encantada	DSHC	14°32'47"N	87°41'41"W	505	2,078	12	4	5	—	—	4					12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	
* El Cajon	ENEE	15°02'32"N	87°44'44"W	102	8,614													9	—	—	8	7	—	—	—	—	—	4							11	9						
Guacamaya	DSHC	14°44'17"N	87°38'12"W	321	2,570															9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	
Lagunetas	ENEE	15°11'41"N	87°52'27"W	55	10,205																7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7
* Piedra Parada	ENEE	14°57'00"N	87°43'00"W	105	3,679																		8	—	—	—	—	—	—	—	—	—	—	—	7							
Las Vegas	DSHC	15°00'15"N	87°26'20"W	380	393														9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8		
Santa Clara	DSHC	14°26'28"N	87°16'46"W	725	55														9	—	—	—	4					10	—	—	8	9	—	—	—	—	—	8				
El Sarro	DSHC	14°56'20"N	87°22'24"W	337	3,372																		9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	
* Los Naranjos	ENEE	14°57'00"N	87°44'00"W	120	4,618																		8	—	—	—	—	—	—	—	—	—	—	—	7							
Siale	ENEE	14°51'29"N	87°12'07"W	453	586																		4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
El Jicaro	ENEE	14°55'18"N	87°27'12"W	300	3,535																																	6	—	—	8	
Agua Caliente	DSHC	14°40'19"N	87°18'58"W	537	1,573															9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	
Los Encuentros	ENEE	14°49'00"N	87°12'33"W	446	2,658																		4	—	—	—	—	10		8	—	—	—	—	8	9	—	—	4			
El Desmonte	DSHC	14°57'21"N	87°17'12"W	445	443														9	—	—	—	—	—	—	—	8	9	—	—	—	—	—	—	—	—	—	—	8			
* Agua Blanca	ENEE	14°50'00"N	87°45'00"W	150	224																		5	—	—	—	—	—	—	—	—	—	—	—	—	10						
San Nicolas	DSHC	14°42'23"N	87°18'52"W	550	225																9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	
Talanguita	DSHC	14°28'38"N	87°13'11"W	600	584																											9	—	—	—	—	—	8				
Maragua	ENEE	14°48'26"N	87°44'58"W	310	225																																			9	—	4

Figure 6-2 Measurement Period of Daily River Runoff

* Not working now

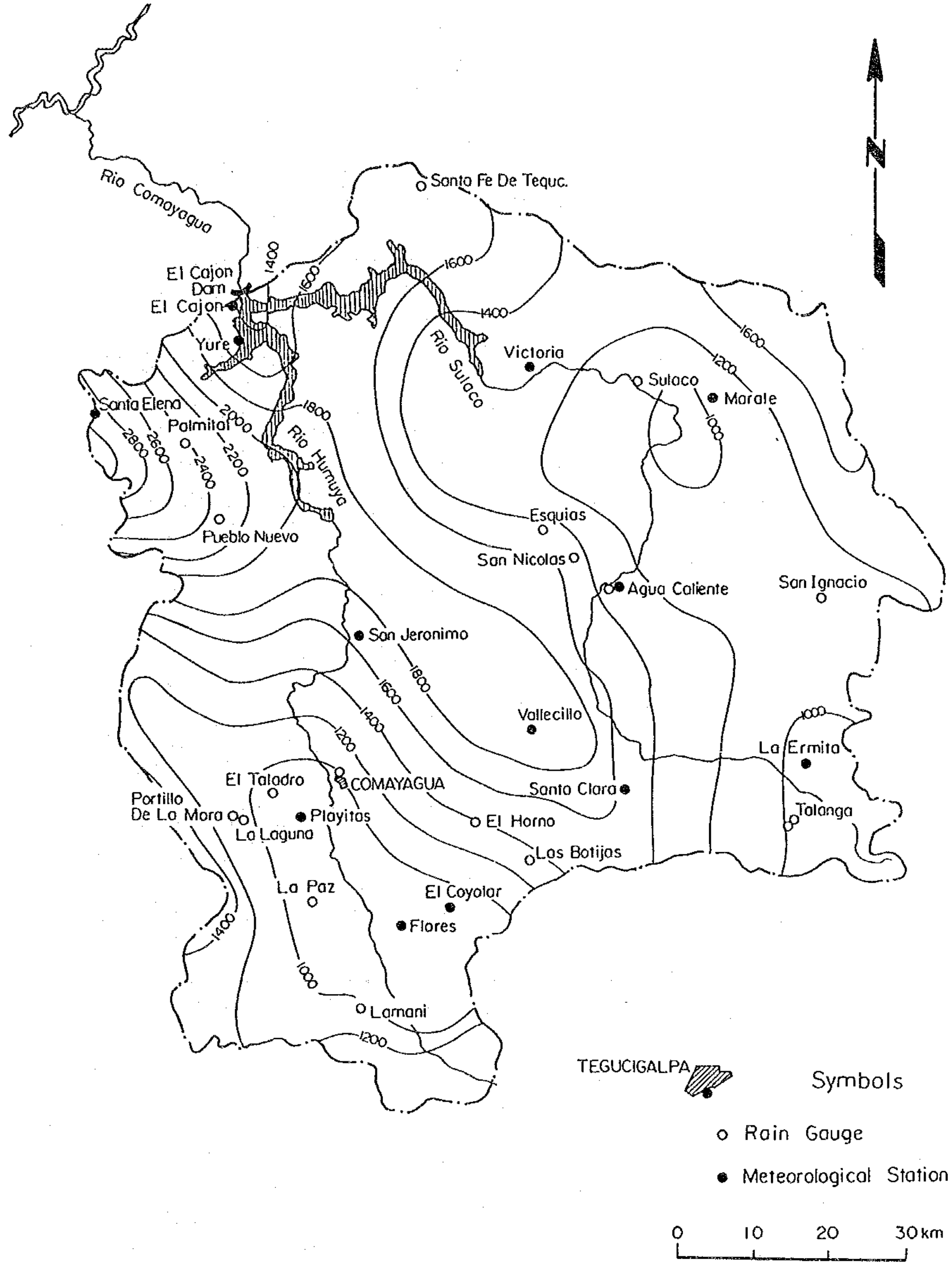

Figure 6-3 Location of Meteorologigal Gauging Stations and Isohyetal Map of El Cajon Dam Basin

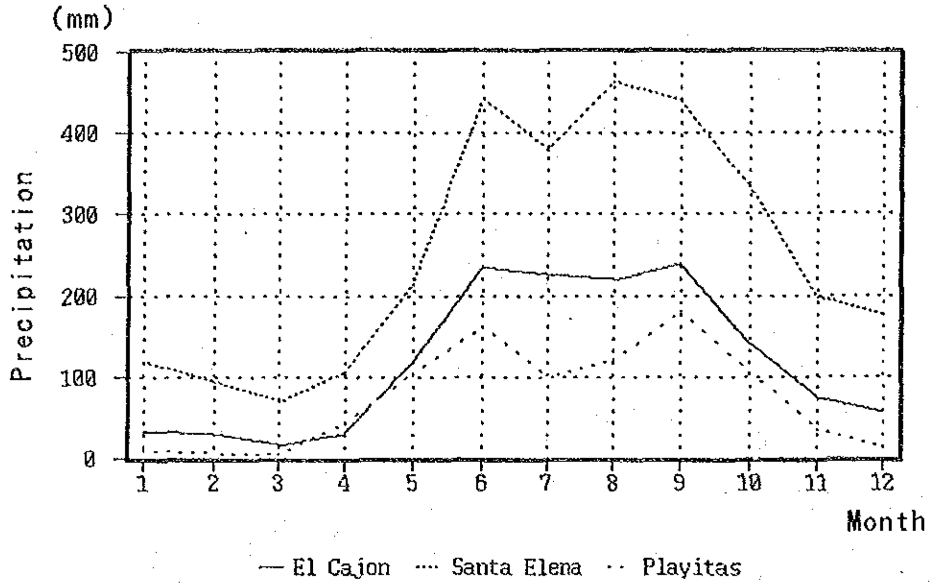

Figure 6-4 Monthly Precipitation in El Cajon Dam Basin

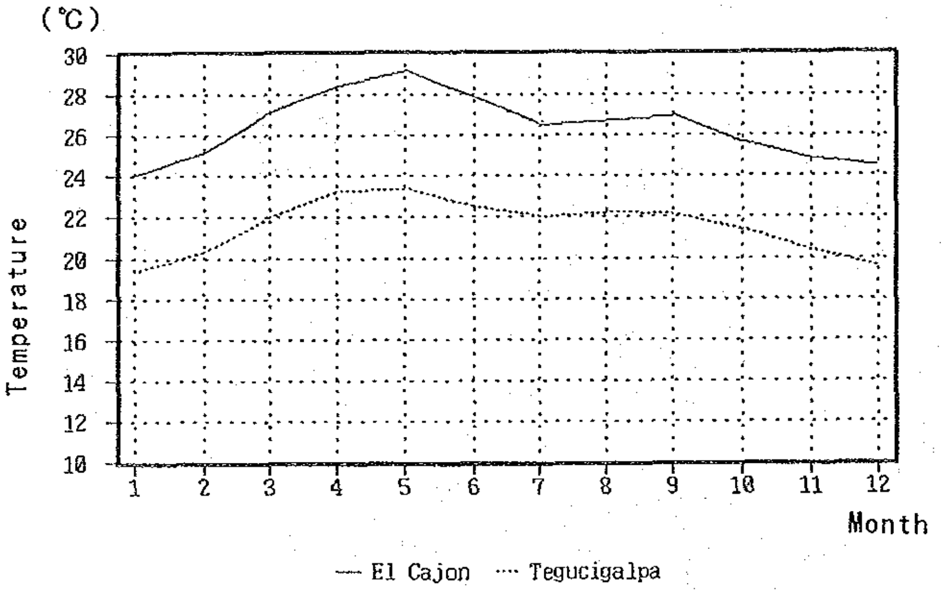

Figure 6-5 Monthly Average Temperature in El Cajon Dam Basin

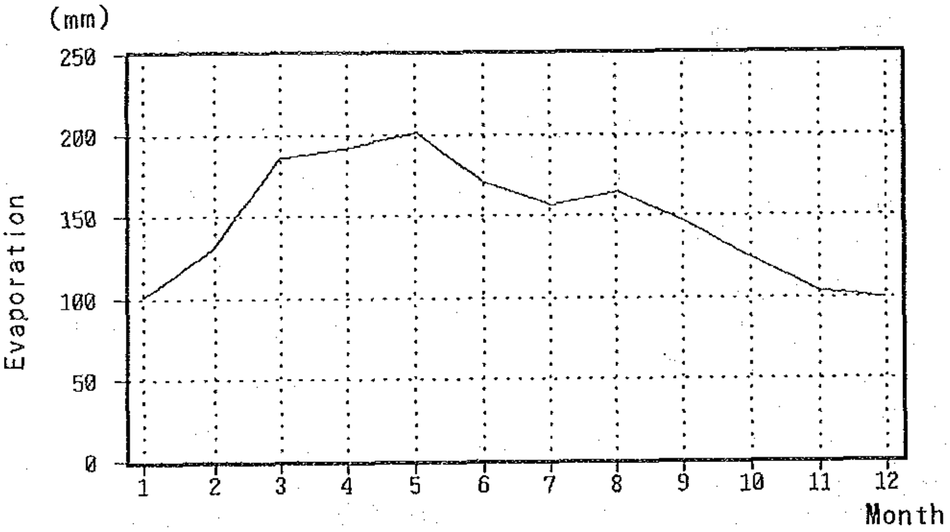

Figure 6-6 Monthly Evaporation at El Cajon Gauging Station

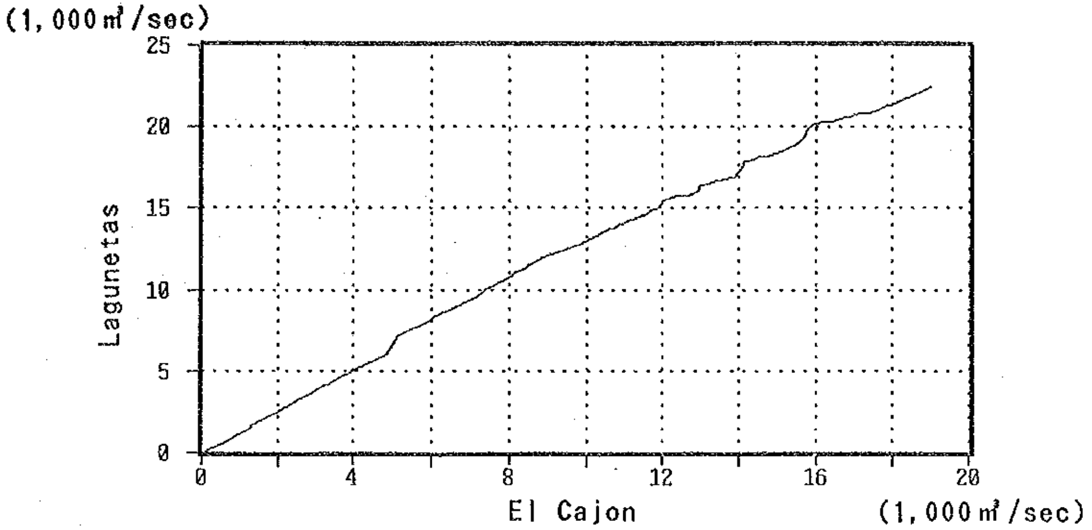

Figure 6-7 Double Mass Curve of Monthly Average Runoff at El Cajon and Lagunetas Gauging Stations

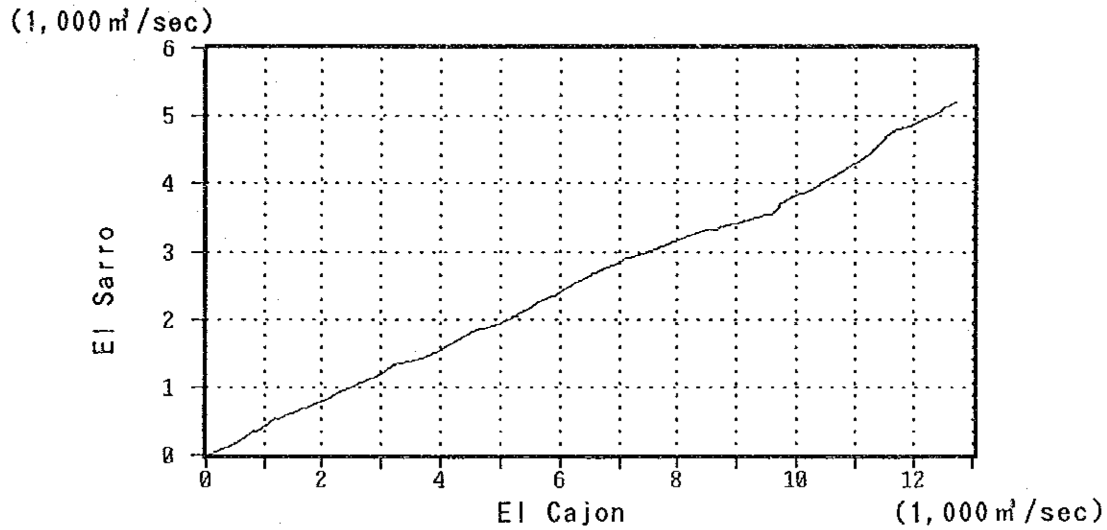

Figure 6-8 Double Mass Curve of Monthly Average Runoff at El Cajon and El Sarro Gauging Stations

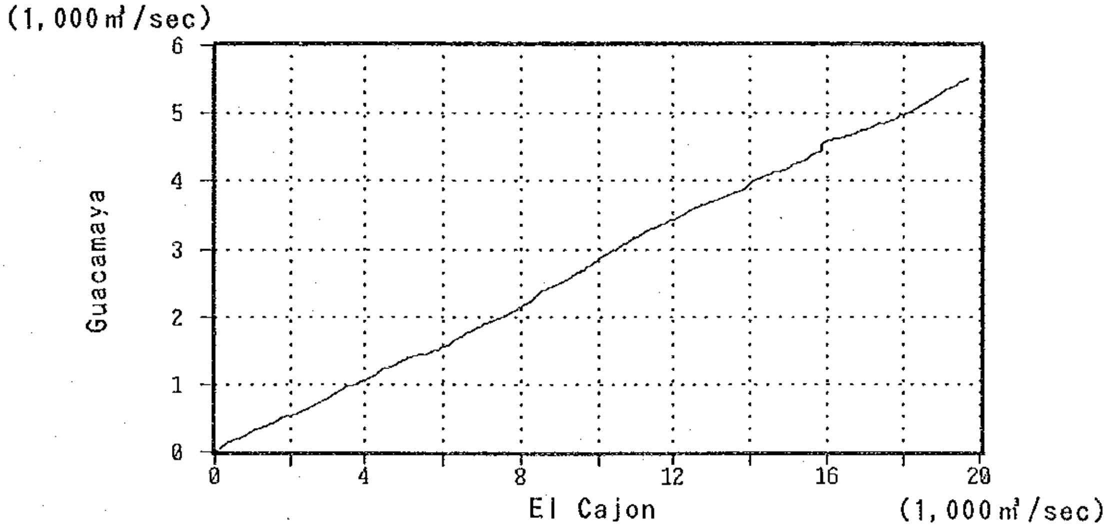

Figure 6-9 Double Mass Curve of Monthly Average Runoff at El Cajon and Guacamaya Gauging Stations

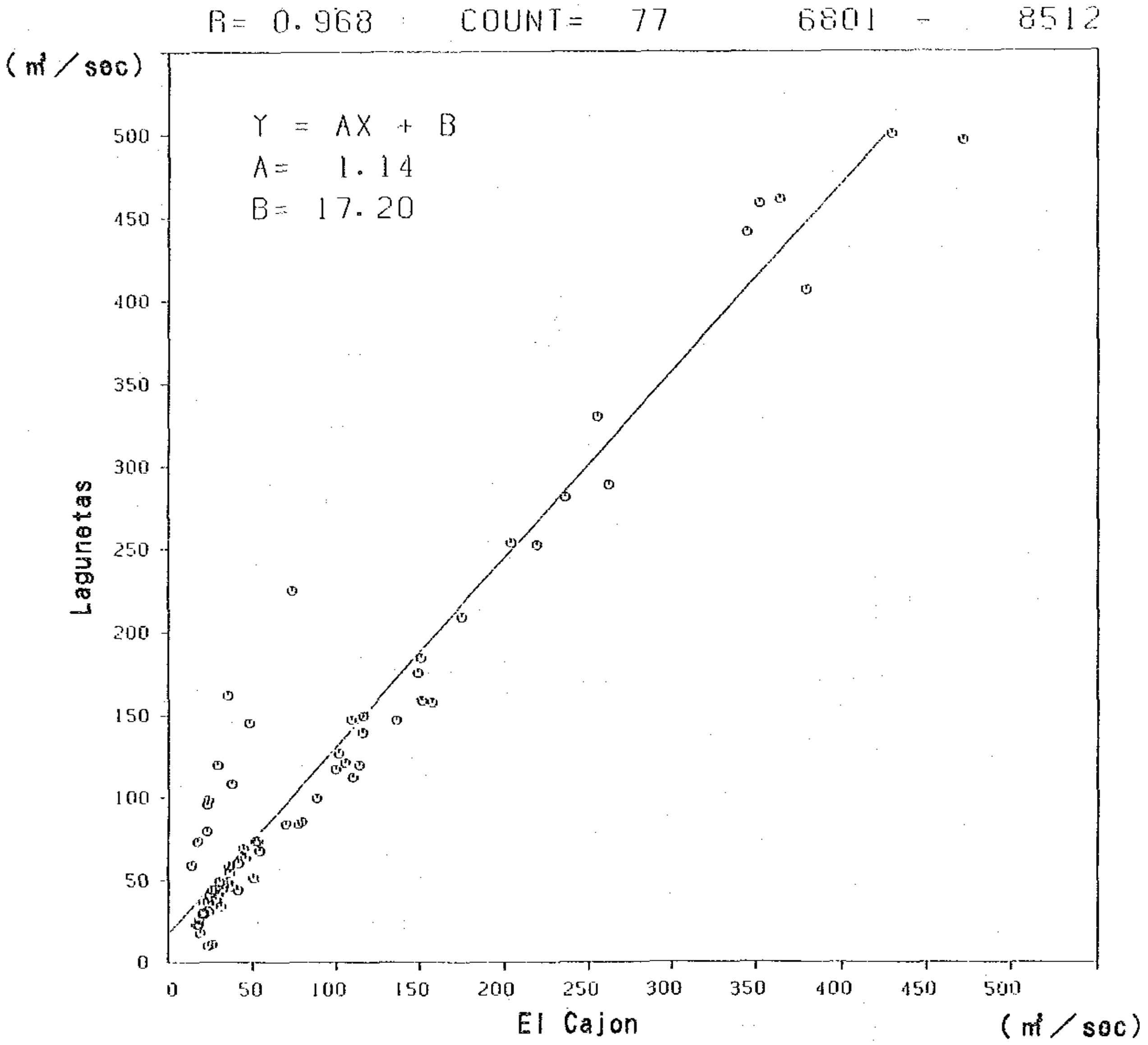

Figure 6-10 Correlation between Monthly Average Runoff at El Cajon and Lagunetas Gauging Stations

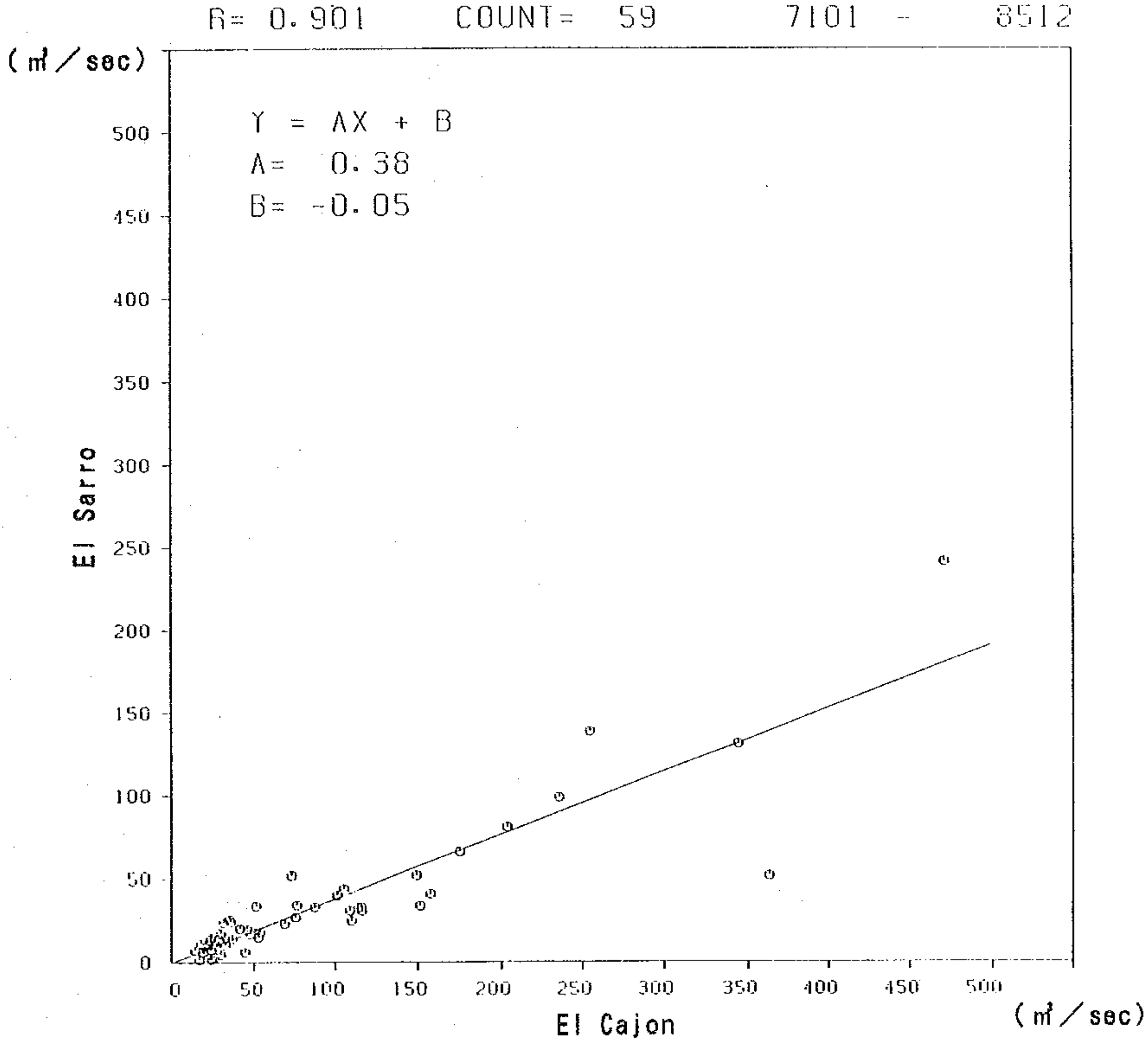

Figure 6-11 Correlation between Monthly Average Runoff at El Cajon and El Sarro Gauging Stations

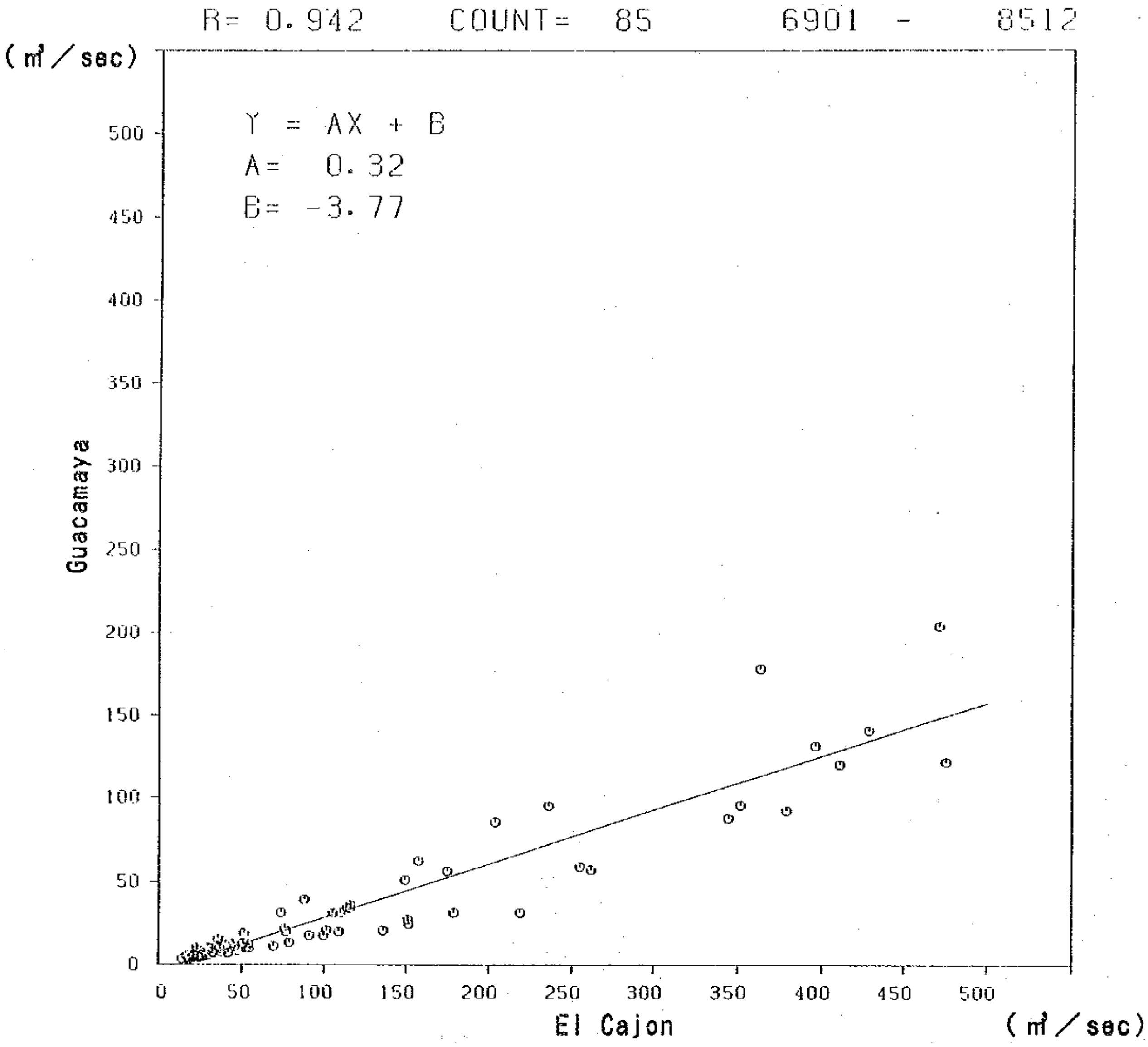

Figure 6-12 Correlation between Monthly Average Runoff at El Cajon and Guacamaya Gauging Stations

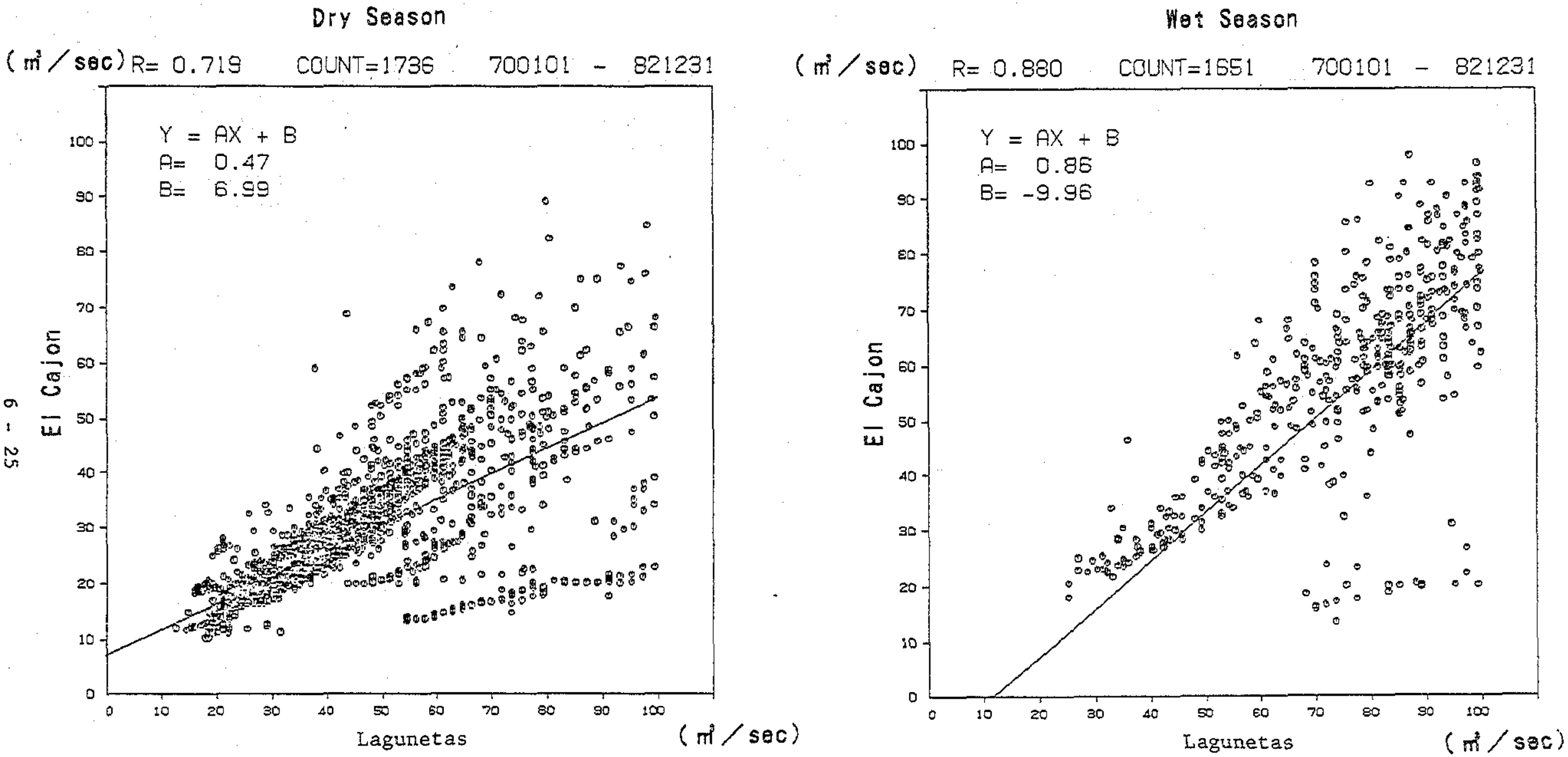

Figure 6-13 Correlation between Daily Runoff at El Cajon and Lagunetas Gauging Stations

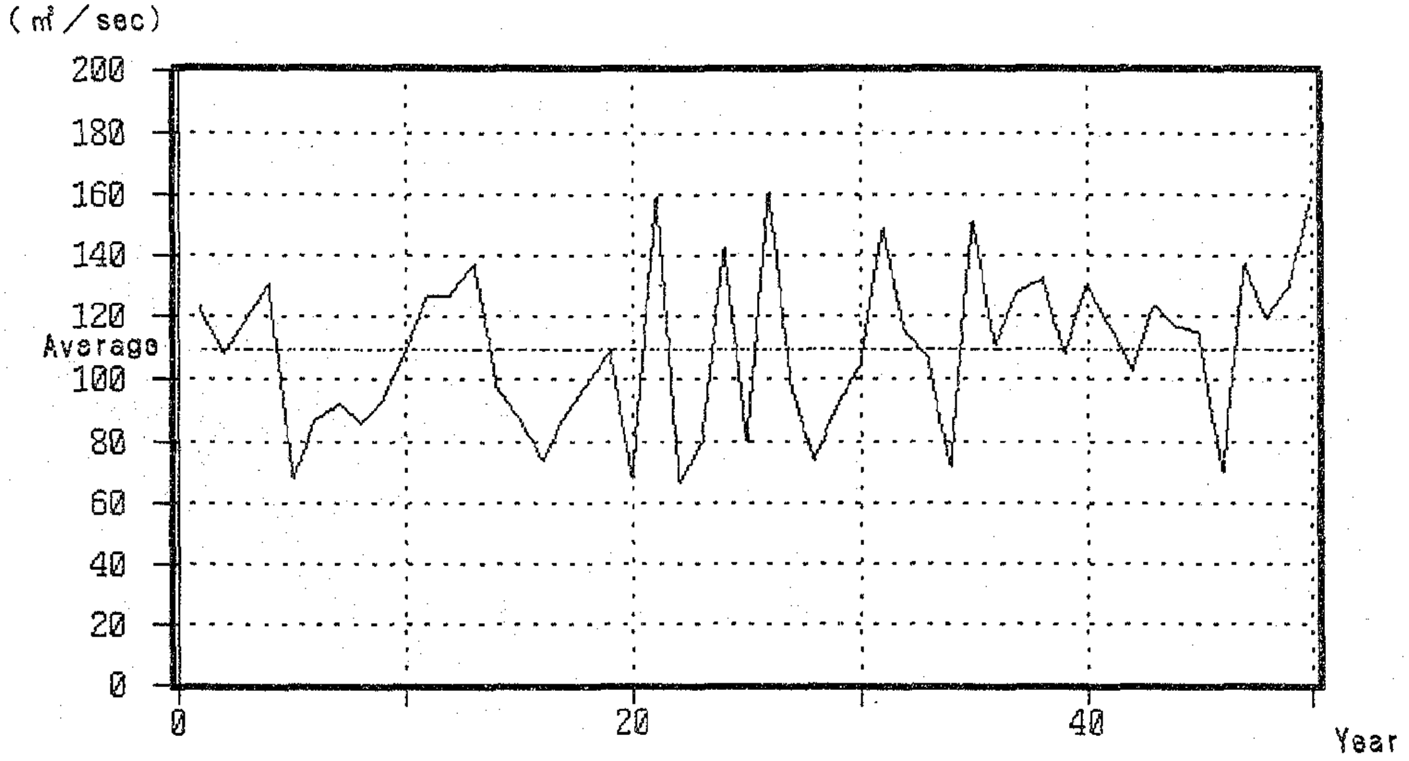

Figure 6-14   Synthetic Annual Average Runoff at El Cajon Gauging Station

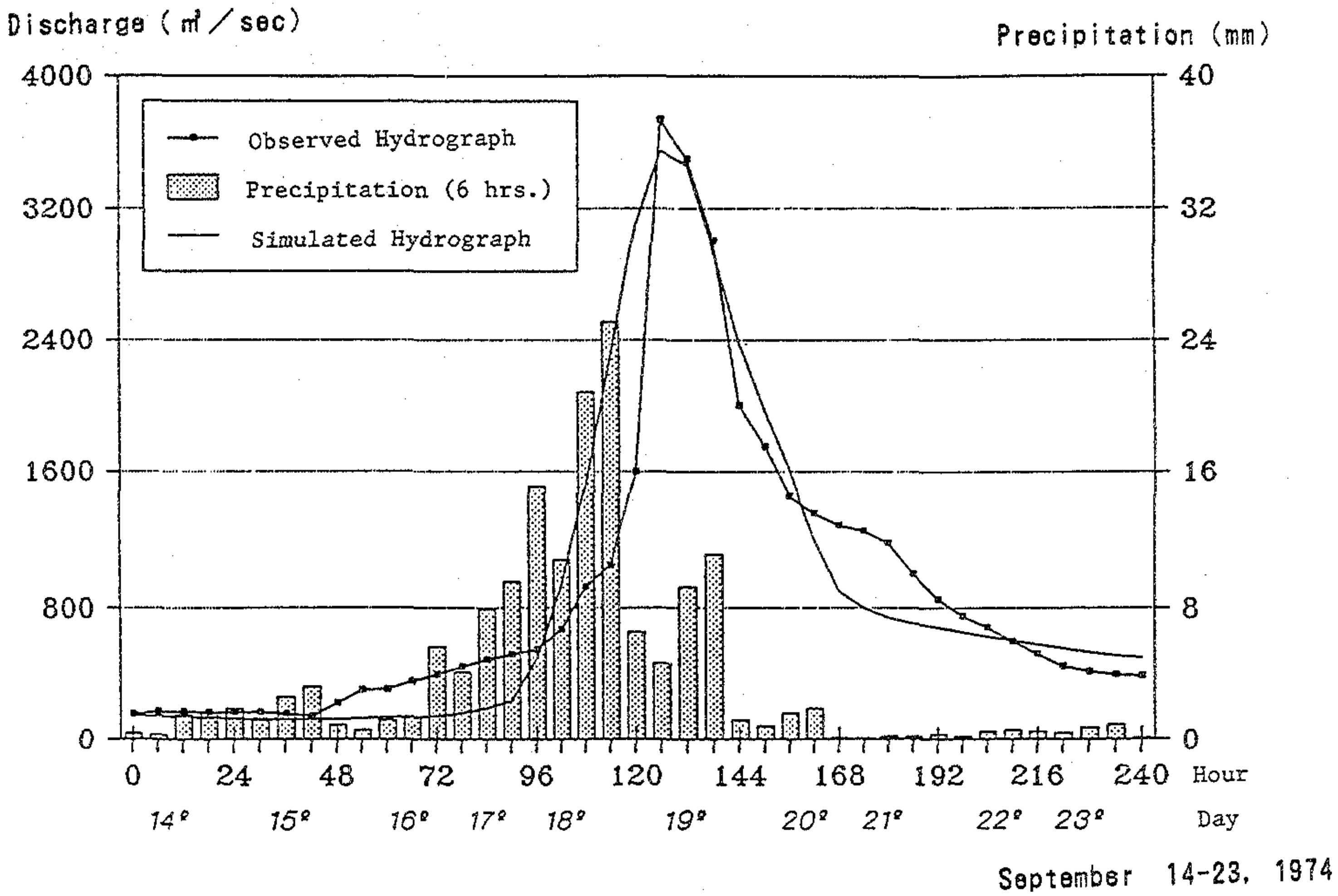

Figure 6-15 Precipitation and Hydrograph of Hurricane "Fifi"

Chapter 7 GEOLOGY

Chapter 7

GEOLOGY

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Chapter 7 GEOLOGY

7.1 Introduction

To fully understand the geological conditions of the El Cajón Amplification Project area and to facilitate its design and construction, the available information has been collected and analyzed; as well, a site-observation has been carried out.

The hydraulic circuit and the powerhouse to be amplified are planned to be constructed adjacent to the existing structures. Therefore, it is of prime importance that the geological and geotechnological information obtained through the previous construction should be collected and organized in order to utilize for the Amplification Project. Geological data have been compiled with this point in view.

7.2 General Geology

7.2.1 Topography

The El Cajón Amplification Project area is situated approximately 2 km downstream of the joint of the Humuya and the Sulaco Rivers. The area is located in a mountainous area with an average altitude of approximately 600 to 1,000 m, and characterized by flat ridges and gentle slopes. The altitude of the river bed of the Humuya River is approximately 100 m, and the high water level of the El Cajón Reservoir is 285 m. The slopes on both banks from the dam to 15 km downstream are steep. Especially, the gorge amplifies downstream of El Cajón Dam site for some 500 m. The amplification structure is planned to be installed underground of a steep slope on the left bank located downstream of the dam.

7.2.2 General Geology

The geology of the El Cajón Project area consists primarily of the Yojoa Group of the Cretaceous period, irregularly covered by volcanic rocks of the Tertiary or the Quaternary period (**Fig. 7-1, Table 7-1**).

The Yojoa Group consists of the Cantarranas Formation, the Atima Limestone, and the Guare Formation. The Cantarranas Formation consists of clayey marl, the Atima Limestone of thick bedded limestone, and the Guare Formation of thin bedded limestone and marl, respectively. The El Cajón Amplification Project Area is underlain by Atima limestone, which is exposed at the gorge in the vicinity of the dam site.

Generally, Atima Limestones are of grayish-brown to dark-brown color, weathered to a light grey, and partially contain large amounts of lamellibranchia and gastropods and everywhere microfossils. Certain zones include nodules or layers of chert, others appear dolomitized.

The Volcanic Rocks surround Atima Limestone exposures of El Cajón on all sides, covering the limestone. At the upstream end of the gorge, they are directly exposed at the river, then ascending downstream on both sides forming the chains of hills flanking the gorge. Downstream of the El Cajón gorge, the Volcanic Rocks come again down to the river.

The Volcanic Rocks comprise a variety of different rocks. Lavas, tuffs, and agglomerates of andesitic composition are quite frequent and mostly of red, reddish-brown or, more seldom, green color.

Among the existing civil structures, the dam, the underground powerhouse and most sections of the hydraulic circuit as well as the quarry site are located in or on the Atima Limestone. Also, all of the amplification structures are planned to be built in this limestone.

7.3 Outline of Geological and Geotechnological Study

During this study, the information materials were collected, a site investigation was carried out, and the organization and analysis of the collected data were executed.

7.3.1 Data Collection

The geological data and reports collected in relation to El Cajón are shown on **Table 7-2**. Collection of many valuable information materials was possible through a full-scale cooperation of the ENEE counterpart. We were also able to obtain a significant volume of the construction reports and their appendixes concerning the geology and behaviors of the rock mass during the previous construction.

7.3.2 Site Investigations

A series of site investigations were conducted from June to July 1992 at the following sites:

- Existing structure sites:
  - Dam : Both Abutments, downstream river bed
  - Underground powerhouse : Main unit, access tunnel
    Santa Barbara Tunnel
  - Quarry site
- Amplification structure sites:
  - Underground powerhouse : Santa Barbara Tunnel
  - Tailrace Tunnel : Santa Barbara Tunnel
  - Outlet : Observation from the right bank

At the dam site, from the crest of the dam and at the river bed, the surfaces of foundation rock of the dam were observed. In the vicinity of the underground powerhouse, in addition to the main station and the access tunnel, the unlined Santa Barbara Tunnel were investigated to prepare geological sketches. Besides, the quarry site was also investigated.

7.3.3 Arrangement and Analysis of the Investigation Results

Field investigation and existing excavation relating to the amplification are shown in **Table 7-3～5**.

Among the information materials that were collected, the boring data related to the Amplification Project was compiled and edited in a form of a summarized geological log (See **Fig. 7-4** and **7-5**), while the geological records of adits and existing structure sites were compiled into plans (See **Appendix Fig. 1** and **2**) and profiles. Furthermore, the problems and countermeasures for each structures shown on individual reports, at the study and construction phases, were also summarized.

On the basis of the investigation results, the geology and engineering geology of the amplification structure sites were studied and evaluated.

7.4 Geology of Amplification Project Area

Fig. 7-2 and **7-3** show the geology of the El Cajón Amplification Project area (around the existing dam and the powerhouse).

The El Cajón Amplification Project area is located in the valley formed by the Humuya River. The depth of the valley is approximately 500 m, and the altitude of its river bed is approximately 100 m, and high water level of the reservoir is 285 m. The valley is flanked by 70° or steeper slopes rising some 200 meters above river bed. The slopes located above these steep portions are not so steep, with a gradient less than 50°. The structures of the Amplification Project are planned to be built in the hillside on the left bank downstream of the dam.

While, vicinities of this valley are covered mostly by volcanic rocks, in the valley Atima Limestone distributed in the section with a length of about 800 meters surrounding the dam site. The structures of the Amplification Project are scheduled to be built in Atima Limestone.

The Atima Limestones are extremely thick, measuring more than 700 m. From bottom to top they can be divided into 4 different lithologic units, shown below.

Massive Sublithographical Limestones

This unit is more than 400 m of thickness form the lowest recognized beds. Partly there seems to be no stratification at all but where it is discernible, the beds reach a thickness of several meters.

Limestones with Chert

This unit is 45 - 50 m thick. The black chert nodules appear embedded in the limestone in form of genuine layers. The limestone itself has a sublithographical texture but shows well developed bedding in sequences of 0.5 - 3 m.

Thin Bedded Sublithographical Limestones

This unit is 100 - 120 m thick. The bedding planes are well visible in the outcrops. The bedding thickness ranges from 0.2 to 2.0 m. Unlike the underlying Limestones with Chert, the Thin Bedded Limestones of this sequence are quite rich in fossils (lamellibranches, gastropods).

Dolomitic Limestones

This unit is the top layer and 140 m thick. Bedding is clearly visible, the individual beds attaining a thickness of approximately 5 m. They exhibit a spathic texture differing clearly in the hand-specimen size from the underlying Sublithorgrphical Limestones.

The volcanic rocks overlie the Atima Limestones with strong discordance. They comprise a variety of different mainly effusive rocks of dacitic to andesitic composition.

The alluvials encountered in the river bed consist of gravel and sand. Terrace deposits composed of fine-grained older river materials were partly encountered. Scree (talus deposits) partly covers valley slopes.

The limestone beds generally dip as a more or less uniform thicklayer in a NNW direction: In the southern part of the gorge the dip ranges between 15 - 20° increasing toward the northern end of the gorge up to 35°. In the whole it forms the northern branch of a simple anticline. The volcanic rocks lying discordantly over the limestones are throughout dipping with 20° to 30° southward.

The entire limestone formation is cut by several large, vertical to subvertical faults. Important ones amplify throughout the whole gorge in a N-S to NNW-SSE direction, more or less parallel to the gorge. The most important fault in the Amplification Project Area is Fault IV which is subvertical and amplifies in a NNW-SSE direction. A second subordinate system trends approximately W-E but is rather rare.

These faults are very well recognizable both at the surface and in the drillholes, adits, and confirmed during the excavation of existing civil structures. Their thickness varies from some cm up to 15 m, the gaps are mostly filled with calcite, some parts clay deposits and karst occurrences.

Beside the big faults the rock mass is marked by different systems of discontinuities, dipping all with a few exceptions almost vertically. the most frequently observed system trends practically parallel to the big faults and, therefore, parallel to the canyon.

Atima Limestone constitutes excellent rock mass from the standpoint of rock mechanics.

The foundation for the arch dam was placed on this limestone and the large cavern for the underground powerhouse was excavated in this limestone. However, because the limestone is easily karstified, providing an increased permeability, water tightness of the reservoir was a big task to be proved in the F/S and construction stages of the existing project. At the Damsite due to the characteristics of the limestone an extensive grouting was executed.

7.5 Geology of the Structure Sites

General layouts for individual structures of the Amplification Project have already been decided in the Definite Study of the existing project. Thereafter, the existing structures were successfully constructed, the geological condition for these structures were confirmed to be as expected, and no problems has been found in maintaining these structures. Therefore, in designing the amplification structures laid out at the adjacent site to the existing structures, a set of organized information concerning the confirmed geological conditions and the behavior of the rock mass obtained during construction of the existing structures is essential. Care should be taken concerning the change of conditions in the rock mass resulting from the completion of the existing structures and the start of the dam's operation (especially the change of conditions of the underground water corresponding with the impoundage of the reservoir). The geological conditions and engineering geology of individual sites of the existing structures are described below.

7.5.1 Pressure Shaft

The amplification shaft is planned to be built at a location above the existing shaft. At the amplification shaft site, the data from boring S4, SC-4, SC-6 and adit G-1 are also available.

The amplification shaft is in the Massive Sublithographic Limestone of which bedding planes dip with 10° - 18° northwestward.

The direction of existing shafts correspond to that of Fault IV. Pressure Shaft A just reached a branch of Fault IV, which follows over its whole length. Existing shafts encountered fractured or very fractured rock mass which is partially weathered and with karstic cavities. Fault IV was nevertheless only 0.5 m to 1 m wide with clay core only in some places. It did not give rise to much excavation difficulties and did not need any steel ribs. It was decided to carefully wash the karst cavities, to fill them with concrete and, later on, to grout them through the steel lining.

The steel lining of the Pressure Shafts is designed to resist the full internal and external pressure. Therefore, it was not required to make a very detailed survey of the rock quality, as is necessary for reinforced concrete.

The geological conditions of the manifolds were good. Nevertheless, some overprofiles occurred due to the bedding planes. Some hot water springs flowed from the floor during excavation without main problem for the project. Some of these waters are now connected to the Power Station pump and some flow by gravity to the open channel at the north end of the cavern and out to the river.

The geology of amplification pressure shaft site is expected to be similar to the existing site. But, attention should be paid at the section neighboring the existing powerhouse, where the rock mass had loosened. The rock condition of amplification pressure shaft site is not so favorable as that of existing powerhouse site. The rock mechanical properties obtained at existing powerhouse site which is described in the next section must be discounted, in applying to the amplification pressure shaft site. During excavation of amplification project special attentions should be paid to vibrations influence to the existing structures.

7.5.2 Powerhouse

(1) Geology

The amplification powerhouse is planned to be constructed at a location downstream of the existing powerhouse. There exist borings (SC-8, 10 and 15) and adits (GC-2, 3, 4, and 5) in addition to the work tunnel (Santa Barbara Tunnel) for the existing powerhouse.

In the surrounding area of the existing powerhouse, massive sublithographic limestone is distributed. A major fault (Fault IV) runs parallel to Rio Humuya with a distance of about 150 m.

For the site selection of the underground powerhouse including amplification powerhouse the following geological requirements were fulfilled:

- the cavern should be placed within the Massive Sublithographic Limestone, being the most favorable lithological rock type at El Cajón dam site
- within the Sublithographic Limestone the cavern shall have a favorable orientation with respect to the few bedding planes (high angle of intersections)
- the cavern should not border to one of the known fault system
- the situation of the cavern should be in such a depth that sufficient rock overburden is available. Here, of course, mechanical conditions are more stringent. The same requirement holds for placing the cavern away from the river into the rock mass as much as possible. However, a safe distance to the fault zone IV had to be guaranteed.

The existing cavern is bordered at 20 m to the West by Fault IV, and at 90 m to the East by the Humuya River. The depth of overburden varies from 114 to 128 m for the minimum.

The geology of existing powerhouse is as follows.

The whole cavern was excavated in the "Massive Sublithographic Limestone". The bedrock is elastic, homogeneous, with a high strength value. It has a trend to spall in plates 0.5 - 1 m^2 parallel to the major discontinuity systems.

Fault IV runs in the North-South direction and has been found in the Access Tunnel, in the Manifolds and Pressure Tunnels, as well as in Adit G-1, Grout Galleries and other structures more to the south. It had no impact over the excavation stability of the cavern itself.

Four bedding planes, dipping with 25° towards the North West, crossed the whole excavation.

Two major fracture systems are running vertically in the direction of the Cavern's long axis, and two minor fracture systems cross the cavern perpendicularly with a steep dip towards the South.

Karst features are linked to the major fracture systems, i.e. mostly vertical with North South orientation, always filled with wet clay. Water dropped through the karst constantly, with a high intensity at the end of the rainy season (November).

The cavern orientation was chosen to fulfill various requirements, and especially, to keep "a safe distance from Fault IV Area". The cavern disposition is convenient for avoiding Fault IV, however, it is worse for the stability of the walls running parallel to these fracture systems (East and West walls).

Judging from the geological information obtained from adits, borings and Santa Barbara Tunnel, the geology of the amplification powerhouse site is expected to be virtually the same as that of the existing powerhouse site.

(2) Engineering Geology

The geotechnical characteristics of the limestone of the powerhouse site are reported in 1978 as follows.

Uniaxial compressive strength:	between 1,330 and 2,030 kgf/cm^2.
Static modulus of elasticity :	between 980 and 1,050 tf/cm^2.
Specific gravity :	2.7 t/m^3.

In general, the rock quality is very good. The core recovery in boreholes always was 80 - 100%, the mean RQD value between 81 and 96%. Per linear meter of drilling, 1 -4 fractures were recorded on average. Discontinuities with clay layers or films are scarce.

In general, the rock conditions were very good. But some geological features demand treatments shown below during excavation.

Joint

- At the roof more rockbolts than average were installed at the zone characterized by dense North-South vertical fractures.
- The rock mass is interspersed by microfissures and split in plates parallel to the East and West walls under the decompression effect. This effect was however only superficial as it could be proved by the 3 m extensometer readings which did not register such a movement.

Bedding Plane

- Four bedding planes were found. Although their orientation was disfavorable for the stability of the roof, no rock slumped down.
- Above the tunnel to manifold number one, the rock was crossed by a continuous bedding plane with clay filling. This unstable rock was cut down and the vault was completely reconstructed with concrete. This was also the case for the blocks left between Turbines 1 and 2, and 2 and 3, which were affected by the same bedding plane.

Karst

- The karst openings often filled with clay had to be carefully washed out and filled with concrete.
- Vaults 2 - 3 to the proximity of an 1 - 1.5 m clay filled karst feature, limited by fractures running almost N-S direction with 70° dip towards west, were supported with more rock bolts than average.

On the southern central part at El. 85 m (near the bottom of the cavern), a small karst hole was found during excavation. This hole was investigated with six drill-holes and TV camera inspection. A karst cavity with 1 - 2 ℓ/s water flow was found in one drill hole. Considering the possibility of other karst holes below the turbines, the foundation plates of the 4 turbines were deeply anchored into the bedrock in order to avoid a floor uplift. Water inflow (2 ℓ/s) was observed South of turbine one. All the karst zones were carefully washed and completely grouted.

Ground Water

- During excavation of the Powerhouse manifolds, an active thermal karst system was found from EL. 92 m down to EL. 85 m. This water flowed through interconnected open channels with a total of < 1.0 ℓ/s. All characteristics (temperature, absence of clay or calcite deposits, etc.) indicate a deep active karst.

- In August, 1984, when the reservoir level rose about 100 m to EL. 200 m, a total of 45 ℓ/s was still flowing, pumping into the shaft, associated with reservoir increasing.

Like the case of the existing site, the rock mass for the amplification site is generally good. The phenomena observed during excavation that are caused by these geological features will provide valuable information for designing and construction of the amplification powerhouse.

Special attention should be paid to conditions of karsts and underground water.

In particular, it should be noted that the condition of underground water is expected to differ from that at the time of construction of the existing powerhouse. When the existing site was excavated, there was no water flowing on the river bed at the dam site and near the outlet as the flow had been deviated. It should be noticed that the excavation work for the amplification site will be executed with the reservoir having been filled and the water from the outlet flowing at a level of approximately 103 m.

The water from the surrounding area of the underground powerhouse is gathered into a vertical shaft for drainage at a location adjacent to the northern end of the existing powerhouse (Pozo Norte), and it has been observed that the volume of this water is increasing. Additional grouting has been prepared by ENEE to decrease the quantity of water inflow. This clearly indicates that the water level at the underground powerhouse site has risen from the time of the excavation of the existing site, suggesting a possibility of an increased water inflow at the time of excavation of the amplification site. Special attention should be paid to drainage and grouting for the amplification site particularly at the mountain side of the proposed amplification of the powerhouse.

7.5.3 Tailrace Tunnel

The site for the amplification tailrace tunnel is located approximately 50 meters downstream of the existing site. Boring (SC-1), a adit (GC-1), drainage tunnel, and Santa Barbara Tunnel also, provide geological information. The geological conditions at the existing site are described below:

The existing site is located in a massive sub lithographic limestone.

The rock conditions of the existing tunnels were very good. The rock was sound almost to the outlet. No major fracturing was found during excavation. Here too, some small thermal springs flowed from the floor without problem for the Project.

Although it is anticipated that the rock mass of the amplification site is as good as that of the existing site, a fault with a fracture zone of 1 meter wide that has been observed in Santa Barbara Tunnel (Fault

II or its branch amplifying in the NNW-SSE direction) is expected to appear at a position 20 meters distant from the outlet.

A large amount of water inflow may occur during excavation of the tailrace tunnels due to the flowing water on the river bed. Boring SC-1 (30 meter long) near the left bank river bed met mainly karsts and sections where the injection pressure does not rise during the Lugeon test, and indicates that the water permeability is high.

7.5.4 Tailrace Outlet

No investigation work has been executed at the amplification site.

The amplification site is distributed with massive sublithographic limestone. According to observations from the opposite bank, there is no bedding plane, while vertical joints of the NNW-SSE direction is observed. Although the weathering is weak, it is possible that several meters from the surface may be loosened along joints. However, no collapse has been found at existing outlets or mouths of adits, indicating that rocks in the vicinity of the amplification outlet site slopes are so stable as to need only local countermeasure.

Table 7-1 Stratigraphy Around El Cajón Area

Age	Stratigraphic Classification		Lithology
Quaternary			
	Volcanic Rocks		andesitic lava, tuff and agglomerate
Tertiary			
Cretaceous	Yojoa Group	Guare Formation	thin bedded limestone and marl
		Atima Limestone	thick bedded limestone
		Cantarranas Formation	clayey marl

Table 7-2 Data Obtained

1.	Feasibility Study vol. 1 Synopsis and Conclusions	Dec. 1973	Motor Columbus
2.	Feasibility Study vol. 6 Geology and Geotechnics	Dec. 1972	Motor Columbus
3.	Estudio de Factibilidad vol. 6A Perfiles Geológicos de las Perforaciones y Galerías de Sondeo	Dec. 1972	Motor Columbus
4.	Condiciones Hidrogeológicas en el Sitio de la Presa y de la Central Subterranea	Apr. 1978	Motor Columbus
5.	Investigaciones en el Sitio de la Central Subterranea	Feb. 1978	Motor Columbus
6.	Investigaciones Geológicas y Geotectónicas 1976/1977 Informe Final Folletos No. 4 Estructura Geologica y Sismicidad del Area de Proyecto (En Inglés)	Jun. 1978	Motor Columbus
7.	Seismic Hazard Analysis of Honduras	Aug. 1979	A.S. Kirenidjian et al
8.	Power Station and Dam vol. 5 Geological and Geotechnical Information	Apr. 1979	Motor Columbus
9.	Report of the Concrete Arch		Motor Columbus
10.	Mesured and Predicted Behavior of the El Cajón Underground Powerhouse, Hondurus	Sep. 1983	P Jewitt
11.	Civil Works, First Annual Safety Evaluation Report June 1984 - May 1985	1985	ENEE/Motor Columbus
12.	Informe Final de Construcción	Set. 1986	Motor Columbus
13.	Annex of Chapter 13 of Informe Final de Construcción	Sep. 1986	Motor Columbus
14.	Mapa Geológico de Honduras (scale 1:500,000)	1991	Instituto Geográfico Nacional

Table 7-3 List of Drillhole

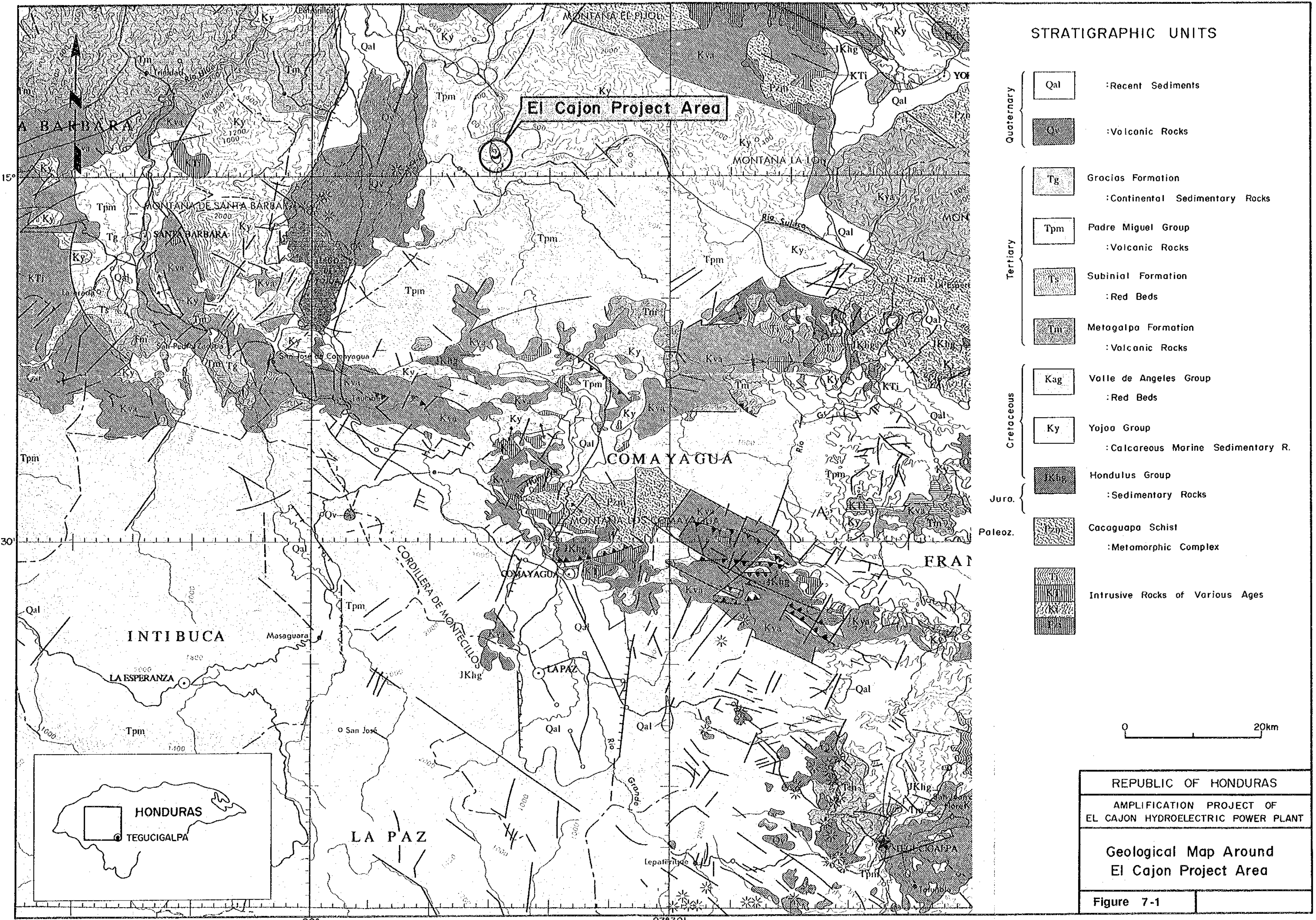
Name	Elevation	Length	Direction/ Inclination	Amplification Site
SC-1	119.61	30.00	- -90°	Tailrace Tunnel
SC-2	119.54	40.16	N75°E -45°	"
SC-3	119.54	40.51	- -90	Power Station
SC-4	119.54	40.32	S75°W -45°	Pressure Shaft
SC-5	120.82	60.40	S75°W 0°	"
SC-6	122.38	39.86	- +90°	Power Station
SC-8	122.92	40.06	- +90°	"
SC-10	120.36	29.50	N15°W 0°	"
SC-11	120.69	20.14	S75°W +5°	"
SC-12	120.62	20.18	S75°W +5°	"
SC-15	119.72	40.45	- -90°	"
S-3	316.50	110.00	S81°W -45°	Pressure Shaft
S-4	209.70	171.00	S81°W -45°	"
S-11	306.70	110.00	S81°W -45°	"

Table 7 - 4 List of Adit

Name	Elevation (m)	Length	Direction	Amplification Site
G-1	209.70	112.50	S88°W	Pressure Shaft
GC-1	119.61	95.50	S75°W	Power Station Tailrace Tunnel
2	119.54	70.00	N15°W	Power Station
3	119.72	24.60	N75°E	"
4	119.72	18.50	N15°W	"
5	119.72	25.00	S75°W	"
6	119.54	50.00	S15°E	"
9	119.47	24.70	S75°W	Pressure Shaft

Table 7-5 List of Existing Excavation

Name	Amplification Site
• Pressure Shaft	• Pressure Shaft
• Power Station	• Power Station
• Access Tunnel	• Pressure Shaft
• Water Cooling Reservoir	• Tailrace Tunnel
• Drainage Tunnel	• Tailrace Tunnel
• Santa Barbara Tunnel	• Power Station Tailrace Tunnel
• Tailrace Tunnel	• Tailrace Tunnel

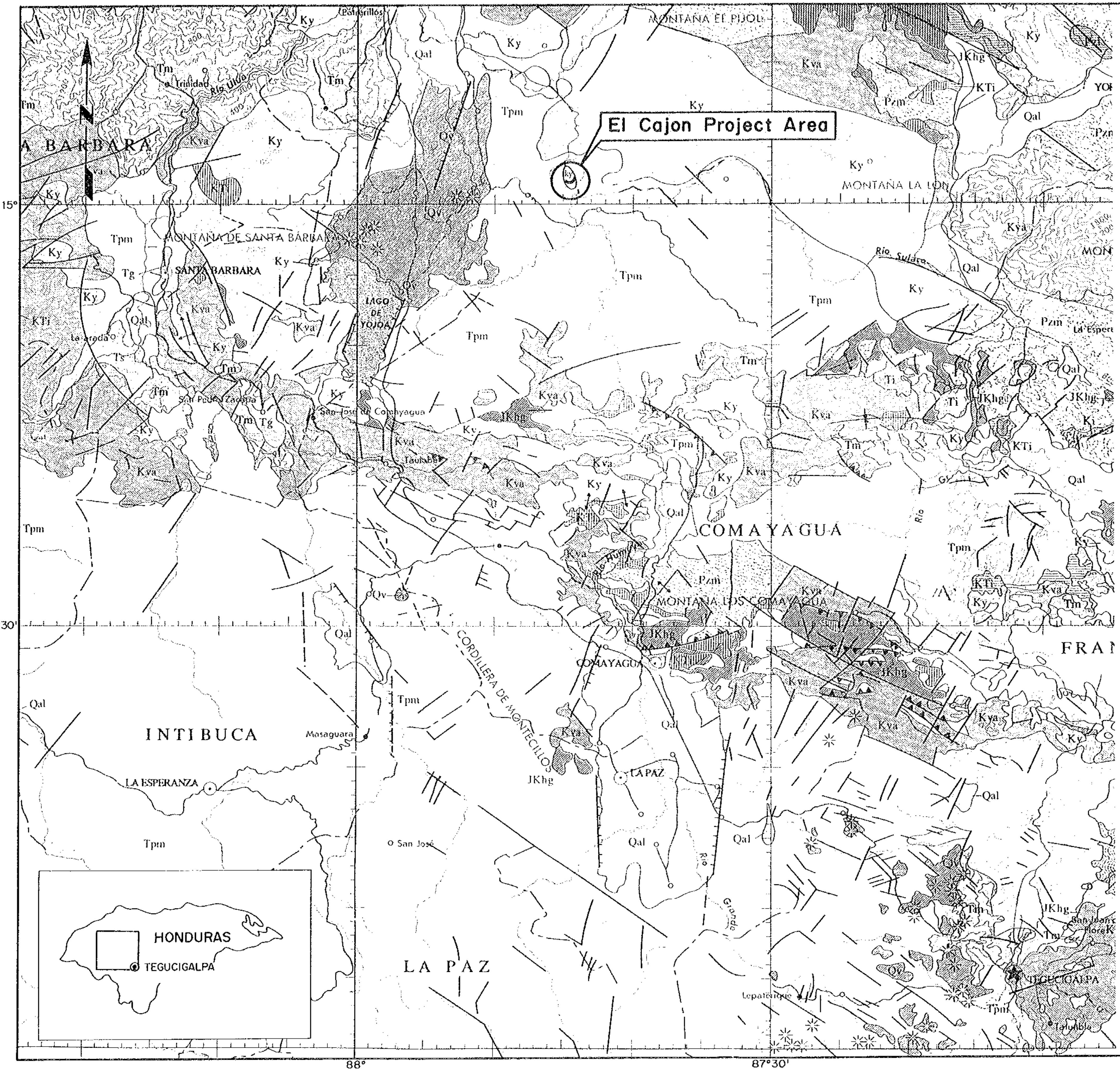


REPUBLIC OF HONDURAS

AMPLIFICATION PROJECT OF
EL CAJON HYDROELECTRIC POWER PLANT

Geological Map Around
El Cajon Project Area

Figure 7-1



STRATIGRAPHIC UNITS

Quaternary	Qal	:Recent Sediments
	Qv	:Volcanic Rocks
Tertiary	Tg	Gracias Formation :Continental Sedimentary Rocks
	Tpm	Padre Miguel Group :Volcanic Rocks
	Ts	Subinial Formation :Red Beds
	Tm	Metagalpa Formation :Volcanic Rocks
Cretaceous	Kag	Valle de Angeles Group :Red Beds
	Ky	Yojoa Group :Calcareous Marine Sedimentary R.
Jura.	JKhg	Hondulus Group :Sedimentary Rocks
Paleoz.	Pzm	Cacaguapa Schist :Metamorphic Complex
	Ti KTi Ki Pzi	Intrusive Rocks of Various Ages

0 20km

REPUBLIC OF HONDURAS

AMPLIFICATION PROJECT OF
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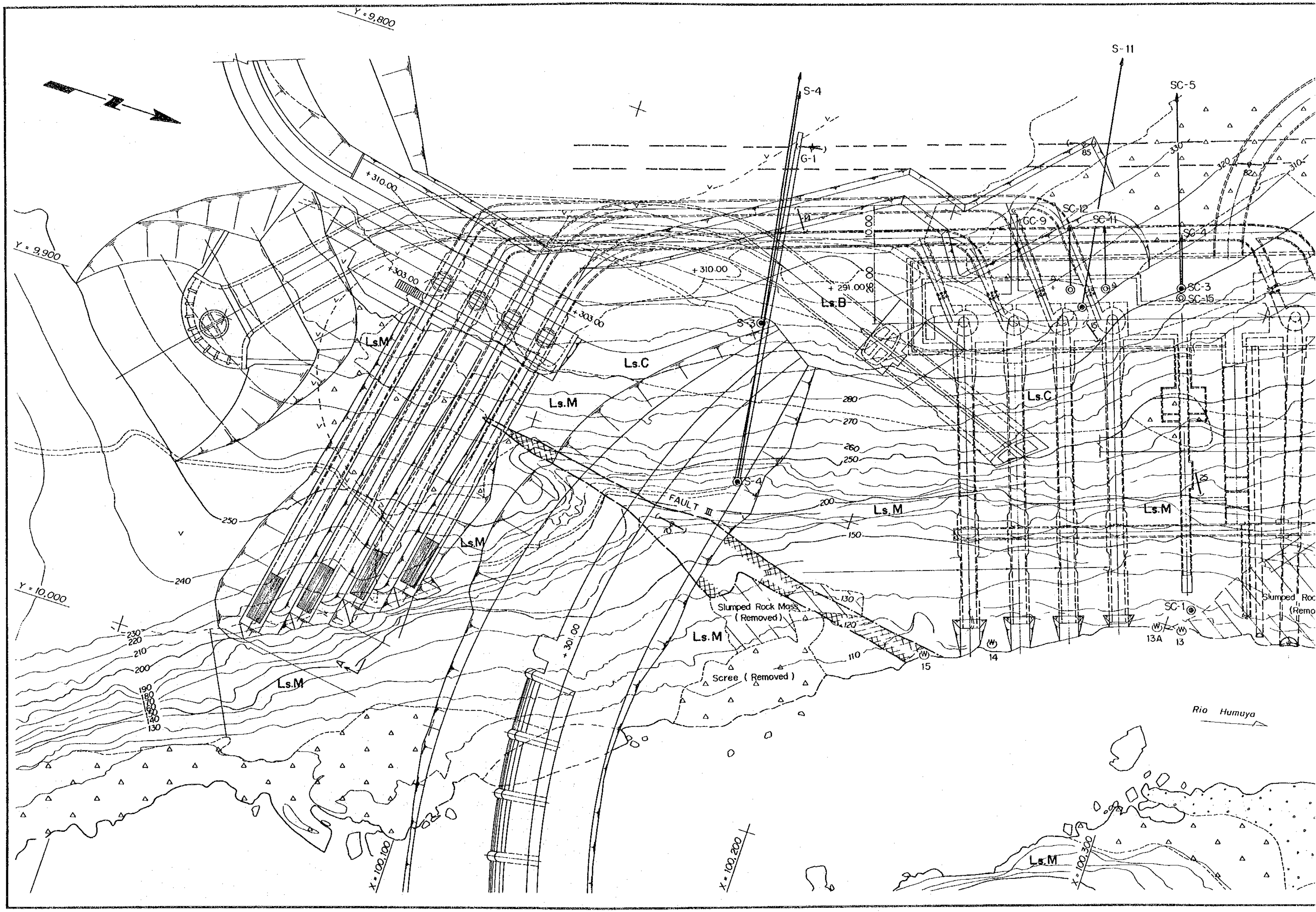
Geological Map Around El Cajon Project Area

Figure 7-1


Y = 9,800
Y = 9,900
Y = 10,000
S-4
G-1
S-11
SC-5
85
82
330
320
310
+310.00
+303.00
+303.00
+310.00
+291.00
10.00
20.00
10
GC-9
SC-12
SC-11
SC-4
SC-3
SC-15
S-3
Ls.B
Ls.M
Ls.C
Ls.M
Ls.C
280
270
260
250
S-4
200
150
FAULT III
70
Ls.M
Ls.M
Ls.M
25
250
240
230
220
210
200
190
180
170
160
150
140
130
Slumped Rock Mass (Removed)
130
120
110
Ls.M
Ls.M
Scree (Removed)
+301.00
15
14
SC-1
13A
13
Slumped Roc
(Remo
Rio Humuya
X = 100,100
X = 100,200
X = 100,300
Ls.M