(3) Environmental Problems after Completion of Dam and Reservoir

In general, the causes of environmental problems arising after completion of a dam are the following:

a) Existence of Dam Body and Reservoir

Variation in water quantity, variation in reservoir surface water level, variation in water quality

b) Existence of Hydroelectric Power Station

Conduction of water from dam to powerhouse by headrace tunnel, reduction in water quantity in area downstream of dam due to river diversion

c) Change in Traffic Volume

Increase in traffic volume

d) Change in Organism Facies

Gradual change in organism facies

e) Agricultural Land Reduction

Recovery of agricultural land area reduced by submersion

These need to be studied and countermeasures set up.

6.2 Environmental Problems at El Siete No.1 and No.2 Hydroelectric Power Development Project Sites

The effects of the two projects on the environment are as follows:

(1) El Siete No.1 Dam and Regulating Pond Scale

El Siete No.1 Dam is to be a medium sized, gravitytype concrete dam, with a height of 55 m, crest length of 207 m, and volume of 143,000 m^3.

Since the pondage would be regulated daily, both the required 540,000 m3 regulating capacity, and the 926,000 m3 total storage are small, and there is extremely little possibility of the problems outlined in 6.1 occurring.

(2) Sediment Flowing into El Siete No.1 Regulating Pond

As described in 8.5, the annual average sediment inflow at the regulating pond is estimated at 1,556 x 10^3 m^3. By discharging sediment deposited in the regulating pond from the flushing gate, it will be possible to prevent putrification and eutrophication due to deposited sediment in the pond.

(3) House Relocation and Reduction in Cultivated Land

Accompanying water impoundment at El Siete No.1 Dam no agricultural land will be submerged, with only 0.66 ha of pasture inundated, and regional agriculture will not be affected.

Only 8 houses will need to be relocated because of submersion, so that relocation will not be difficult, and living conditions will not be adversly affected.

(4) Influence of El Siete No.1 Regulating Pond on Meteorology

The El Siete No.1 regulating pond has a 7.6 ha (0.076 km^2) reservoir surface area and compared with the Project's catchment area of approximately 300 km^2 it is extremely small, and there will be absolutely no influence on evaporation from the pond, or the reduction in mountain forests due to submersion on meteorology.

(5) Problems Caused by El Siete No.1 Dam Construction Work

In the El Siete No.1 Dam construction work, the quantity of open excavation, including earth and rock, will be as much as approximately 560,000 m^3, as shown in Chapter 15.

The Atrato River is in a turbid condition throughout the year and there is considerable possibility of sediment yield being increased by dam construction. However, there are few people living in the downstream area and water from the main stream is not used for municipal water supply, irrigation, and drinking water, and therefore it can be said that at this time treatment of turbid water is not necessary.

It will be necessary for the national road between Medellin and Quibdo at the rightbank side of El Siete No.1 damsite to be relocated because of construction. As described in 14.2, the distance to be relocated is 1.6 km. The route will not be changed as the present road is only to be raised above the 1,450 m high water level of the El Siete No.1 regulating pond, and will not result in a change in the regional living or economic conditions. Neither will it be necessary to stop traffic on the national highway, even temporarily, during the road relocation work. The route can also be selected to ensure it does not interfere with grazing being carried on in the vicinity. It will however be necessary for the relocated road to be completed as a preparatory work prior to the start of dam construction work.

Noise and dust pollution arising from the dam construction work will not be a problem since there are no inhabited areas in the vicinity.

(6) Problems at El Siete No.1 Auxiliary Dam

El Siete No.1 Auxiliary Dam is an intake dam to be used for power generation while sediment is being flushed from El Siete No.1 Dam and there will be no particular effect on the environment.

(7) Environmental Problems of El Siete No.1 Power Station and El Siete No.2 Intake Dam

The El Siete No.1 powerhouse and the El Siete No.2 Intake Dam work will involve open excavation totalling approximately 227,000 m^3. Therefore, turbid water will be increased due to topsoil erosion by rainwater, but the turbid water will not be of an extent to destroy the downstream area environment similarly to the case of El Siete No.1 Dam.

The El Siete No.1 penstock will be provided crossing grazing land, but this problem can be overcome by providing foot bridges for cattle and horses.

Since there are no houses in the vicinity, construction from noise and dust pollution will not pose a problem.

(8) Environmental Problems of El Siete No.2 Power Station

The El Siete No.2 powerhouse site has been selected at a location which is presently forested mountainland, but the powerhouse will not utilize such a large lot as to affect vegetation. After relocating the national road crossing the No.2 penstock route by a tunnel, construction can be executed without hindering traffic on the road.

With regard to turbid water produced by excavated earth, it will be the same as previously mentioned.

Three or four houses exist in the vicinity, but they are at sufficient distance not to be affected by the construction work and will not be any problem.

(9) Mines, Historic Relics

There are no reports that promising mines, historical relics or cultural assets exist at the sites to be used for permanent structures in the two projects.

(10) Effect of Construction Camp

Approximately 5,000 engineers and laborers, together with their families, will live in temporary camps at the two project sites during the construction period. Accordingly, domestic waste water, and organic and inorganic pollutants would be discharged down the Atrato River. Pollutant naturally, treatment would be obligatory, but there would be concern that pollutants will make their way down the river, even with the strictest controls exercised. However, the Grande River, which has a large catchment area, will join the Atrato when the downstream El Once district has been reached, while the Playas River will join in at El Dieciocho district, so that the Atrato River will develop into a river with a very large discharge and the pollutant concentrations will be lowered.

The downstream El Lloro hamlet and Quibdo City will therefore be unaffected.

However, strict control should be exercised so that substances likely to be causes of contagious diseases will be completely incinerated at the camps.

These camps are to be completely removed after completion of construction work and the sites restored to their original states.

6.3 Environmental Problems after Completion of Project

The environmental problems expected to arise after completion of El Siete No.1 Hydroelectric Power Project and El Site No.2 Hydroelectric Power Project are as follows:

(1) Problems Inside El Siete No.1 Regulating Pond

When Siete No.1 regulating pond is in operation it will be subject to water level variations of 10 m in a single day, since it will be a daily regulating pond.

During operation of the power station, there will be flow in the direction of the river flow, whilst inside the pondage there will be flow variations upward, downward, sideways at all times so that phytoplanktons, zooplanktons, and adhering algae will not be readily produced.

Additionally, since the river will flow in the condition of a natural stream 90 days out of the year for sediment flushing, the El Siete No.1 regulating pond will have comparatively few of the environmental problems that many other reservoirs generally have.

(2) Reduction in Discharge of Area Downstream of El Siete No.1 Dam and El Siete No.2 Intake Dam

Both El Siete No.1 and El Siete No.2 Hydroelectric Power Projects are projects to be developed as dam-and-waterway types resulting in water reduction in the river channels along the waterway tunnel routes.

Consequently, it is customary for river maintenance water to be discharged from the dams. However, residents of the region directly use the waters of the tributaries joining the Atrato River for domestic use and it will not be necessary to release river maintenance water from the dams in this case.

(3) Problems Occurring Outside El Siete No.1 Dam Regulating Pond

El Siete No.1 Regulating Pond is for daily regulation in accordance with the power generation load. As a consequence, there will be pondage water level fluctuation of as much as 10 m in a day. It is expected that the groundwater table in strata comprising the surroundings of the pondage will vary as a result of interaction with the pondage water level variation.

Regarding the geology of the ground making up the surroundings of the pond, it is comparatively stable ground as described in 10.3. However, the ground at the right bank approximately 200 m upstream of the dam axis (a section of approximately 100 m between the dam axis and the Toro River) presents a terrace facies and is composed of deposited materials so that fluctuations in the regulatinjg pond water level will affect the groundwater cable and there will be concern that interacting variations will occur. The measure to be taken is to limit the pondage water level in a range wherein groundwater table fluctuation will not cause landsliding.

El Siete No.1 Dam, as described in 11.2 (3), is to have a dam height of 55 m, a high water level of 1,450 m, and a surcharge water level of 1,451 m.

As a result of studies of the previously mentioned landslide danger area, it was judged that there would be no concern regarding ground stability. (See Chapter 10)

The scenery will not be spoiled by construction of El Siete No.1 Dam and the regulating pondage. As the pond is only 9.6 ha and small, and considering the fact that the shoreline has no flat areas for recreational facilities, tourism and rest area effects cannot be expected.

Whether the living conditions of the wildlife would be adversely affected and the movements of that wildlife hindered, the regulating pondage would be short, reaching only about 1 km, and it is considered this is not long enough to have any effect.

6.4 Social Development Effect

Completion of the El Siete No.1 and El Siete No.2 Hydroelectric Power Projects will greatly contribute to the social and economic development of the Republic of Colombia and the stabilization of the people's livelihood.

Both projects are for hydroelectric power generation, which is renewable energy. It is also a clean energy where in pollution can be held to a minimum.

The socio-economic development effects can be expressed either quantitatively or qualitatively, but most can only be expressed qualitatively.

The following elements are conceivable as the effects of the two projects on social and economic development.

a) Contribution to the Colombian economy

b) Stable electric power supply and promotion of provincial electrification

c) Stimulation of regional development

d) Improvement of the regional population's welfare and stabilization of people's livelihood

The effects of the two projects divided into those during construction and those during power generation operation will be described in connection with the points listed above.

(1) Effects During construction

- Where the two projects were to be developed simultaneously, as described in 14.6, the period of construction, including preparatory works, will be 5 years.

  During this construction period there will be procurement of construction materials in Colombia, importation of equipment and materials, inland transportation within the country and employment of labor.

Quantities procured and approximate amounts are shown in Table-6.3.

- The cement used in the two projects will total 148,000 ton/year as shown in Table-6.2, which would be purchased from Compania de Cemento Argos S.A. or Cementos El Carro S.A., Medellin City.

  The annual production capacity of the two companies is 910,000 ton/year and the cement used by the projects annually will correspond to 5.5 of that output percent. From a national point of view, consumption would represent 0.8 percent of the total 6,415,000 ton/year production.

- Regarding reinforcing steel, 8,110 tons will be required. When averaged for 3 years, consumption would correspond to 9 percent of domestic production, amounting to 30,000 ton/yr.

- The domestic transportation cost of imported equipment will be US$3,334 Thousand, as shown in Table-6.3. This will lead to stimulation of the transportation industry.

  Columbia's transportation and communication industry accounts for 9.8 percent of the national GDP and when it is considered that it is an important pillar in the economic activity structure, the economic effect will be considerable.

- In 1983, the volume of imported items handled through Colombia's ports was 3 million ton/year corresponding to US$4,888 million, contrasted to which the amount of imports related to the two projects is estimated at approximately US$47,145 Thousand CIF. Calculating customs duty on imported items at a rate of 20 percent, the amount would be US$9,334 Thousand, which would be transferred to the Colombia Government.

- The effect on the employment of labor will be great. As shown in Table-6.3, a maximum of 5,000 persons will be employed. It is estimated that presently, the unemployment rate stands at 11.4 percent with 28 thousand persons unemployed, and there will therefore be a great effect of implementation of the two projects on the unemployment reduction policy.

Choco Prefecture particularly has a high unemployment rate compared with other prefectures and the effect of increased employment in the prefecture through a construction project will be especially marked, preventing migration of the population to cities, and stabilizing the livelihood of poeple in the prefecture.

- For Electrificadora de Choco (head office, Quibdo) which supplies electricity in Choco Prefecture this will be the largest construction project since its establishment, and with this, conversion can be made from its present business which consists mainly of power distribution, to a broad-based operation with the expansion of its construction sector.

  Owning and operating hydroelectric power stations as a power supply source will greatly serve to improve and ensure efficient company management.

  The telecommunications facilities to be temporarily provided for the construction and the telecommunication facilities installed between the two power stations can be used by the company, which will have an extremely great effect on improving company operation efficiency.

- Procurement of domestic good by the employees and their families connected to the construction work would be centered at Medellin and Quibdo, and this will serve to enhance the commercial activities of the two cities.

- Although the sharp influx of population to the town of Carmen de Atrato to serve as the base during the construction period will have certain detrimental aspects, the expansion of commerce and other tertiary industries and the improvement of medical facilities can be looked forward to.

- There will be an increase in traffic volume on the national road between Medellin and Quibdo during the construction period, due to the transportation of construction materials and movement of laborers so that increased commercial activities along the road can be expected. With improvement and repair of the road carried out by the constructors of the two projects, will be improved road conditions can be looked forward to.

- Through completion of the two projects, the conditions for development of the El Dieciocho No.1 and No.2 hydroelectric Power Projects downstream on the Atrato River will be improved. As a result, the development timing will be hastened and the regional development of Choco Prefecture will be moved to the west. The entire works of the two projects can be seen by Choco Prefecture residents from the national road. This would help the people of Choco to understand modern technology and promote expectations for development, enhance social development consciousness, and the educational effects will be substantial.

Table-6.2 List of Cement Factory in Colombia

Name of Factory	Location	Daily Production	Annual Production
Compania de Cemento Argos S.A.	Medellin, Antioquia	1,800	460,000
Cemento El Cairo S.A.	Montevello Antioquia		450,000
Cemento Blanco de Colombia S.A.	Puerto Nare Antioquia		75,000
Cemento del Nare S.A.	Puerto Nare		220,000
Cementos Rio Claro	Puerto Triunto (1986)	1,500	
Total			6,415,000
Cementos de Caldas S.A.	Neira, Manisales		330,000
Cementos del Valle S.A.	Puerto Lsaacs Cali, V. Cauca		900,000

Table-6.3 Monetary Sums Concerning Stimulation of Domestic Economy

Item	Quantity	Approximate Sum for Procurement	Place of Procurement
A. Materials			
Cement	148,000 ton	@US$72/ton 10,656,000	Medellin City and suburbs
Reinforcing bar	8,100 ton	12,496,000	
Steel	2,400 ton	8,410,000	
Sub Total		31,562,000	
B. Imported Equipment		CIF	
Gate, steel pipe		12,405,000	Imported item
Generating equipment		24,880,000	
Telecommunications equipment		1,020,000	
Transmission equipment, materials		8,840,000	
Sub Total		47,145,000	
C. Transportation Cost		3,334,000	
D. Labor	Max. 5,000	11,120,000	
Total		93,161,000	

Note: See Chapter 15, Construction Cost, for quantities and amounts.

(2) Effects After Construction

- Both projects are hydroelectric power, providing clean, renewable energy.

  Colombia's power generating facilities are expected to reach the 8,072 MW in 1993, according to long-range plans, and the maximum 160 MW output of the two power stations would represent a mere 2 percent of the total supply capacity.

  However, when considered converting into finite energy such as coal and oil, the energy produced by the two projects during their 50-year service lives would be 23,000,000 tons in terms of coal, and 87,800,000 barrels in terms of oil. That these finite resources are not consumed will mean at least some contribution to the global energy problem, while if these were diverted to exports, it would correspond to a foreign currency revenue of US$16 million.

  This will contribute to the stabilization and strengthening of Colombia's economic base.

- In Choco Prefecture, power supply within the prefecture will be stabilized and low prices maintained over a long period, which will be an inducement for regional development and stabilization of the people's livelihood.

  It will also contribute to development of industries utilizing the abundant forest resources of the Atrato Plain.

  It can also be expected that jobs will be created with the development of industry, and at the same time improvements in productivity and income standards can be looked forward to.

- Choco Prefecture can expect a share of the tax revenues based on the income from electric power which will serve to stabilize finances of the Prefecture, and investments for social development can be expanded.

  Expansion and improvement of the road transportation network is the first step in the regional development of Choco Prefecture, and development of resources in forestry, agriculture, fishing on the Pacific Ocean coast, and mining can be initiated through construction and improvement of roads as a consequence of the projects.

- When the two power stations go into operation, operation and maintenance personnel will have to be employed. These employments will be long term and stable, and constitute an improvement in the labor situation. Ordinarily, there would be approximately 60 persons employed for operation and maintenance of the two power stations and the transmission line, with most being employed locally.

CHAPTER 7. POWER DEMAND FORECAST, SUPPLY AND BALANCE STUDY

CHAPTER 7 POWER DEMAND FORECAST, SUPPLY AND BALANCE STUDY

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CHAPTER 7. POWER DEMAND FORECAST, SUPPLY AND BALANCE STUDY

7.1 Power Demand Forecast Method

The construction of new power plants, transmission lines and substations requires vast investment sums and a long period of time, from 3 to 10 years. To spend the limited sum of investments most effectively, future power demand must be estimated correctly and accurately. In developing countries, it would be quite difficult to accurately forecast power demand, since the nation's economic activities generally tend to fluctuate violently with excessive fluidity with the power demand following these economic tendencys very closely.

Power supply areas by the Project is the National Interconnected Power Grid which was completed in 1982 through the construction of a 500 kV transmission line with the circuit, 524 km long by which the CORELCA power system was interconnected with the central power system. However, a greater part of energy generated by the Project would be consumed in Medellin city with its population of 2 million followed by Bogota city and the industrialized surrounding areas of Medellin.

In view of the socio-economic development plan and Colombia's present economic situation and also by suggestion of the World Bank, ISA reviewed a power development scheme* in Colombia which covers from 1985 to 2000.

Note: * Sistema Interconnectado Colombia, Actualizacion Plan Expansion, Medellin, Octubre, 1984, ISA

According to the ISA report, the future annual energy increase was estimated at 6.5% per annum. The Survey Team deemed that the ISA's demand forecast is appropriate. However, the Team decided to make its own forecast by a method different from that used by ISA.

Since the Atrato Project is proposed for power generation development, the period of power demand forecast covers the long term projection and up to the year 2000 in view of coordination to be required with evaluation of the Project through 12 years from 1993 when the Project will be put into service.

7.2 Present Power Demand Status

7.2.1 Comparison of Per-Capita Energy of Latin American Countries

Regarding the difference in consumption between Colombia and other South American countries, there is generally a close correlation between per-capita power demand and gross domestic product (GDP).

Generated energy per capita and GDP per capita in the Latin American countries are shown in Table-7.1 and Fig. 7-1.

Energy consumption per capita in Colombia is figured on the line shown in Fig. 7-1 and based on the actual value of the Latin American countries.

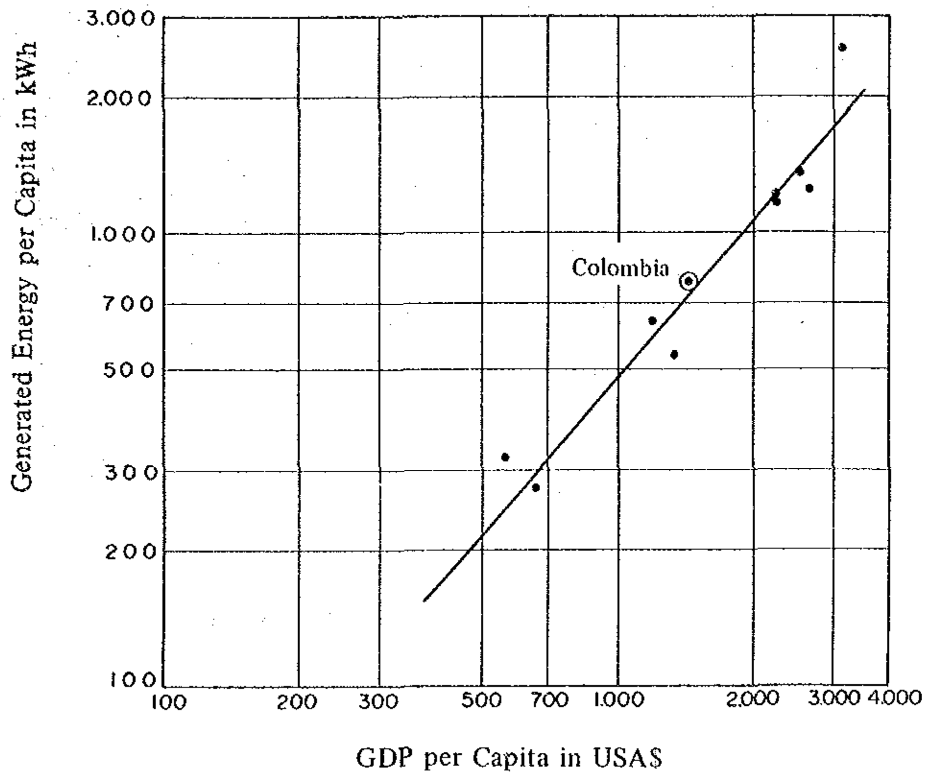
It is indicated that a possible energy consumption per capita in Colombia would be 2 times if the GDP per capita increases to US$3,000 from in 1982's US$1,460.

Table-7.1 Per Capita Energy Production and GDP of Latin American Countries as of 1982

Country	Energy (kWh)	GDP (US$)
Argentina	1,369	2,530
Bolivia	316	570
Brasil	1,209	2,240
Colombia	794	1,460
Chile	1,028	2,210
Ecuador	537	1,350
Honduras	275	660
Peru	648	1,200
Uruguay	1,234	2,650
Venezuela	2,557	3,080
Haiti	70	300

Source: Boletin de La CIER, Septiember de 1983

Fig. 7-1 Correlation between GNP per Capita and Generated Energy per Capita



7.2.2 Energy Consumption by Categories and Particularity

For the past ten years energy consumption throughout Colombia has increased steadily and highly at an annual incremental ratio of 7.8% as indicated in Table-7.2. The annual increase ratio in the residential sector was 9.6 percent per annum, comparatively higher than those of other sectors. There were 2,973 thousand residential customers at the end of 1983 and the energy consumption per customer was 2,650 kWh, corresponding to the energy consumption recorded in Japan in 1980.

This high energy consumption in the residential sector is due to the power demand for coolers which are popular in certain prefectures which have extremely hot climates. It is estimated that approximately 60% of the total population benefit from electricity.

Colombian energy consumers are classified into residential, compercial, industrial and others (public building and street lighting) which is shared at 18.6 percent, a comparatively high portion of the total energy consumption.

Table-7.2 Energy Consumption by Category

Unit: 10^6 kWh

Year	Residential	Commercial	Industrial	Others	Total
1973	3,119	1,011	2,864	1,373	8,367
1974	3,488	1,137	3,071	1,505	9,201
1975	3,888	1,233	3,203	1,648	9,972
1976	4,286	1,354	3,648	1,819	11,107
1977	4,457	1,465	3,663	1,924	11,509
1978	5,170	1,621	4,060	2,186	13,037
1979	5,758	1,668	4,321	2,433	14,180
1980	6,284	1,777	4,389	2,856	15,306
1981	6,397	1,725	4,439	2,890	15,451
1982	7,273	1,862	4,476	3,097	16,708
1983	7,790	1,950	4,693	3,308	17,741
Average Increase (%)	9.6	6.8	5.1	9.2	7.8

Source: Colombia Estadistica '85, DANE

7.2.3 Demands in Major Power Systems

Colombia's nation-wide system interconnection of major power systems was established in 1982 with the completion of the 534 km long, 500 kV transmission line (tentatively operated at 230 kV) from San Carlos Hydroelectric Power Station to Sabanalarga Substation. This national power system is composed of the power systems of 5 major utilities, the Empresa de Energia Electric de Bogota (EEEB), the Empresas Publicas de Medellin (EPM), the Corporacion Autonoma Regional del Lauca (CVC), the Corporacion Electrica de la Costa Atrantica (CORELCA), and the Instituto Colombiano de Energia Electrica (ICEL). The Interconexion Electrica S.A. (ISA) power systems are also included in this system, but ISA has no customers of its own, and is engaged in the construction of the interconnection lines for the 5 major utilities while wholesaling the electricity from the hydro and thermal power plants. The electric demands of major utility systems as of 1983 are presented below, in which there is no demand corresponding to ISA due to the functions of this corporation.

Electric Demand in Major Utility Systems (1983)	
EEEB	1,158 MW
EPM	963 MW
CVC	593 MW
ICEL	906 MW
CORELCA	727 MW
Interconnection Loss	73 MW
Maximum Demand in the whole interconnected system	4,238 MW

The electric demands described above are the bus-bar values, including house service powers in hydro and thermal plants as well as transmission and distribution losses.

7.3 Electric Demand Projection

7.3.1 Basic Assumptions for Demand Projection

Several basic assumptions are required to establish a reasonable projection of electric demand. First, it must be assumed that stable economic conditions will continue in the Republic of Colombia, and that the economic growth rate of 5% per annum is assured for a long future period, as stated in the economic policy target of the Colombian Government. As indicated in Table-7.3, the annual economic growth rates in the 1970's were generally above 6%, but the growth rate has dropped to the order of 1% in the 1980's due to a stagnant world economy. However, it can be expected that Colombia will be able to realize a 5% economic growth rate in the long run, considering this country's abundant exportable resources such as oil, natural gas and coal.

Table-7.3 Economic Growth Rate vs. Electricity Generation

Year	Electricity Generation (GWh)	Annual Growth (%)	GDP in 1975 Price (106 pesos)	(%)	ELasticity GWh/GDP
1975	12,137	8.4	405,108	2.3	3.65
1976	13,484	11.1	424,263	4.7	2.36
1977	14,129	4.8	441,906	4.2	1.14
1978	16,132	14.2	479,335	8.5	1.67
1979	17,796	10.3	505,119	5.4	1.19
1980	19,428	9.2	525,765	4.1	2.00
1981	19,631	1.0	535,736	2.3	0.43
1982	21,487	9.4	542,573	0.9	10.44
1983	22,825	6.2	546,914	0.8	7.75
Average Growth Rate	(%)	8.2	-	3.8	-

Source: Colombia Estadistica 85, DANE.

The policy of Four Year Socio-Economic Development Plan (Plan National de Desarrollo) from 1983 to 1986, published by the DNP of Colombia, is as follows:

(1) Agriculture and Stockbreeding

- To increase food production and obtain foreign currency through these increases in production, to increase the production yield by 4% annually, to set a target of a 10% annual increase for exported farm production (mainly coffee), to increase the required investment by 15% annually

- To improve the existing irrigation areas of 188,000 ha and to newly develop an irrigation area of 99,000 ha

(2) Industry

- For short-term strategy, to restore domestic demand and increase the vocational opportunities, since in the 1980's, industrial dynamic growth was sluggish

- To restore the domestic market, to encourage substitution of import industries and promote export industries

- To exercise strict control over smuggled articles to protect domestic products

- To increase construction material production (cement, reinforcement steel, timber, glass, plastic, etc.) for short-term strategy

- To finance enterprises for lightening the burden of interest etc.

(3) Housing

- To construct 442,000 houses in urban areas and 42,000 houses in rural areas for a planned four years

- To provide low cost housing and enlarge the financing limit for housing loan

- To establish a supply center for low cost construction materials

(4) Petroleum

- To establish a financing institute to enable the direct development of petroleum by government of Colombia

- To improve the voice of ECOPETROL in the matter of joint development

- To maintain the existing price system in order to increase the production of domestic crude oil

- To expedite the dig of oil wells

- To import the crude oil of 65.8 million barrels in 1983 and 76.5 million barrels in 1986 required from full operation of the refinery plants

(5) Natural Gas

- Along Atlantic cost, to increase the utilization of coal instead of natural gas

- To conduct the feasibility study of plant construction for ammonia and urea for utilizing surplus natural gas

(6) Coal

- To actuate the coal development in Cundinamarca, Antioquia, Norte de Santander, Valle, Cesar, Cordoba, Bolivar, Sucre and Guajira prefeetures

- To search the feasibility of export of bulk coal and to give an excitant in order to exchange fuel from hydrocarbon (oil and natural gas) to coal used by power plants and industrial customer

- To put domestic technology and industries into the coal development projects

(7) Electric Power

- To invest 450,000 million pesos (7,090 million US$) into the electric power field, to reorganize the power utilities and to study availabilities of required funding at the national level

- To establish a political electricity tariff system in order to enable the utility to get internal reservation in truth meaning

- To execute power plant project construction works expected to operate from 1983 upto 1995

(8) Road

- To repair 1,500 km of roads linking the consumption and production areas, to carry out pavement construction of 1,500 km of second class national highway, and construct 2,400 km of new roads

- To maintain the road network in the border areas

- To commence the construction works of roads between Bogota and Villavicencio, Medellin and Valle del Oriente, and Bogota and Buenaventura

(9) Telecommunications

- To install local telephone circuits 981 miles in length

- To double the present 2,250 telegram circuits and the 12,230 telex circuits

- To establish 220 telephone offices in cities, towns and villages

- To progress telecommunication projects covering 18% of the rural population

(10) Tourism

- To make efforts to obtain foreign currency by atracting foreign tourists and to set a target of 20% of the population for the number of tourists in 1985

- To maintain a tourism information system and carry out market studies, and to establish a comprehensive tour information and tour logistics organization

- To develop tourist resorts in Suroccidente, Amazonia, Llanos, Orientales, Nororiente and Caribe

Colombia's GDP growth rate from 1960 to 1970 was 5.2% and 6.1% from 1970 to 1980.

The government of Colombia indicated these policies for a four year plan toward reactivation of her economy on the basis of the achievement of these growth rates.

According to the policy, it is estimated that an economic growth rate target of 5.0% per annum is possible. It is also estimated that the present GDP per capita can be doubled after 25 years if the population growth is small.

7.3.2 Methodology Used in Electric Demand Projection

In creating an electric demand projection, it is essential to have the real status of electric demands reflected in the projection, by conducting actual surveys on the major demand areas, in addition to reviewing the basic data available on electric demand (such as past demand records, demographic trends, national development projects and demand related to such projects). For this, the study mission conducted the following site surveys.

(1) The study mission surveyed the electric demand records for all of Colombia, both at the power plant bus-bars and at customers' receiving end, based on data available in ICEL for a 13 year period from 1971 to 1983. For the bus-bar demands, each utilities power generation records were surveyed. For the customer's end demands, the amount of loads of each customer category were surveyed according to the Colombia's load classifications.

(2) As the Atrato Hydroelectric Project is situated in northwestern Colombia, most of its output is consumed in Medellin City and its surrounding areas. However, to assess the loads that may be supplied

through the national interconnection grid, the mission travelled to Bogota, Colombia's capital city and also Medellin City, Barranquilla City, Cartagena City and Cali City, to visit utilities in these cities and to conduct hearings on the status of power demand and rural electrification programs.

(3) The mission visited the head office of ISA in Medellin City, and conducted hearings on the status of electric power development in Colombia and the future electric demand. ISA plays a significant role in Colombia's power supply with its large hydro and thermal power plant and development programs and its construction of 500 kV transmission lines. This utility is expected to contribute to even greater lengths in electric supply in the future. In this context, ISA's electric power development programs and load projections have significant meaning. ISA provided sufficient information to the mission which was extremely useful in creating the demand forecast.

(4) The mission visited Barranquilla Thermal Power Station (314 MW), Salvajina Hydroelectric Power Station (210 MW) and Ancon Sur Substation, which have key functions in the national interconnection system. In these facilities, the mission surveyed the power supply records, load curves, and the status of facility periodical inspection and fault shutdowns.

The electric demand projection was developed in reference to past records and based on the methodology described below. It is well known that electricities consumption is closely correlated to national economic activities, and which is expressed by a macroscopic parameter termed GDP. As electric power is used almost universally in all national economic activities, including in the production and consumption of goods and services, the amount of electricity consumed has a very good correlation to the GDP in long termed observations.

A long term macroscopic projection of a nation's electric demand is usually performed by relying on the correlation between GDP per capita and the amount of electric consumption per capita, or kWh/capita. The coefficient of this correlation is determined by such factors as the size of the economy and the living standard of the people, and which differ considerably from one country to another. According to a statistical survey conducted by EPDC on various countries, and authorized by international institutions such as the International Atomic Energy Agency (IAEA) and the World Bank (IBRD), it is found that a general statistical trend correlates the electric power consumption per capita to the per capita income level. To utilize this trend in a electric demand projection, the following parameters are required.

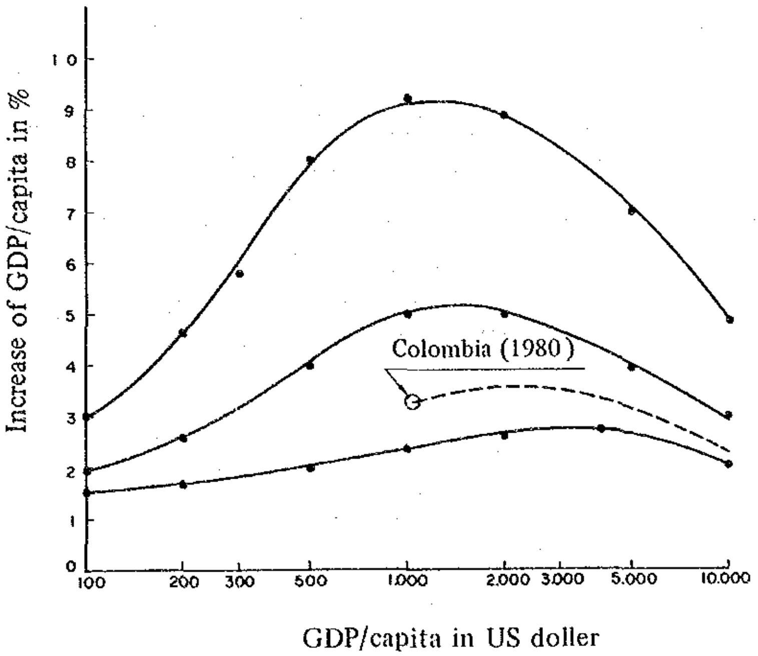
- The present average GNP/capita growth rate as deduced from past records of national economy.
- The present GNP/capita level.
- The present of kWh/capita level.
- The trend in the change of the economic growth rate corresponding to GNP/capita growth.

As of 1982, Colombia's GDP per capita was 1,460 U.S. dollars. GDP per capita in 1980 was 1,040 U.S. dollars in the 1980 price, as shown in Fig. 7-2. By extending the long term trend line representing Colombia's GDP/capita growth rate, expressed by the dotted line in the figure, it can be assumed that the GDP/capita will reach 2,440 U.S. dollars in 25 years, or in the year 2005. It can also be assumed that the growth of electricity consumption per capita will follow the trend given in Fig. 7-3. That is, starting from the 717 kWh electricity consumption per capita in 1980, this figure will be 1,760 kWh after 25 years, or in 2005.

7.3.3 Electric Demand Projection

The electric demand projection established by the study mission is very similar to the projection created by ISA, as shown in Table-7.4. In the year 2005, ISA's projection is only 2% higher than that of the study mission. The average growth rate of electric demand up to the year 2000 is 6.5% in ISA's projection, and 6.2% in the projection prepared by JICA's study mission. The study mission thus concluded that ISA's electric demand projection is appropriate.

Fig. 7-2 Increase of GDP/Capita (Constant Price in 1980)



Year	GDP/capita (US$)	Increase (%)
1980	1,040	
		3.3
1985	1,223	
		3.4
1990	1,444	
		3.5
1995	1,715	
		3.6
2000	2,045	
		3.6
2005	2,440	

Note a) GDP/capita in 1982: 1,460 US$

b) GDP/capita in 1980: (constant price)

$$1,460 \times \frac{47.05}{63.51} = 1,082\text{US\$}$$

Fig. 7-3 Energy Path per Capita

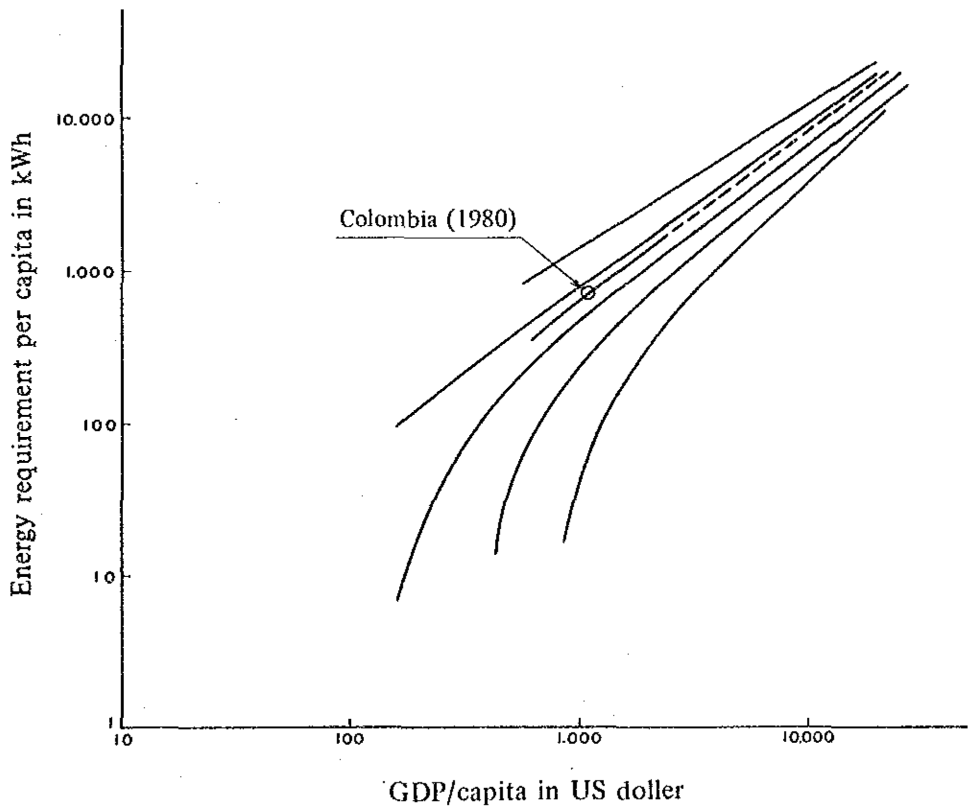


Table-7.4 Power Demand Estimated by JICA

Year	Estimated by JICA		Generated Energy		by ISA	Ratio
	Population	Increase	per Capita	Total (A)	(B)	(B)/(A)
	(10^3 persons)	(%)	(kWh)	(GWh)	(GWh)	
1960	15,420		201	3,105	-	-
		3.2				
1965	18,040		279	5,034	-	-
		2.6				
1970	20,530		361	7,406	-	-
		2.9				
1975	23,640		513	12,137	-	-
		2.8				
1980	27,090		717	19,428	-	-
		2.7				
1985	30,940		860	26,608	26,446	0.99
		2.6				
1990	35,144		1,030	36,198	37,039	1.02
		2.4				
1975	39,540		1,229	48,594	50,479	1.04
		2.2				
2000	44,080		1,467	64,665	67,300	1.04
		2.0				
2005	48,670		1,760	85,660	87,958	1.02

Table-7.5 Power Demand Forecast for National Power System

Year	EEEB		EPM		CVC		ICEL: CQR		ICEL: NORDESTE		ICEL: Electrificadoras		ICEL: Sub-total		CORELCA		Interconnected Line Loss		National Power System		
	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(%)
1983	(1,158)	(5,857)	(963)	(5,042)	(593)	(2,986)				(1,642)			(906)	(4,308)	(727)	(4,258)	(73)	(366)	(4,238)	(22,824)	(61.5)
84	1,222	6,310	1,011	5,312	622	3,161	295	1,420	347	1,761	293	1,412	935	4,593	811	4,816	98	490	4,501	24,682	62.6
85	1,305	6,738	1,072	5,647	659	3,361	316	1,523	371	1,890	315	1,523	1,002	4,936	881	5,264	100	500	4,807	26,446	62.8
86	1,393	7,199	1,134	5,989	699	3,557	337	1,634	400	2,032	337	1,631	1,074	5,297	956	5,680	120	600	5,148	28,322	62.8
87	1,485	7,659	1,202	6,361	741	3,772	359	1,738	429	2,173	364	1,758	1,152	5,669	1,040	6,179	132	660	5,508	30,300	62.8
88	1,583	8,175	1,282	6,780	789	4,033	387	1,878	464	2,337	389	1,899	1,240	6,114	1,135	6,658	144	720	5,913	32,480	62.7
89	1,681	8,706	1,362	7,191	840	4,290	414	2,018	496	2,512	423	2,052	1,333	6,582	1,227	7,176	156	780	6,322	34,725	62.7
1990	1,777	9,297	1,438	7,635	886	4,529	442	2,151	531	2,683	453	2,199	1,426	7,033	1,313	7,715	166	830	6,711	37,039	63.0
91	1,882	9,857	1,524	8,085	940	4,810	474	2,320	567	2,875	487	2,360	1,528	7,555	1,405	8,245	211	1,055	7,177	39,607	63.0
92	2,002	10,504	1,614	8,582	993	5,058	507	2,477	605	3,082	522	2,547	1,634	8,106	1,499	8,762	224	1,120	7,634	42,132	63.0
93	2,109	11,156	1,699	9,078	1,044	5,336	541	2,653	644	3,293	555	2,722	1,740	8,668	1,600	9,353	234	1,170	8,072	44,761	63.3
94	2,225	11,814	1,795	9,579	1,098	5,611	578	2,817	685	3,525	589	2,926	1,852	9,268	1,712	10,021	250	1,250	8,560	47,543	63.4
95	2,346	12,464	1,897	10,134	1,157	5,932	616	3,011	728	3,751	633	3,144	1,977	9,906	1,821	10,683	272	1,360	9,075	50,479	63.5
96	2,480	13,145	1,998	10,679	1,218	6,253	656	3,208	777	4,013	683	3,385	2,116	10,606	1,936	11,389	312	1,560	9,642	53,632	63.5
97	2,608	13,856	2,100	11,248	1,280	6,589	694	3,424	824	4,251	731	3,627	2,249	11,302	2,053	12,159	344	1,720	10,192	56,874	63.7
98	2,734	14,615	2,195	11,835	1,342	6,917	737	3,641	869	4,500	779	3,881	2,385	12,022	2,177	12,977	377	1,880	10,746	60,246	64.0
99	2,867	15,660	2,304	12,732	1,405	7,452	784	3,783	921	4,712	833	3,949	2,538	12,444	2,322	13,422	399	1,990	11,344	64,700	64.1
2000	3,016	16,458	2,421	13,372	1,473	7,830	830	4,017	974	5,024	888	4,238	2,692	13,279	2,492	14,261	421	2,100	11,967	67,300	64.2
01	3,182	17,281	2,547	14,105	1,548	8,222	882	4,258	1,034	5,330	941	4,514	2,857	14,102	2,666	15,159	440	2,200	12,578	71,069	64.5
02	3,357	18,145	2,679	14,850	1,627	8,633	938	4,514	1,099	5,656	998	4,807	3,035	14,977	2,853	16,114	464	2,330	13,262	75,049	64.6
03	3,542	19,052	2,819	15,576	1,710	9,064	997	4,784	1,167	6,001	1,058	5,120	3,222	15,905	3,053	17,130	489	2,450	13,970	79,177	64.7
04	3,736	20,005	2,965	16,241	1,797	9,517	1,060	5,071	1,239	6,367	1,121	5,453	3,420	16,891	3,267	18,209	515	2,590	14,701	83,453	64.8
05	3,942	21,005	3,119	16,935	1,889	9,993	1,127	5,376	1,316	6,755	1,188	5,808	3,631	17,939	3,505	19,356	541	2,730	15,471	87,958	64.9
Increase (%)																					
1984–2000	5.8	6.2	5.6	5.9	5.5	5.8	6.7	6.7	6.6	6.8	7.2	7.1	6.8	6.9	7.3	7.0	-	-	6.3	6.5	-
2000–2005	5.5	5.0	5.2	4.8	5.1	5.0	6.3	6.0	6.2	6.1	6.0	6.5	6.2	6.2	7.0	6.3	-	-	5.2	5.5	-

Source: Sistema Interconectado Colombiano, Actualizacion Plan Expansion by ISA, Medellin Octubre, 1984.

Note : Figures in parenthesis indicate the actual value of power demand Agrregated peak demands are calculated with the diversity factor of 1,043.

CQR : Caldas, Quindio and Risaralda)
NORDESTE : Boyaca, Santander and Norte de Santander
Electificadoras: Cauca, Narino, Talima, Huila and Caqueta

7.3.4 Balance of Power Supply and Demand

At present, the capacity of hydroelectric power stations accounts for 76% of the total supply capacity in Colombia's national power grid, with thermal power stations accounting for the least, at 24%. This ratio is expected to be 87% vs. 13% in the year 2000.

With this heavy emphasis on hydroelectric power, it is necessary to examine the balance of power supply and demand paying careful consideration to the change of supply capability from the wet season to the dry season, and seasonal load changes.

The effective installed capacity and corresponding supply capability in the national power grid are illustrated in Table-7.6 for the 4 years 1980 to 1983. This table indicates that the supply capability fell short of 80% of the effective installed capacity in only 2 months, namely November, 1981 and 1982. Since both existing hydroelectric power stations and those planned for future construction are located on the main streams and tributaries of the Cauca and Megdelens Rivers, it can be expected that the hydroelectric power station supply characteristics will remain almost the same as in the record of the past 4 years. That is, the demand (kW) balance will be generally maintained if the supply capability, which is assumed to be 20% less the effective installed capacity, is sufficient to meet the demand. (See Fig. 7-5.)

In studying the energy (kWh) balance, the monthly generations of all electric utilities were studied for the 3 years 1981 to 1983. These records were compared to the available power generations of each power station to confirm the validity of data, which are presented in Appendix-I. Based on these studies, the annual available generations for future years were calculated.

As presented in Table-7.8, the available generations exceed the energy demand of the load. However, the surplus of available generation will be relatively small, being only 3.5% in excess of the energy (kWh) demand of the load in 1993, when the Atrato Hydropower Project is scheduled to commence service.

The calculation results are presented in Table-7.8 and Table-7.9.

7.3.5 Power Balance when El Siete No.1 and No.2 Commence Service

In 1993 and 1995, the supply capability, which is 80% the effective installed capacity, the maximum power demand, and the reserve capacity which is the surplus of supply over demand, will be as presented in the table below.

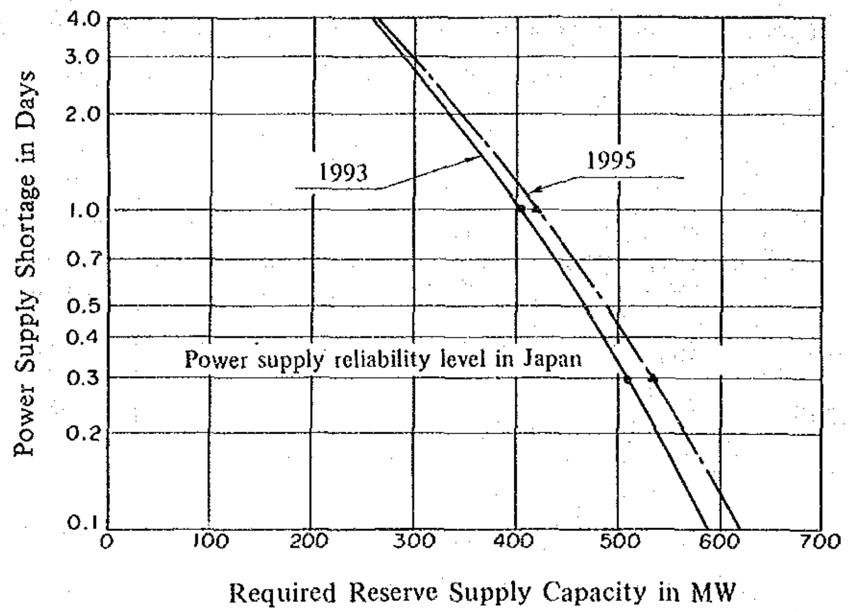
Year	Effective Installed Cap. (MW)	Supply Capability (MW)	Maximum Power Demand (MW)	Reserve Capacity (MW)
1993	10,233	8,186	8,072	114
1995	11,817	9,454	9,075	379

The feasibility study mission set appropriate outage factors (*) (including scheduled and un-scheduled shutdowns) on each type of generator connected to the national power grid, and calculated the power supply shortage probability (the number of days in a year the supply shortage occurs). These calculation results are presented in the table below.

Note: * Refer to Appendix-I.

	Required Reserve Capacity	
Supply Reliability (Shortage in Days)	1993 (MW)	1995 (MW)
1.0	402.9	417.8
0.3	509.6	531.7
0.1	589.9	617.1

Fig. 7-4 Supply Reliability



With proper assumption on the probability of the outage of generators connected to the national power grid, the amount of reserve capacity required in 1993 will be 500 MW using the same reliability evaluation criterion as in Japan. In contrast, the expected reserve capacity will be only 114 MW, or a 400 MW reserve capacity shortage. With this reserve capacity, in 1993 the national power grid will probably experience 5 days of power shortage per year, (or 365 days) resulting in a power system frequency reduction of approximately 0.5 Hz.

Colombia's electric power development program seems fairly appropriate in terms of power supply reliability up to the year 1992. After 1993, however, the supply capability will be insufficient even after El Siete No. 1 (75.0 MW) and El Siete No. 2 (85.0 MW) of the Atrato Hydropower Project are put on line. It would therefore be necessary to have Calima No. 3 (270 MW) and Niel No. 1 (384 MW) Power Stations commence service 1 year earlier than according to the present schedule.

Table-7.6 Actual Supply Capability of National Power System

Unit: P.U.

Months	Interconnected Power System			
	1980	1981	1982	1983
January	0.93	0.870	0.898	0.892
February	0.88	0.892	0.882	0.894
March	0.85	0.884	0.889	0.889
April	0.87	0.899	0.888	0.885
May	0.87	0.883	0.871	0.890
June	0.87	0.888	0.800	0.889
July	0.88	0.856	0.876	0.864
August	0.88	0.845	0.840	0.862
September	0.90	0.850	0.816	0.857
October	0.87	0.802	0.804	0.827
November	0.88	0.786	0.796	0.845
December	0.90	0.899	0.824	0.845

Source: Annual Reports of ISA

Fig. 7-5 Power Development Plan

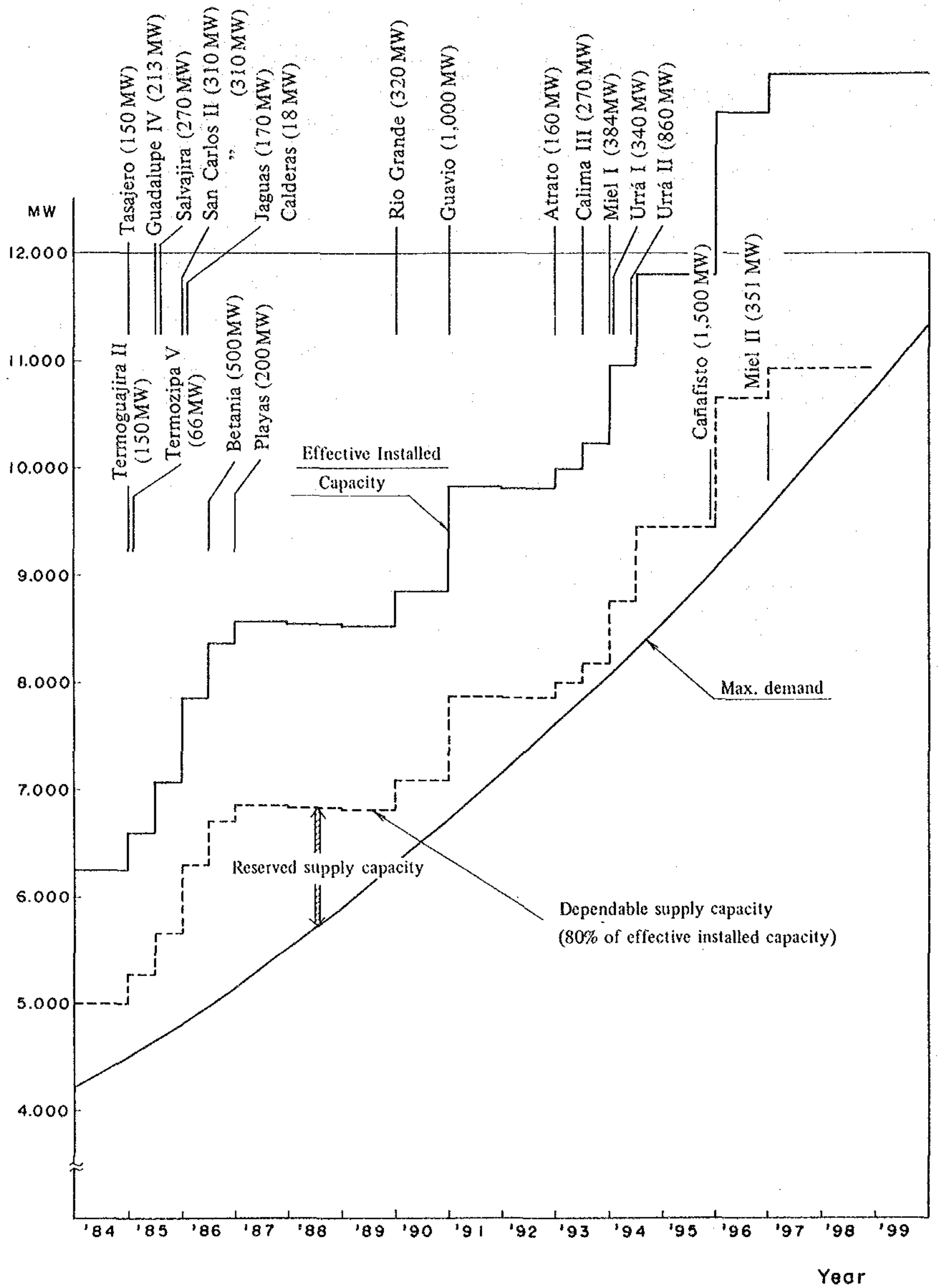


Table-7.7 Actual Energy Supply of Existing Hydro Power Plants

	Unit	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
EEEB (547.5 MW)														
Energy generated in 1981	GWh	193.1	178.9	194.4	236.1	298.2	273.5	237.7	251.3	233.3	244.7	239.8	180.3	2,761.3
" " 1982	GWh	212.1	156.4	215.6	276.4	272.1	256.9	281.0	247.9	239.9	286.8	236.5	217.0	2,898.6
" " 1983	GWh	224.5	232.6	312.4	323.8	311.9	287.8	306.5	256.3	273.5	280.9	249.9	257.5	3,317.6
Average generation	GWh	209.9	189.1	240.8	278.8	294.1	272.7	275.1	251.8	248.9	270.8	242.1	218.3	2,992.4
Plant factor	%	51.3	51.4	59.1	70.7	72.2	69.2	67.5	61.8	63.1	66.5	61.4	53.6	62.4
EPM (995.5 MW)														
Energy generated in 1981	GWh	364.8	341.4	377.9	379.6	339.5	346.8	394.1	379.3	382.5	403.1	364.9	466.5	4,540.4
" " 1982	GWh	364.7	424.9	456.8	428.0	420.1	426.8	472.4	429.4	469.2	477.1	473.0	488.3	5,330.7
" " 1983	GWh	467.0	477.9	470.3	400.4	413.6	385.1	411.8	405.1	423.4	473.7	409.4	353.2	5,090.9
Average generation	GWh	398.8	414.7	435.0	402.7	391.1	386.2	426.1	404.6	425.0	451.3	415.7	436.0	4,987.2
Plant factor	%	53.8	62.0	58.7	56.2	52.8	53.8	57.5	54.6	59.3	60.9	58.0	58.9	57.2
CVC (539.0 MW)														
Energy generated in 1981	GWh	157.7	162.2	161.3	210.1	228.2	185.1	174.3	144.0	152.8	106.3	187.0	178.4	2,047.2
" " 1982	GWh	193.6	177.5	173.7	239.2	234.5	164.2	104.6	100.2	114.7	182.1	183.8	133.0	2,001.1
" " 1983	GWh	105.4	98.2	114.8	163.1	161.8	139.8	74.4	70.4	75.1	119.0	134.7	192.5	1,446.2
Average generation	GWh	152.2	146.0	149.9	204.1	208.2	163.0	117.8	104.9	114.2	135.8	168.5	168.0	1,832.6
Plant factor	%	38.0	40.3	37.4	52.6	51.9	42.0	29.3	26.2	29.4	33.9	43.4	41.9	38.8
ICEL (331.0 MW)														
Energy generated in 1981	GWh	95.7	87.1	107.1	105.8	122.2	130.9	116.5	100.6	94.4	98.5	101.9	111.9	1,272.7
" " 1982	GWh	124.9	112.3	123.5	132.3	127.9	121.4	104.5	90.3	79.1	97.4	111.3	114.9	1,339.8
" " 1983	GWh	112.4	90.1	99.4	106.1	123.7	112.3	99.0	86.3	73.2	83.7	86.8	101.8	1,174.8
Average generation	GWh	111.0	96.5	110.0	114.7	124.6	121.5	106.7	92.4	82.2	93.2	100.0	109.5	1,262.4
Plant factor	%	45.1	43.4	44.7	48.1	50.6	51.0	43.3	37.5	34.5	37.3	42.0	44.5	43.5
ISA (1,000.0 MW)														
Energy generated in 1981	GWh	299.6	281.6	299.7	169.7	166.4	244.9	317.6	368.6	343.0	315.7	302.1	247.3	3,356.2
" " 1982	GWh	194.9	223.9	221.8	180.6	230.7	275.8	362.9	412.8	319.7	234.5	251.5	287.2	3,196.3
" " 1983	GWh	303.6	251.5	268.1	238.9	280.0	311.9	366.6	470.4	415.5	342.7	324.5	314.3	3,888.0
Average generation	GWh	266.0	252.3	263.2	196.4	225.7	277.5	349.0	417.3	359.4	297.6	292.7	282.9	3,480.0
Plant factor	%	35.8	37.5	35.4	27.3	30.3	38.5	46.9	56.1	49.9	40.0	40.7	38.0	39.7
System Total (3,413 MW)														
Average generation	GWh	1,137.9	1,098.6	1,198.9	1,196.7	1,243.7	1,220.9	1,274.7	1,271.0	1,229.7	1,248.7	1,219.0	1,214.7	14,554.5
Plant factor	%	44.8	47.9	47.2	48.7	49.0	49.7	50.2	50.1	50.0	49.2	49.6	47.8	48.7

Source: Annual Reports of ISA

Table-7.8 (1) Energy Balance of National Power System

Unit: GWh

Power System	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
EEEB															
Existing P.P	4,202	4,202	4,202	4,202	4,202	4,202	4,202	5,587	5,587	5,587	5,587	5,587	5,587	5,587	5,587
EPM															
Existing P.P	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740	4,740
Guadalupe IV	-	1,120/2	1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120
Playas	-	-	-	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
La Tasajera	-	-	-	-	-	-	1,289	1,289	1,289	1,289	1,289	1,289	1,289	1,289	1,289
Niquia	-	-	-	-	-	-	156	156	156	156	156	156	156	156	156
Sub-total	4,740	5,300	5,860	7,260	7,260	7,260	8,705	8,705	8,705	8,705	8,705	8,705	8,705	8,705	8,705
CVC-CHIDRAL															
Existing P.P	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167	2,167
Salvajina	-	925/2	925	925	925	925	925	925	925	925	925	925	925	925	925
Calima III	-	-	-	-	-	-	-	-	-	1,118/2	1,118	1,118	1,118	1,118	1,118
Sub-total	2,167	2,629	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,651	4,210	4,210	4,210	4,210	4,210
ICEL															
Existing P.P	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380	2,380
* Tasajero	-	920	920	920	920	920	920	920	920	920	920	920	920	920	920
Atrato I & II	-	-	-	-	-	-	-	-	-	1,063	1,063	1,063	1,063	1,063	1,063
Miel I	-	-	-	-	-	-	-	-	-	-	1,535	1,535	1,535	1,535	1,535
Miel II	-	-	-	-	-	-	-	-	-	-	-	-	-	1,895/2	1,895
Sub-total	2,380	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	4,363	5,898	5,898	5,898	6,845	7,793
CORELCA															
Existing P.P	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979	3,979
Termoguajira II	-	920	920	920	920	920	920	920	920	920	920	920	920	920	920
Sub-total	3,979	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899

Table-7.8 (2) Energy Balance of National Power System

Unit: GWh

Power System	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
ISA															
Existing	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705	4,705
San Carlos I & II	3,900	3,900	5,890	5,890	5,890	5,890	5,890	5,890	5,890	5,890	5,890	5,890	5,890	5,890	5,890
Termozipa V	-	405	405	405	405	405	405	405	405	405	405	405	405	405	405
Calderas	-	79	79	79	79	79	79	79	79	79	79	79	79	79	79
Jaguas	-	780	780	780	780	780	780	780	780	780	780	780	780	780	780
Betania	-	-	2,250/2	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250
Guavio	-	-	-	-	-	-	-	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Urra I	-	-	-	-	-	-	-	-	-	-	1,575	1,575	1,575	1,575	1,575
Urra II	-	-	-	-	-	-	-	-	-	-	2,475/2	2,475	2,475	2,475	2,475
Canafisto	-	-	-	-	-	-	-	-	-	-	-	-	6,700	6,700	6,700
Sub-total	8,605	9,869	12,984	14,109	14,109	14,109	14,109	19,109	19,109	19,109	21,921	23,159	29,859	29,859	29,859
National Power System															
EEEB	4,202	4,202	4,202	4,202	4,202	4,202	4,202	5,587	5,587	5,587	5,587	5,587	5,587	5,587	5,587
EPM	4,740	5,300	5,860	7,260	7,260	7,260	8,705	8,705	8,705	8,705	8,705	8,705	8,705	8,705	8,705
* CVC-CHIDRAL	2,167	2,629	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,651	4,210	4,210	4,210	4,210	4,210
ICEL	2,380	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	4,363	5,898	5,898	5,898	6,845	7,793
CORELCA	3,979	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899	4,899
ISA	8,605	9,869	12,984	14,109	14,109	14,109	14,109	19,109	19,109	19,109	21,921	23,159	29,859	29,859	29,859
A Total	26,073	30,199	34,337	36,862	36,862	36,862	38,307	44,692	44,692	46,314	51,220	52,458	59,158	60,105	61,053
B Energy Demand	24,682	26,446	28,322	30,300	32,480	34,725	37,039	39,607	42,132	44,761	47,543	50,479	53,632	56,874	60,246
C Difference (A-B)	1,391	3,753	6,015	6,562	4,382	2,137	1,268	5,085	2,560	1,553	3,677	1,979	5,526	3,231	807
A-B/A (%)	5.3	12.4	17.5	17.8	11.9	5.8	3.3	11.4	5.7	3.5	7.3	3.9	10.6	5.5	1.4

Table-7.9 (1) Power Balance of National Power System

Unit: MW

Power System	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
EEEB															
Existing P.P	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278
EPM															
Existing P.P	975	975	975	975	975	975	975	975	975	975	975	975	975	975	975
Guadalupe IV	-	213	213	213	213	213	213	213	213	213	213	213	213	213	213
Playas	-	-	-	200	200	200	200	200	200	200	200	200	200	200	200
La Tasajera	-	-	-	-	-	-	300	300	300	300	300	300	300	300	300
Niquia	-	-	-	-	-	-	20	20	20	20	20	20	20	20	20
Sub-total	975	1,188	1,188	1,388	1,388	1,388	1,708	1,708	1,708	1,708	1,708	1,708	1,708	1,708	1,708
CVC-CHIDRAL															
Existing P.P	584	584	584	584	584	584	584	584	584	584	584	584	584	584	584
Salvajina	-	270	270	270	270	270	270	270	270	270	270	270	270	270	270
Calima III	-	-	-	-	-	-	-	-	-	240	240	240	240	240	240
Sub-total	584	854	854	854	854	854	854	854	854	1,094	1,094	1,094	1,094	1,094	1,094
ICEL															
Existing P.P	658	658	658	658	658	658	658	658	658	658	658	658	658	658	658
* Tasajero	-	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Atrato I & II	-	-	-	-	-	-	-	-	-	160	160	160	160	160	160
Miel I	-	-	-	-	-	-	-	-	-	-	384	384	384	384	384
Miel II	-	-	-	-	-	-	-	-	-	-	-	-	-	351	351
Sub-total	658	808	808	808	808	808	808	808	808	968	1,352	1,352	1,352	1,703	1,703
CORELCA															
Existing P.P	934	916	896	896	888	875	864	848	842	842	842	842	842	842	842
Termoguajira II	-	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Sub-total	934	1,066	1,046	1,046	1,038	1,025	1,014	998	992	992	992	992	992	992	992

Table-7.9 (2) Power Balance of National Power System

Unit: MW

Power System	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
ISA															
Existing	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199	1,199
San Carlos I & II	620	620	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240	1,240
Termozipa V	-	66	66	66	66	66	66	66	66	66	66	66	66	66	66
Calderas	-	-	18	18	18	18	18	18	18	18	18	18	18	18	18
Jaguas	-	-	170	170	170	170	170	170	170	170	170	170	170	170	170
Betania	-	-	500	500	500	500	500	500	500	500	500	500	500	500	500
Guavio	-	-	-	-	-	-	-	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Urra I	-	-	-	-	-	-	-	-	-	-	340	340	340	340	340
Urra II	-	-	-	-	-	-	-	-	-	-	860	860	860	860	860
Canafisto	-	-	-	-	-	-	-	-	-	-	-	-	1,500	1,500	1,500
Sub-total	1,819	1,885	3,193	3,193	3,193	3,193	3,193	4,193	4,193	4,193	5,393	5,393	6,893	6,893	6,893
National Power System															
EEEB	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278	1,278
EPM	975	1,188	1,188	1,388	1,388	1,388	1,708	1,708	1,708	1,708	1,708	1,708	1,708	1,708	1,708
* CVC-CHIDRAL	584	854	854	854	854	854	854	854	854	1,094	1,094	1,094	1,094	1,094	1,094
ICEL	658	808	808	808	808	808	808	808	808	968	1,352	1,352	1,352	1,703	1,703
CORELCA	934	1,066	1,046	1,046	1,038	1,025	1,014	998	992	992	992	992	922	992	992
ISA	1,819	1,885	3,193	3,193	3,193	3,193	3,193	4,193	4,193	4,193	5,393	5,393	6,893	6,893	6,893
A Total	6,248	7,079	8,367	8,567	8,559	8,546	8,855	9,839	9,833	10,233	11,817	11,817	13,317	13,668	13,668
B Power Demand	4,501	4,807	5,148	5,508	5,913	6,322	6,711	7,177	7,634	8,072	8,560	9,075	9,642	10,192	10,746
C Difference (A-B)	1,747	2,272	3,219	3,059	2,646	2,224	2,144	2,662	2,199	2,161	3,257	2,742	3,675	3,476	2,922
A-B/A (%)	28.0	32.1	38.5	35.7	30.9	26.0	24.2	27.1	22.4	21.1	27.6	23.2	27.6	25.5	21.4

CHAPTER 8. HYDROLOGICAL ANALYSIS

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CHAPTER 8. HYDROLOGICAL ANALYSIS

8.1 General Weather Conditions in Project Area

8.1.1 General Weather Conditions in Choco Prefecture

The Atrato River originates in the Western Andes Mountains and flows down the western slopes in a south-west direction to the Choco Plain, where it turns and flows further north to finally drain into the Caribbean Sea. Thus, almost all the drainage area of the Atrato River is in Choco prefecture.

Choco prefecture is located in the north-western part of Colombia lying in the neighbourhood of the equator (from N 4°00' to N 8°40'), providing a tropical climate to the Choco prefecture lowlands with the high temperature and humidity and the heaviest rainfall in the world.

The maximum daily temperature is 28° - 30°C and the daily minimum is about 22°C at Quibdo, the capital of Choco prefecture located at the center of the lowlands. This varies by 6° - 8°C in a day and these patterns do not change throughout the year.

The climate gradually changes from tropical, to subtropical and temperate in proportion to increased altitudes as the river goes upstream and the temperature is about 20°C daily maximum and about 13°C daily minimum at La Mansa, the highest meteorological station in Atrato Basin (2,100 m above sea water level).

Seasonal temperature variations at La Mansa are extremely small as well as that in the lowlands and this is a distinctive feature of these areas.

The heaviest rainfall is in the Quibdo, Tutunendo vicinity as shown in Fig. 8-1 (1), (2) sometimes exceeding 12,000 mm annually in very rainy years. This value decreases in downstream and upstream area and is about 2,000 mm/year at the lower reaches of the river, while it is about 3,000 mm/year at La Mansa.

Generally, there is no sharp distinction between rainy and dry seasons and in the lowlands, it rains throughout the year.

8.1.2 General Weather Conditions in Project Area

The project area is located in the uppermost reaches of the Atrato River and is higher than 700 m above sea water level, and therefore has a subtropical or temperate climate.

Rainfall is as much as 6,000 - 8,000 mm/year at the El Piñon rainfall station which is the lowest station in the project area, (EL. 715 m), but decreases as the altitude increases to become about 3,000 mm/year at La Mansa.

Generally, the seasonal rainfall variation is very small and at El Pinon station distinction between rainy and dry seasons is unclear, but at the heigher stations, such as Carmen de Atrato, La Mansa, a small seasonal variation appears and the 3 months from January to March can be considered as the dry season with the remaining months being the rainy season.

The daily maximum temperature is about 20°C with a minimum at about 13°C providing a 7°C daily variation at La Mansa.

The temperature around the project site (EL. 1,000 - 1,500 m) is assumed to be 24° - 27°C daily maximum and 16° - 18°C daily minimum, because temperatures generally increase with decreased altitudes.

The seasonal temperature variation for the project site is considered small, considering the example of Quibdo, La Mansa.

Humidity is very high at a relative humidity of over 80% throughout the year.

Evaporation is about 1,200 mm/year at La Mansa and as in the case of humidity, its seasonal variation is small.

Fig. 8-1 (1) Mean Annual Precipitation (Year: 1974)

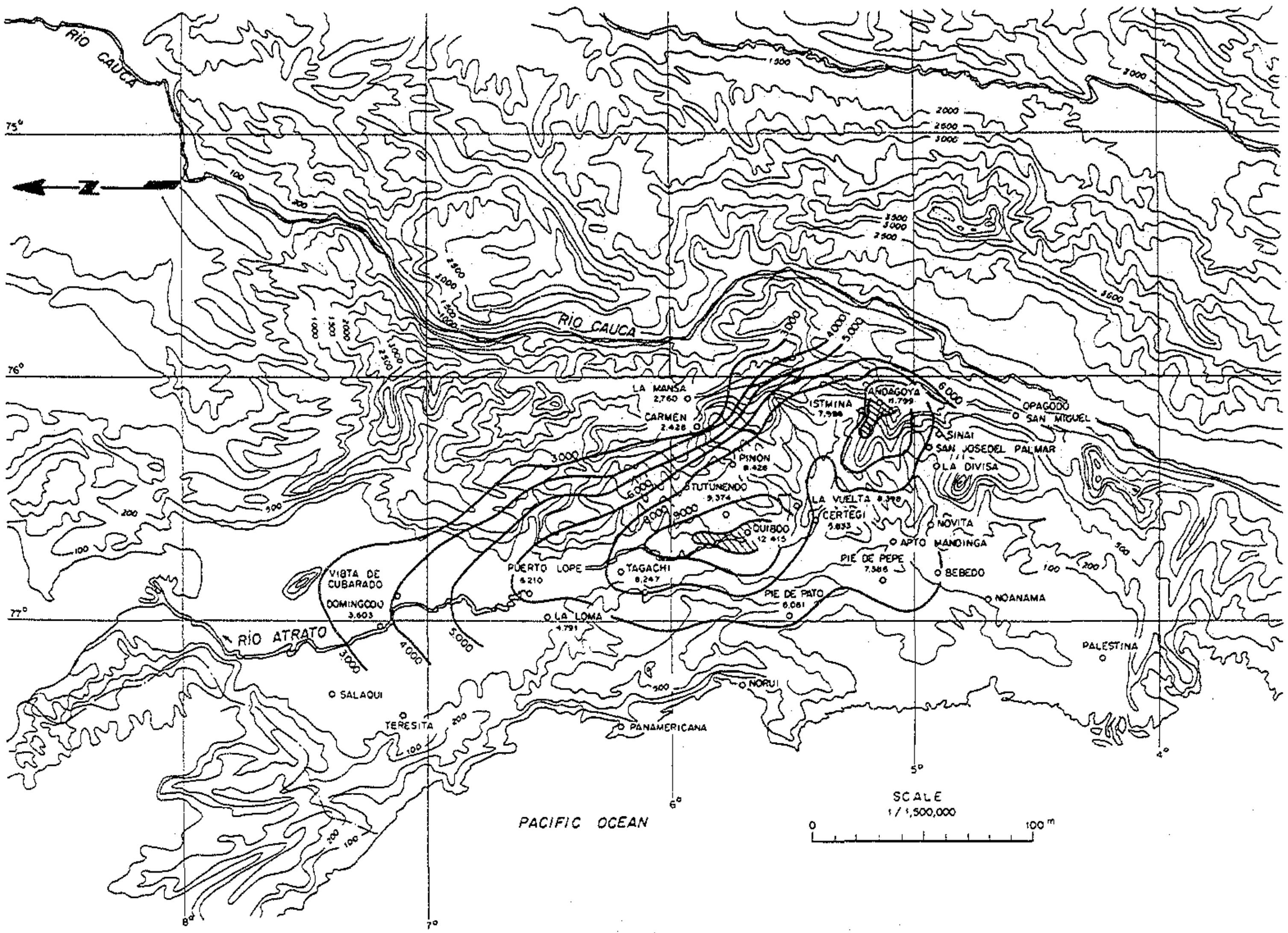
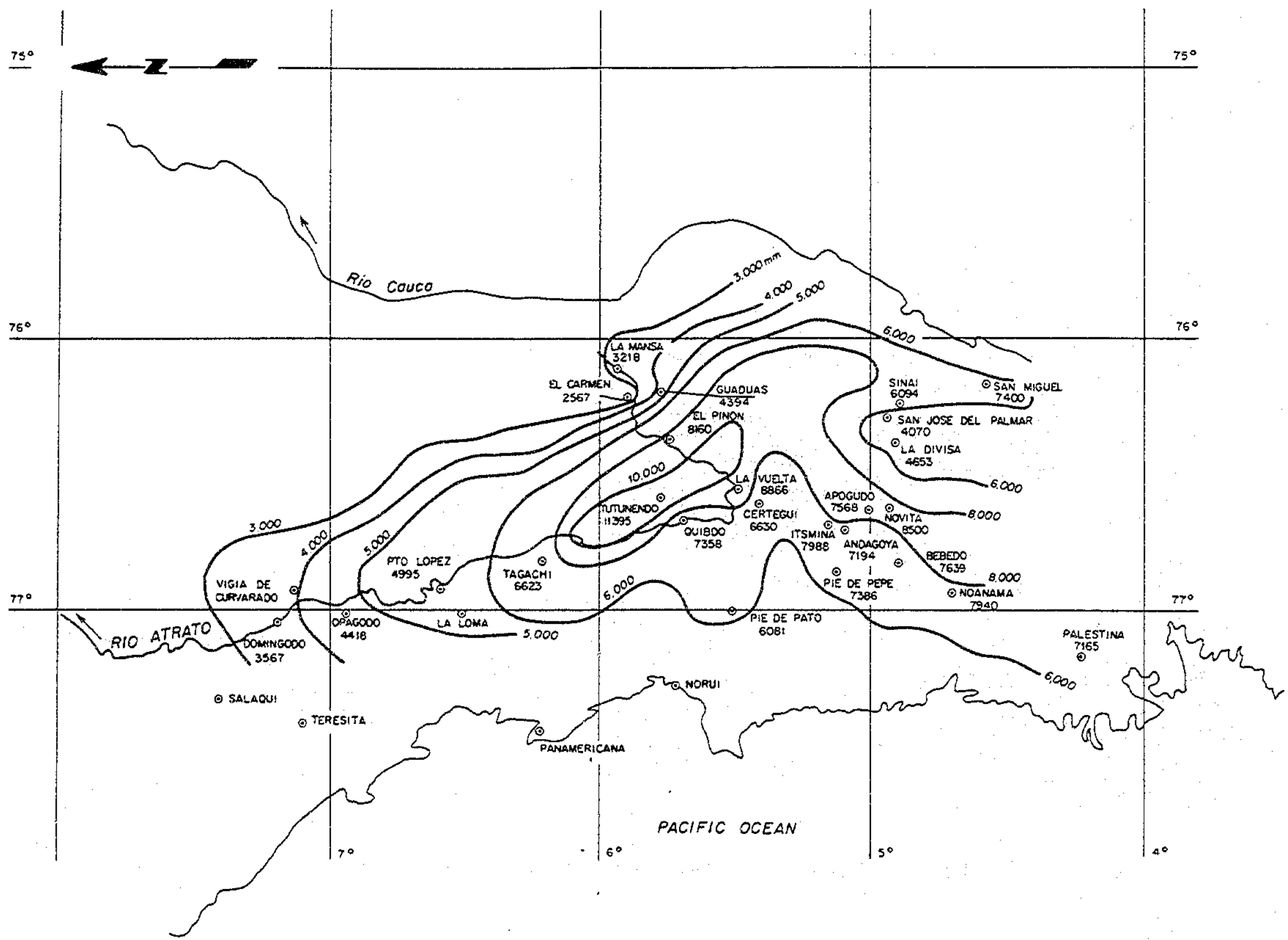


Fig. 8-1 (2) Mean Annual Precipitation (Year: 1984)



8.2 Existing Hydrologic and Meteorological Stations α Those Records

Appendix - II shows all lists of existing hydrologic and meteorological stations in Choco prefecture. Of these, the stations related to the project area hydrological analysis are La Mansa meteorological station, Carmen de Atrato, Girardot, El Pinon rainfall stations and the El Siete, Las Sanchez, Girardot, El Pinon gauging stations, shown in Fig. 8-3. The Girardot rainfall and gauging station was established in 1984 by ICEL according to JICA recommendations and the other stations established and measured by HIMAT (Instituto Colombiano de Hidrologia, Meteorologia y Adecuacion de Tierras).

The recording periods for these hydrologic and meteorological stations are shown in Fig. 8-2, providing the folowing: The recording periods of the gauging stations are very limited and only river stage was observed. Precipitation was observed for a long time compared with river stage, but produces defective records occasionally. Necessary meteorological records at La Mansa have also not been adequately obtained.

As described, the obtained hydrologic and meteorological records are very limited. Taking this into account, it was determined to make hydrological analysis according to the following fundamental plans.

(1) Project site streamflows shall be estimated from the river stage records at related gauging stations, applying the rating curves developed on the bases of the river stage and discharge data measured at the same time in 1984 by ICEL.

(2) However, the runoff analysis shall be made on the basis of precipitation records and calculated runoff be used to complement defective records or unmeasured periods, because the river stage records were measured for a very limited period and are occasionally defective.

(3) Flood discharge shall be predicted by the runoff analysis using the daily precipitation records which cover a long period.

As the precipitaion records are defective, the Probable Rainfall (Stochastic Rainfall, PMP) shall be estimated by different methods and the largest value adopted.

(4) The total sediment load of the stream shall be estimated on the basis of the suspended load measurements carried out in 1984 by ICEL as no other available data exists.

Fig. 8-2 Registered Data of Meteorology and Hydrology

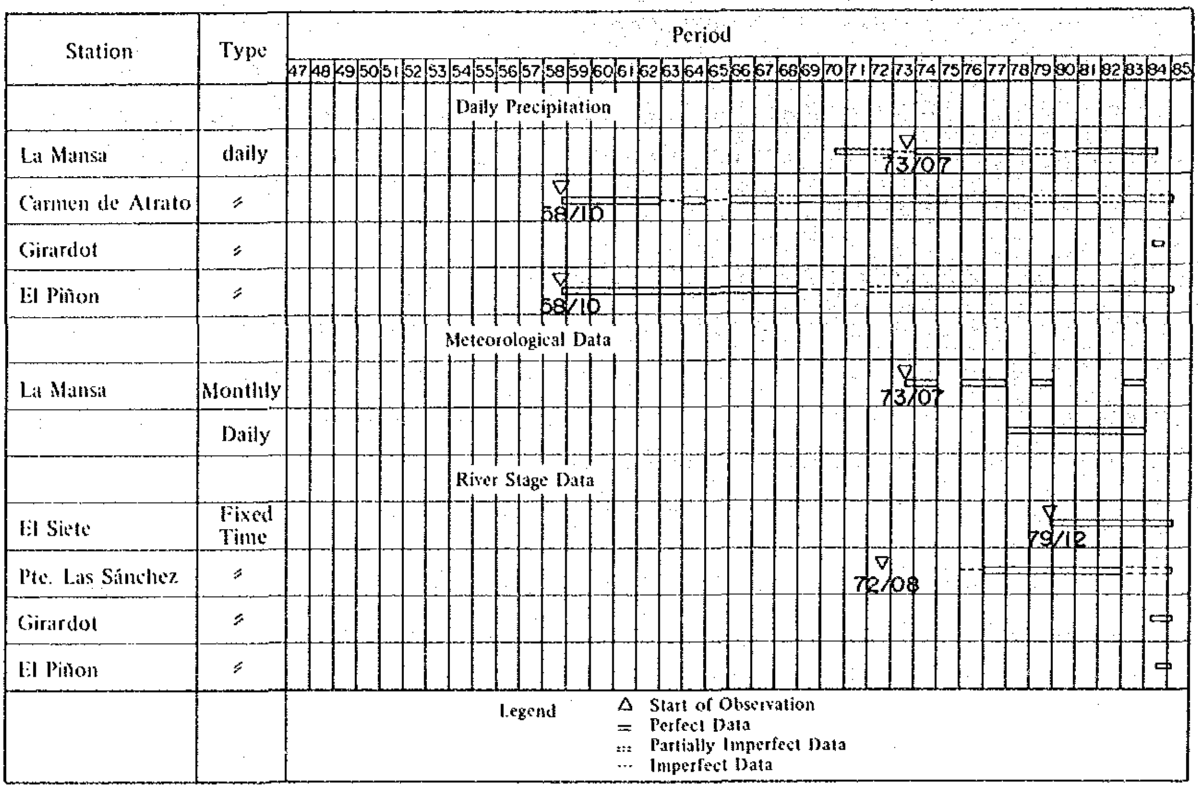
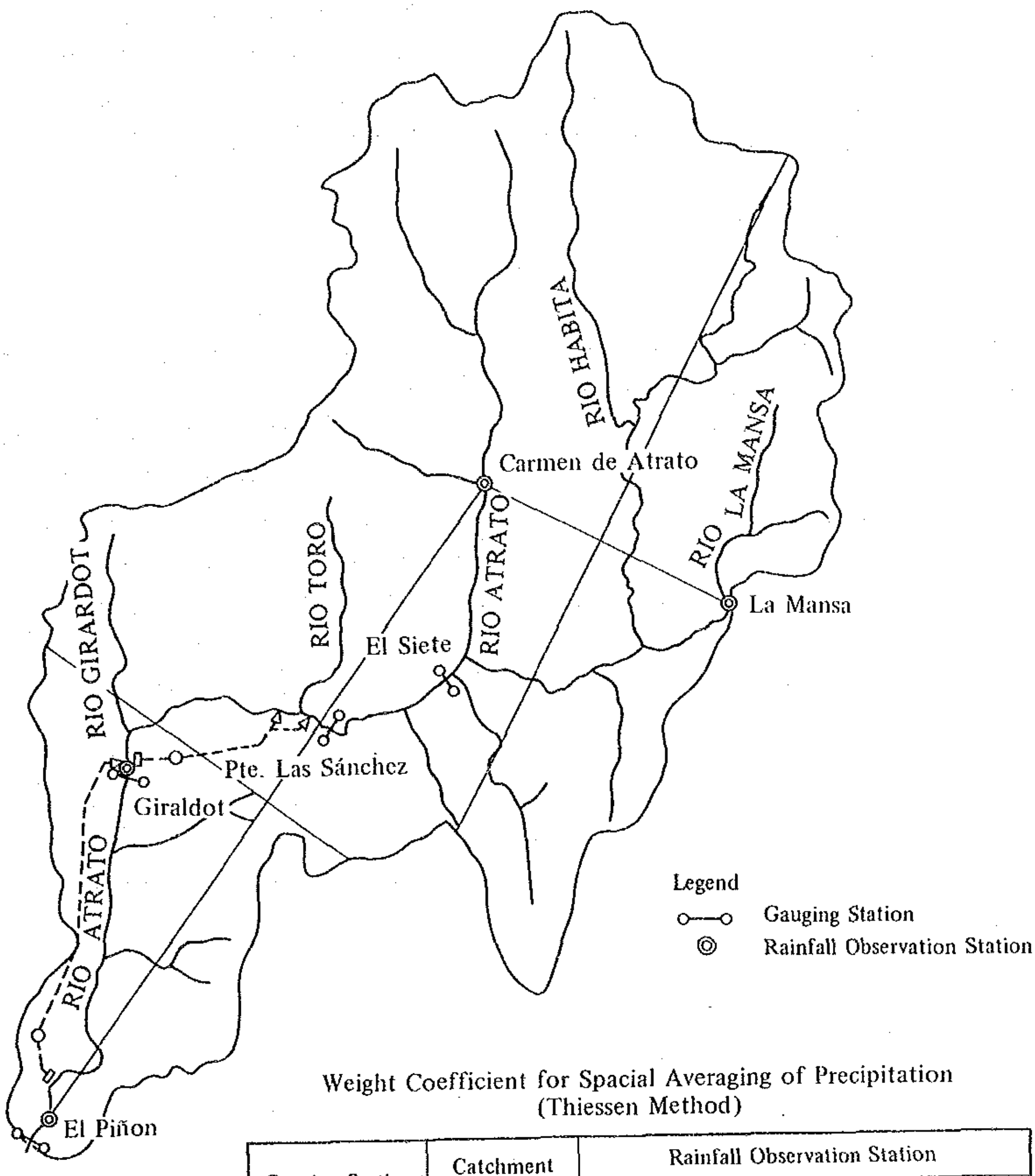


Fig. 8-3 Catchment Area for Atrato Project



Weight Coefficient for Spacial Averaging of Precipitation
(Thiessen Method)

Gauging Station	Catchment Area (km^2)	Rainfall Observation Station		
		La Mansa	Carmen de Atrato	El Piñon
El Siete	216.6	0.367	0.633	—
Pte. Las Sánchez	226.9	0.350	0.650	—
Girardot	297.9	0.263	0.737	—
El Piñon	347.4	0.226	0.607	0.167

8.3 Low Water Runoff Analysis

Stream flow was estimated from the river stage records (water surface elevation) measured at the gauging stations after the rating curves for these stations had been developed. Runoff analysis was then carried out using a "Tank Model", on the basis of precipitation records and calculated runoff used as a predicted streamflow to complement original data.

8.3.1 Rating Curve

The rating curves at El Siete, Las Sanchez, Girardot, El Piñon gauging stations were developed by the least squared method applied to the river stage and discharge records measured at the same time for the above gauging stations. The results are shown in Fig. 8-4 (1) - (4). The dotted lines in these figures show the rating curves obtained by ICEL [1], but the dotted lines seem to indicate that the discharge becomes larger as the river stage increases. It was therefore determined to adopt the rating curve developed here (the solid line) in the following analysis, but considering the scatter of data in these figures, further survey of river stage-discharge relations (especially for high stage) will be necessary for more accurate study.

The Las Sanchez gauging station rating curve was corrected so that the discharge corresponding to river stage of 1.22 m becomes 10 m^3/s, referring to the result of actual survey performed in February 1985 by JICA.

Fig. 8–4(1) Rating Curve (El Siete Gauging Station)

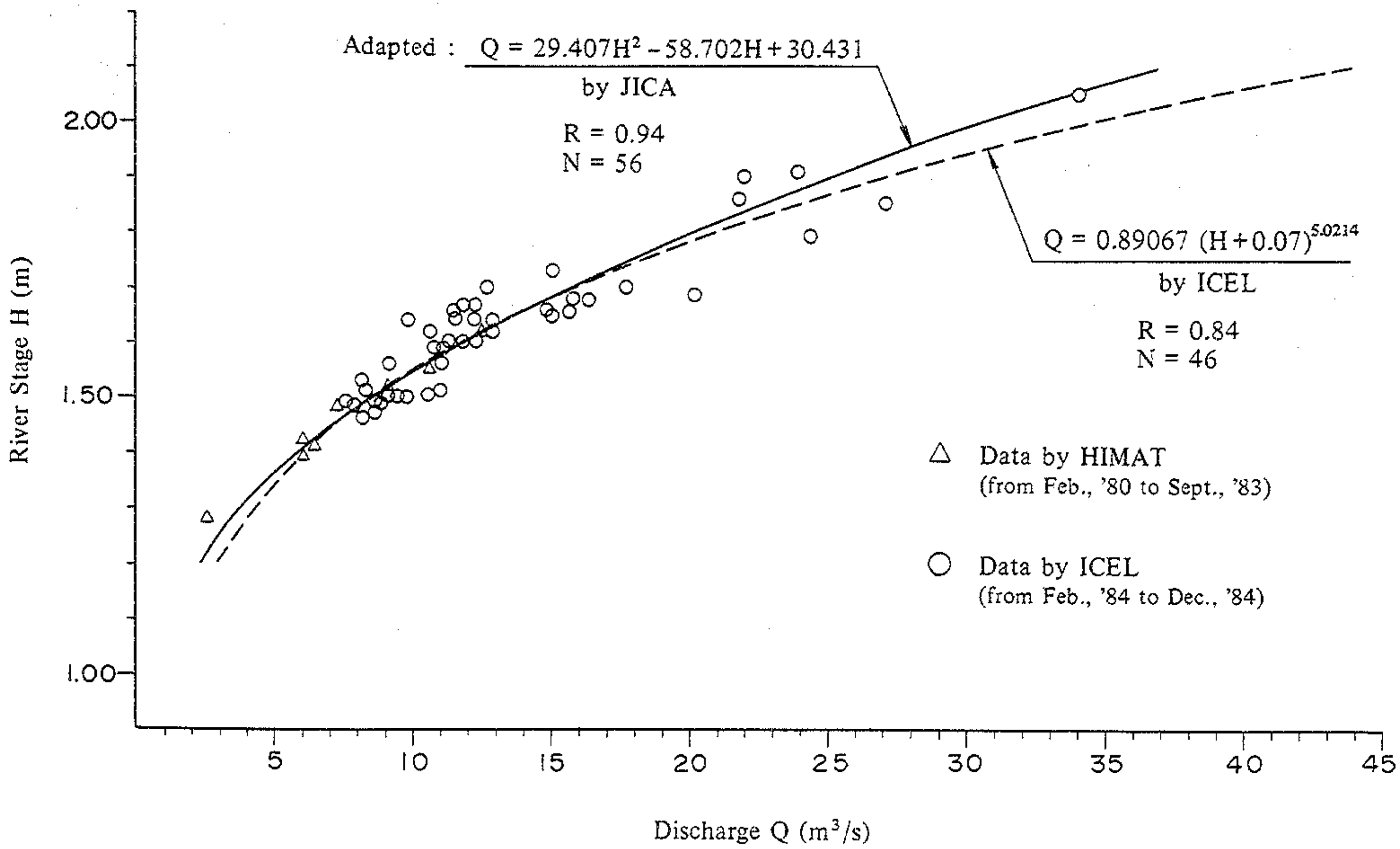


Fig. 8-4(2) Rating Curve (Pte. Las Sánchez Gauging Station)

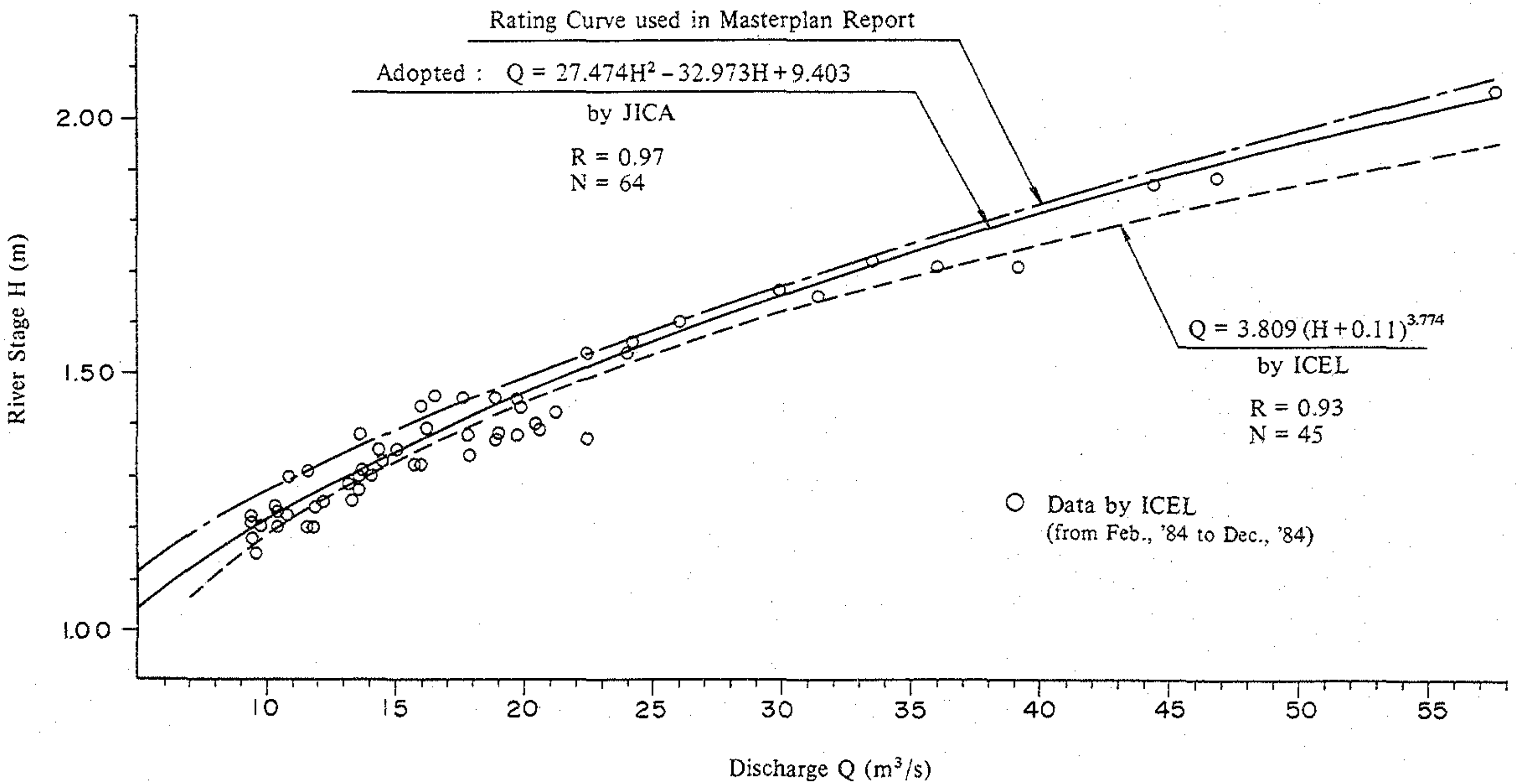


Fig Fig. 8-4(3) Rating Curve (Girardot Gauging Station)

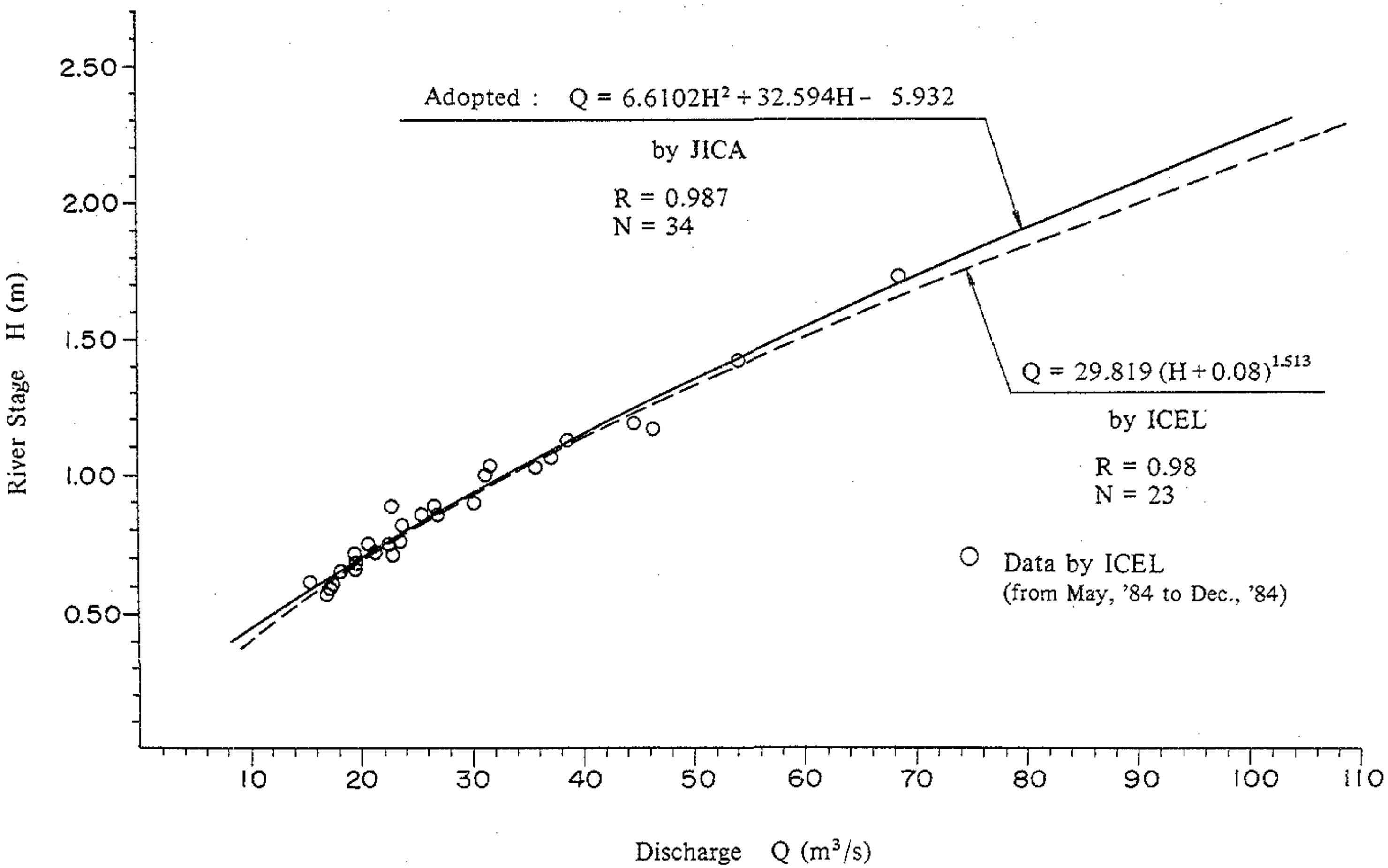
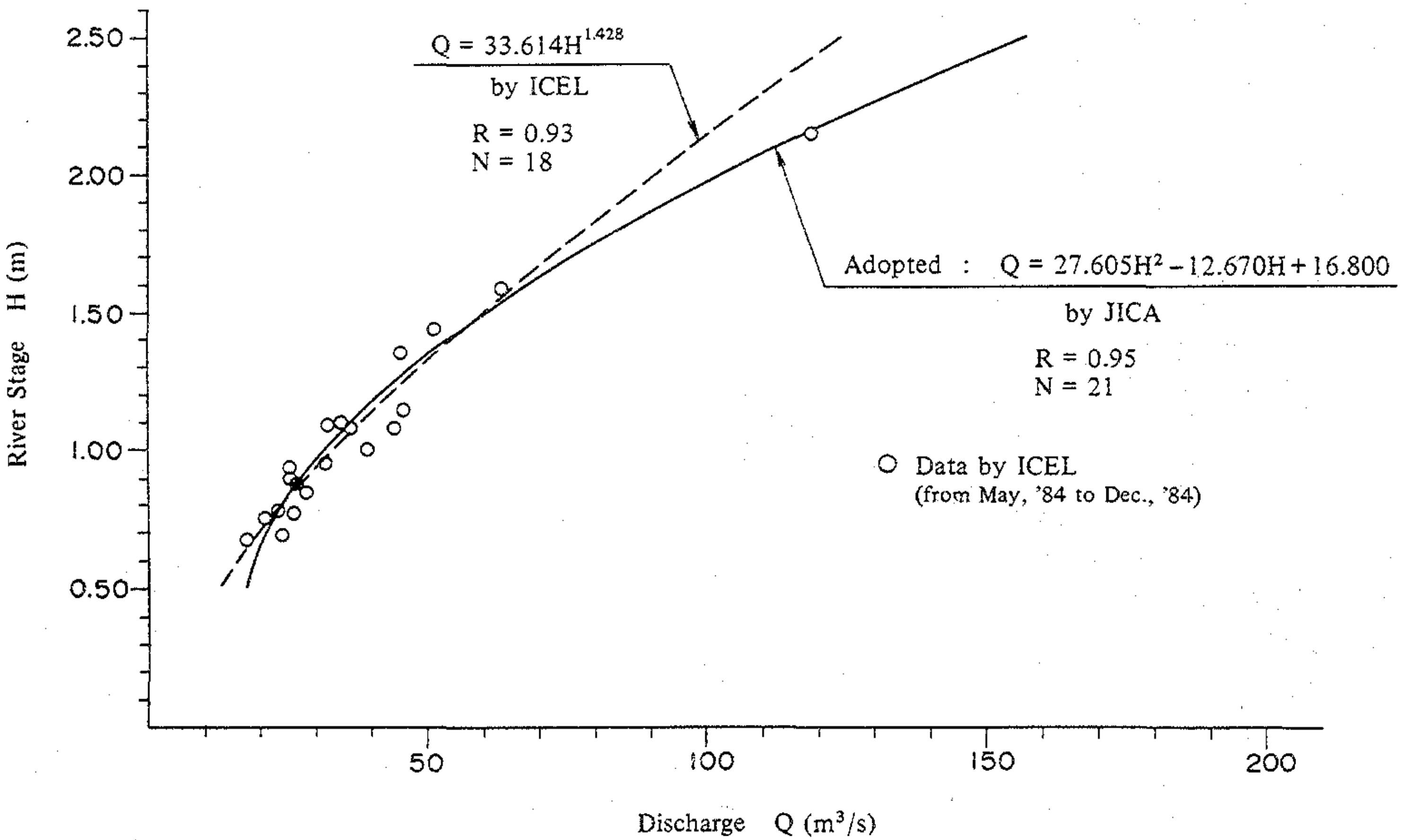


Fig. 8-4(4) Rating Curve (El Piñon Gauging Station)



8.3.2 Average Daily Discharge

Average daily discharge was calculated applying the above rating curves to the arithmetic mean of river stage records at 6 and 18 clock for El Siete, Las Sanchez, Girardot, El Pinon gauging stations. The results are shown in Appendix I-5. The Rainfall in this figure shows spacially averaged rainfall for the Las Sanchez basin calcurated by the Thiessen method. From this, the following points were determined:

(1) Discharge at El Siete gauging station (catchment area = 216.6 Km^2) is too small compared with that at las Sanchez gauging station (catchment area = 226.9 Km^2).

(2) Discharge in 1975, 1982 and 1983 for las Sanchez gauging station is contradictory to the rainfall pattern.

(3) Judging from the precipitation records, stream gauging periods seem to be dry years. Additional stream flow data are necessary to evaluate the average flow duration at the project sites.

This led to the following runoff analysis.

8.3.3 Runoff Analysis by "Tank Model"

(1) Analysis Outline

The "Tank Model" is a runoff analysis method wherein the river basin is modelled by a tank having an efflux hole on the side wall and runoff (equivalent to the outflow through the efflux hole) is estimated as a function of the rain storage volume in the tank.[2)]

The standard Tank Model used in low water runoff analysis consists of a series of 4 tanks, (shown in Fig. 8-5). The rainfall is poured into the uppermost tank and stored there. When the storage depth reaches the height of the side efflux hole, out-flow begins. The initial storage effect can be expressed by the storage of rain before efflux begins. The stored rain below the side efflux hole is poured into the lower tank through the base efflux hole and the same process occurs in the lower tank. The runoff time lag can be automatically given while the rain is transported to the lower tank.

Fig. 8-5 Tank Model and Adopted Parameters

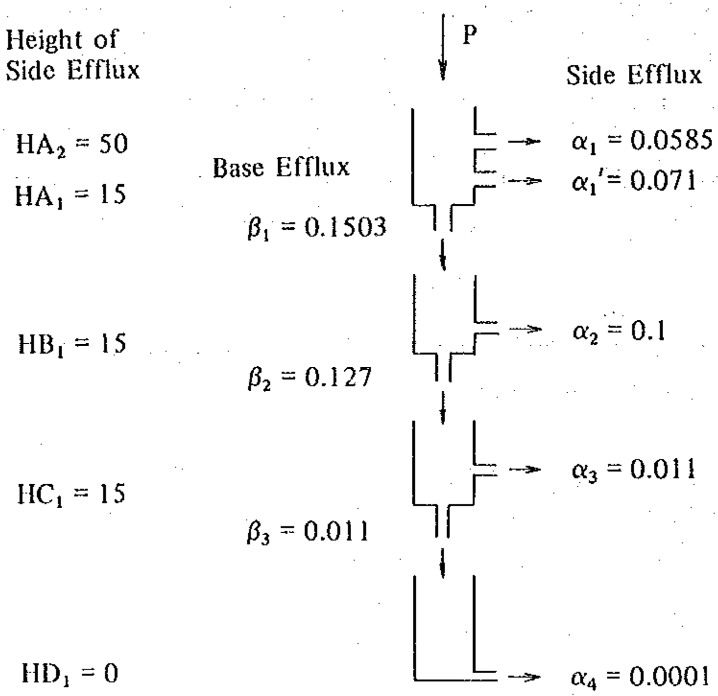
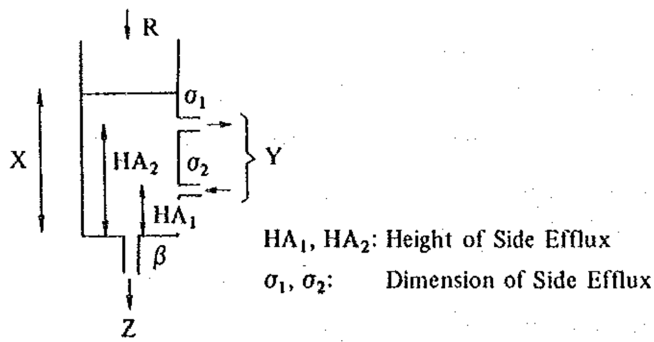


Fig. 8-6 Details of Uppermost Tank



The calculation procedure for the upper tank is as follows:

Let the side efflux hole dimensions be $_1$, $_2$, the base efflux hole dimension be and the efflux hole heights be HA_1, HA_2 as shown in Fig. 8-6. The rainfall, storage depth, side and base efflux depth at n time step are denoted by Rn, Xn, Yn, and Zn respectively, so that is obtained

$$Xn = X_{n-1} + Rn$$

$$Yn = \begin{cases} 0 & (0 < Xn < HA_1) \\ _1(Xn - HA_1) & (HA_1 < Xn \leqq HA_2) \\ _1(Xn - HA_1) + {}_2(Xn - HA_2) & (HA_2 < Xn) \end{cases}$$

$$Zn = \ Xn$$

The remaining storage depth Xn' is

$$Xn' = Xn - Yn - Zn$$

Then, the storage depth at n+1 time step X_{n+1} is obtained

$$X_{n+1} = Xn' + R_{n+1}$$

The above procedure can be repeated at each time step.

The sum of the out-flows from each side efflux hole expresses runoff at that time step.

(2) Runoff Analysis Results

The Tank Model parameters (side and base efflux hole dimensions, side efflux hole heights) were determined by using the spacially averaged rainfall and average daily discharge data of 6 years from 1976 to 1981 for Las Sanchez basin. These are shown in Fig. 8-5.

Runoff analysis was then carried out by the Tank Model using these parameters and spacially averaged rainfall data of 16 years from 1969 to 1984. The results are shown in Fig. 8-7 (1) - (16). In these figures, measured discharge is also shown by solid lines (see Fig. 8-7 (7) - (16)). By comparing the calculated runoff with the measured discharge, the adequacy of this analysis is proved.

The calculated runoff in 1971 was very large due to a heavy rainfall that year, but the year's precipitaion records show a curiously continuous pattern compared to those of other years and were concluded unreliable.

Measured discharge in 1975, 1982 and 1983 are also much different from the calculated value. This is due to measurement deficiencies, judging from the shape of the hydrograph for those years.

8.3.4 Estimation of Stream Flow at Project Sites

(1) Complement of Measured Discharge Data

The measured discharge data (average daily discharge) at Las Sanchez gauging station was complemented using the results of runoff analysis by the Tank Model.

The stream flow for the unmeasured period (1969 - 1975) was predicted by the calculated discharge from the precipitaion records, but nothing has supplemented for 1971.

The measured discharge data for 1982 and 1983 was replaced by the calculated data, as the original data are unreliable.

The partially defective stream flow data (unmeasured on a few days) for 9 years from 1976 to 1984, were complemented by the calculated discharge.

Thus, all stream flow data at Las Sanchez gauging station from 1969 to 1984 (except 1971) was perfected and these are decided to be the basic data for the estimation of stream flow at the project sites.

(2) Flow Duration at Project Sites

Fig. 8-8 (1) - (3) show the relations of specific discharge between El Siete, Pte. Las Sanchez, Girardot and El Pinon gauging stations. In the calculation of specific discharge, monthly averaged discharge and the maximum of the monthly discharge data were used.

These figures led to the conclusion that all gauging stations except El Siete, have the same specific discharge. Therefore, the stream flow at each project site can be calculated in proportion to the drainage area ratio from that of Las Sanchez gauging station.

The average duration curve at Las Sanchez is shown in Fig. 8-9. Table-8.1 shows the flow duration at each project site.

Table-8.1 Flow Duration at Project Site

(Unit: m^3/s)

Duration \ Project Site	Pte Las Sanchez Gauging Station A = 226.9 km^2	No.1 Auxiliary Intake Dam A = 235.7 km^2	El Siete No.1 Dam A = 256.3 km^2	El Siete No.2 Intake Dam A = 297.9 km^2
Maximum	48.1	50.0	54.3	63.2
35 Days	30.2	31.4	34.1	39.6
95 Days	24.0	24.9	27.1	31.5
185 Days	19.2	19.9	21.7	25.2
275 Days	15.3	15.9	17.3	20.1
355 Days	10.3	10.7	11.6	13.5
Minimum	9.2	9.6	10.4	12.1
Average	20.4	21.2	23.0	26.8

Fig. 8-7 (1) Results of Run-off Analysis

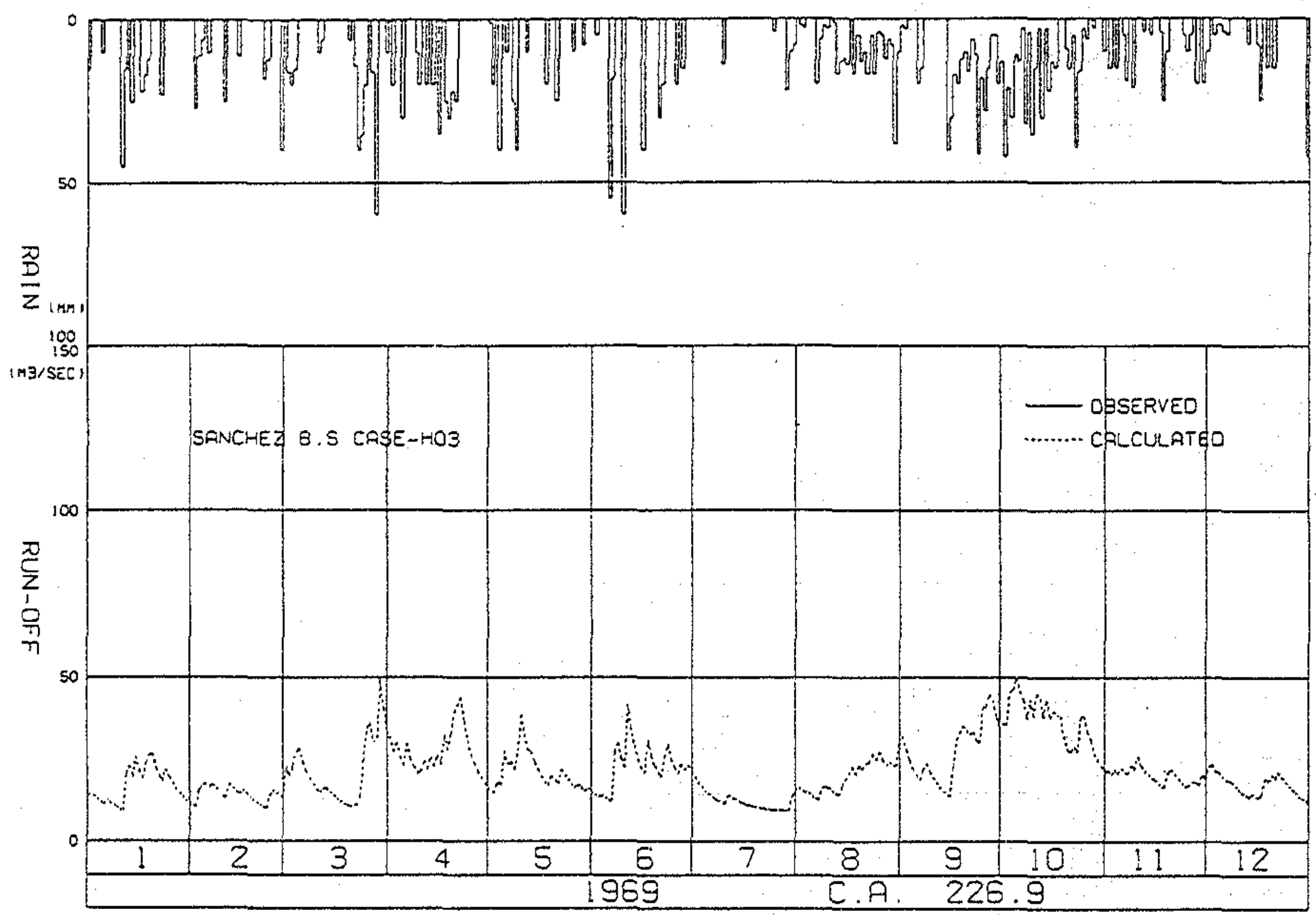


Fig. 8-7 (2) Results of Run-off Analysis

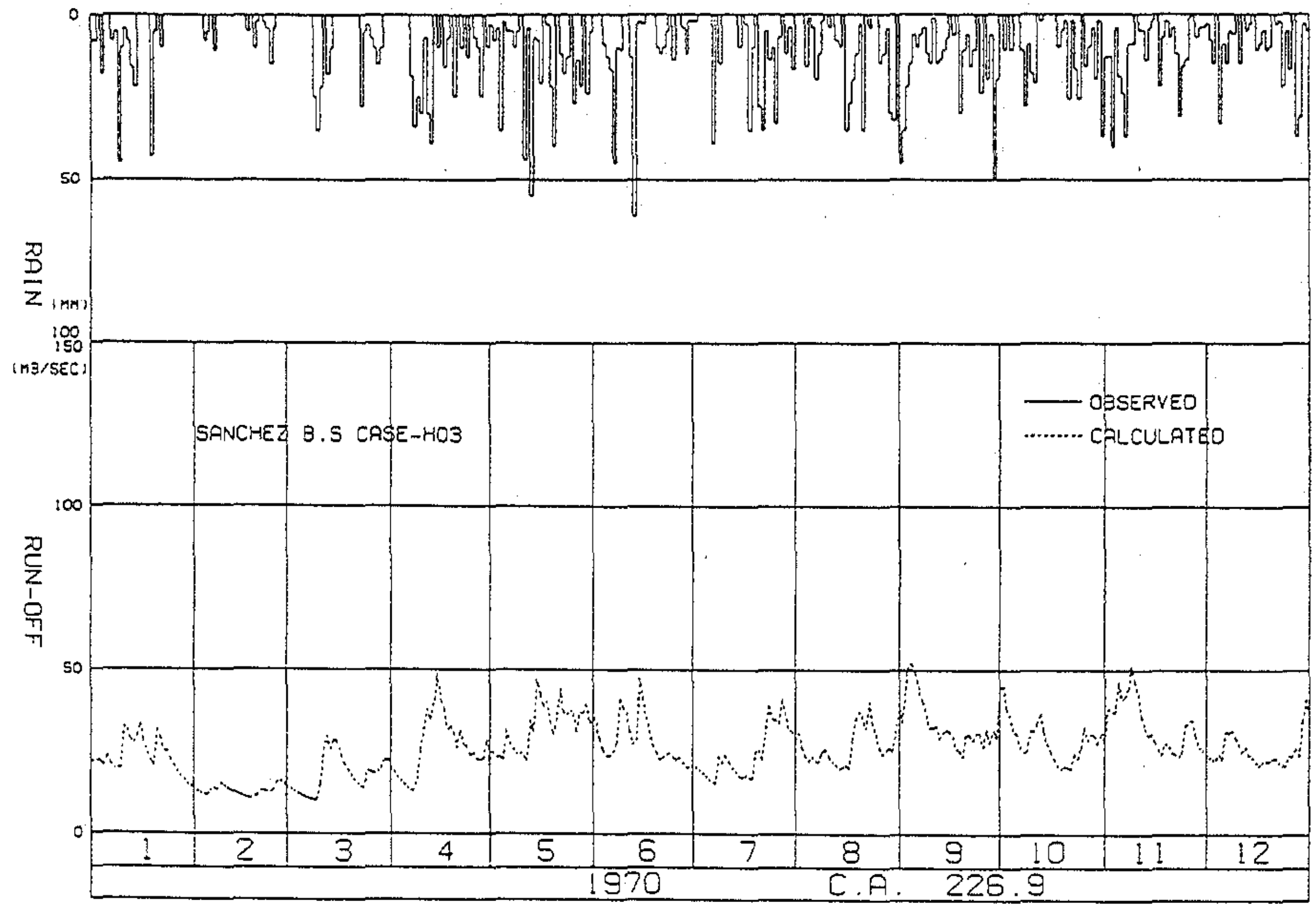


Fig. 8-7 (3)   Results of Run-off Analysis

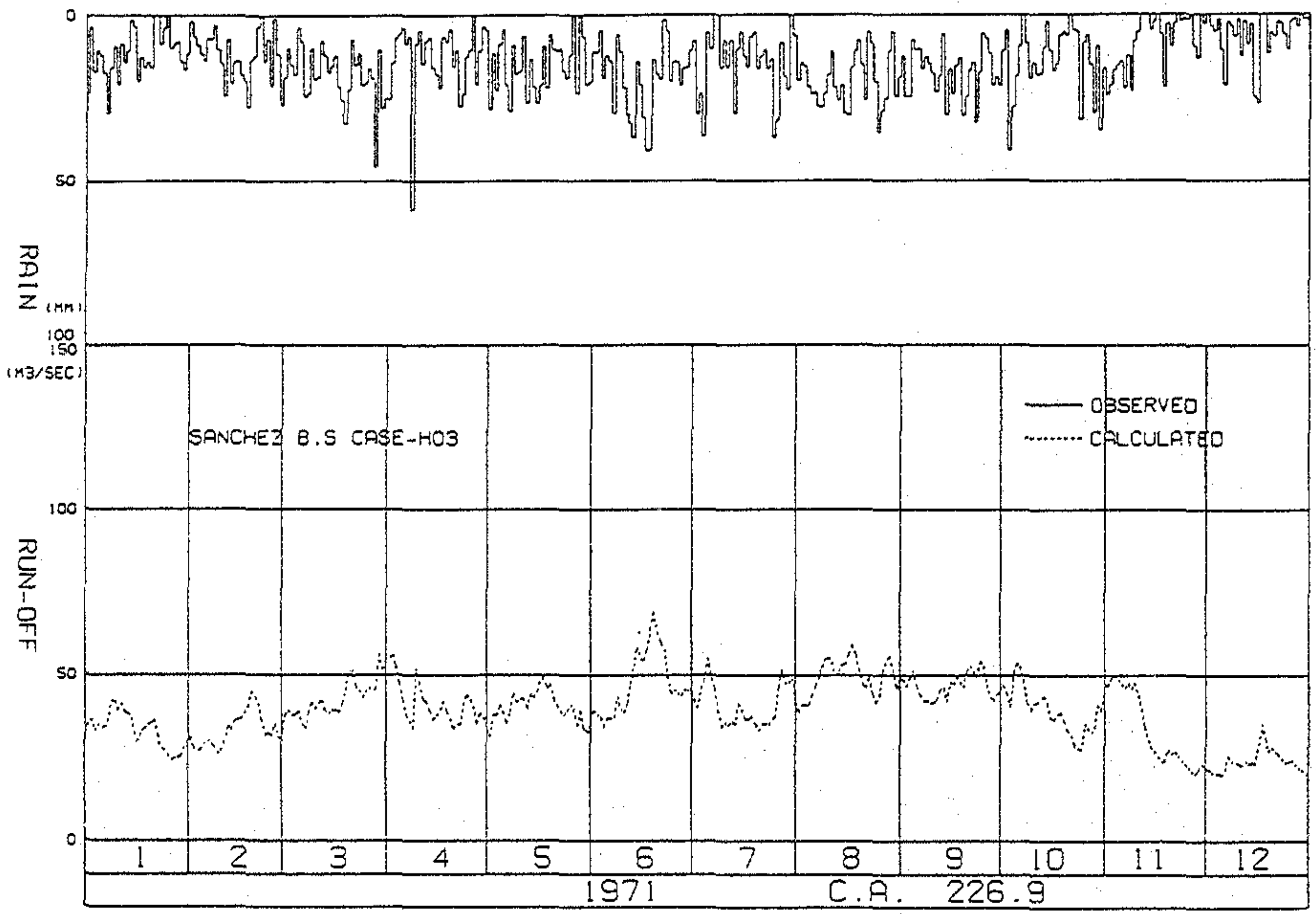


Fig. 8-7 (4) Results of Run-off Analysis

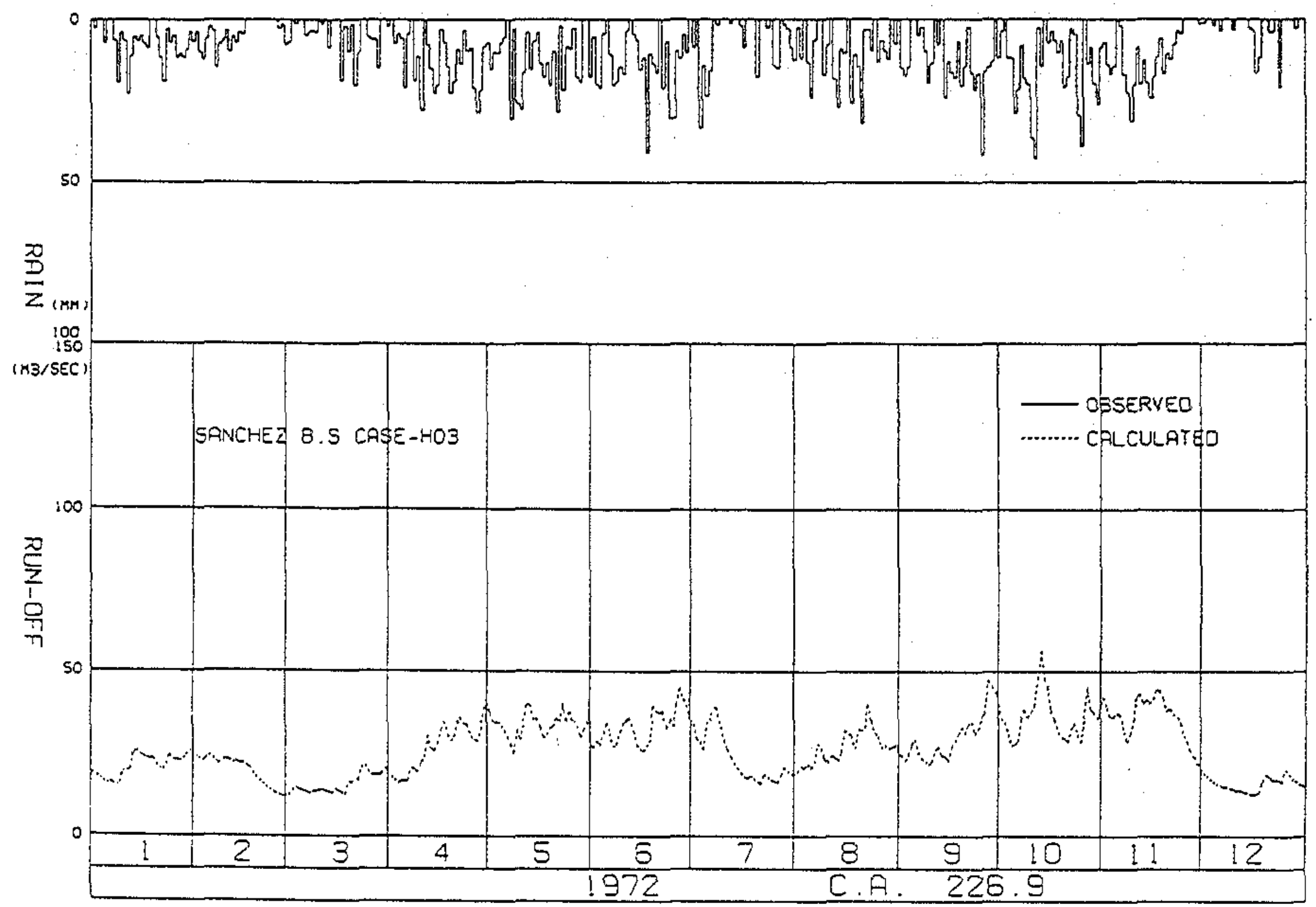


Fig. 8-7 (5) Results of Run-off Analysis

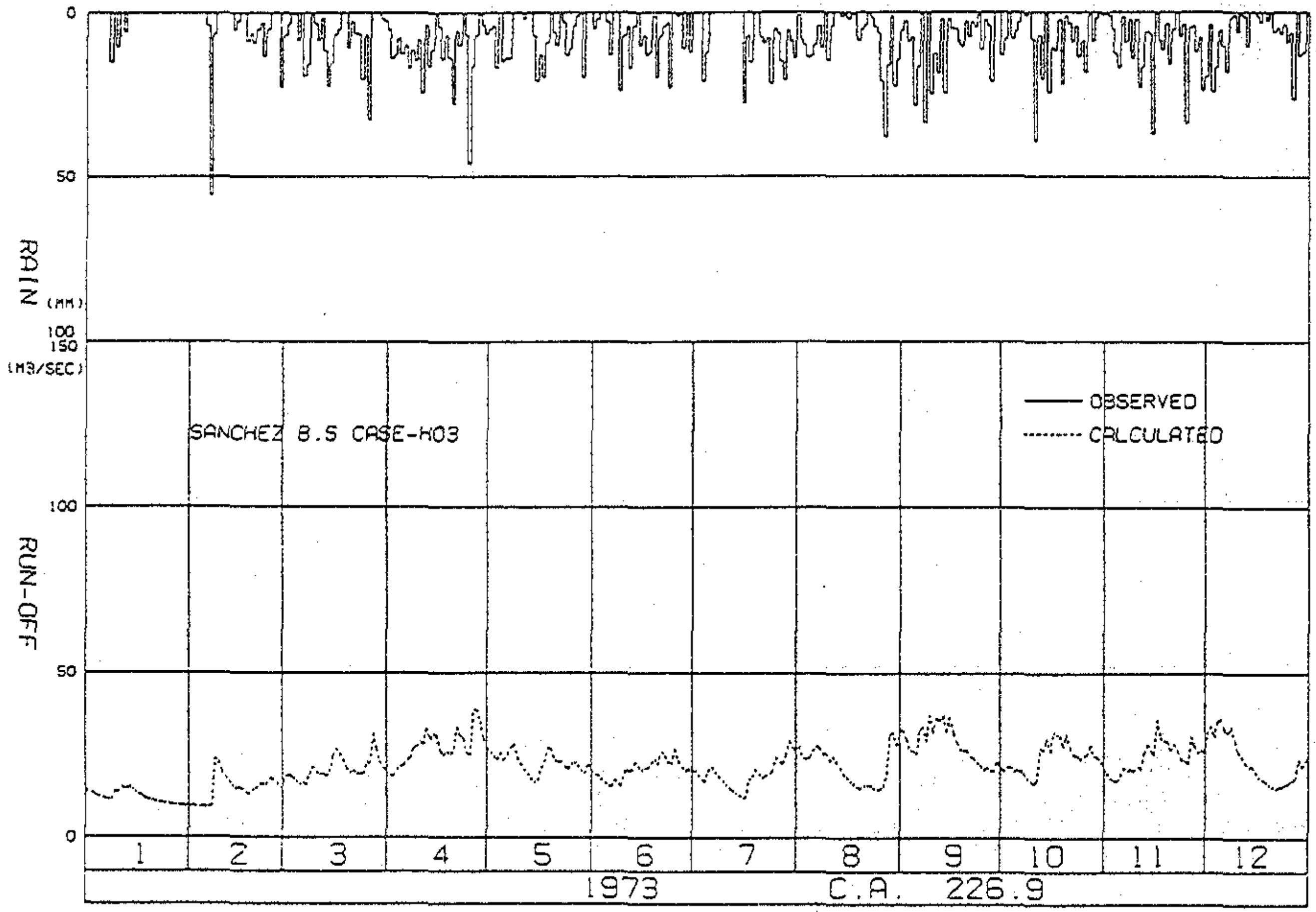


Fig. 8-7 (6) Results of Run-off Analysis

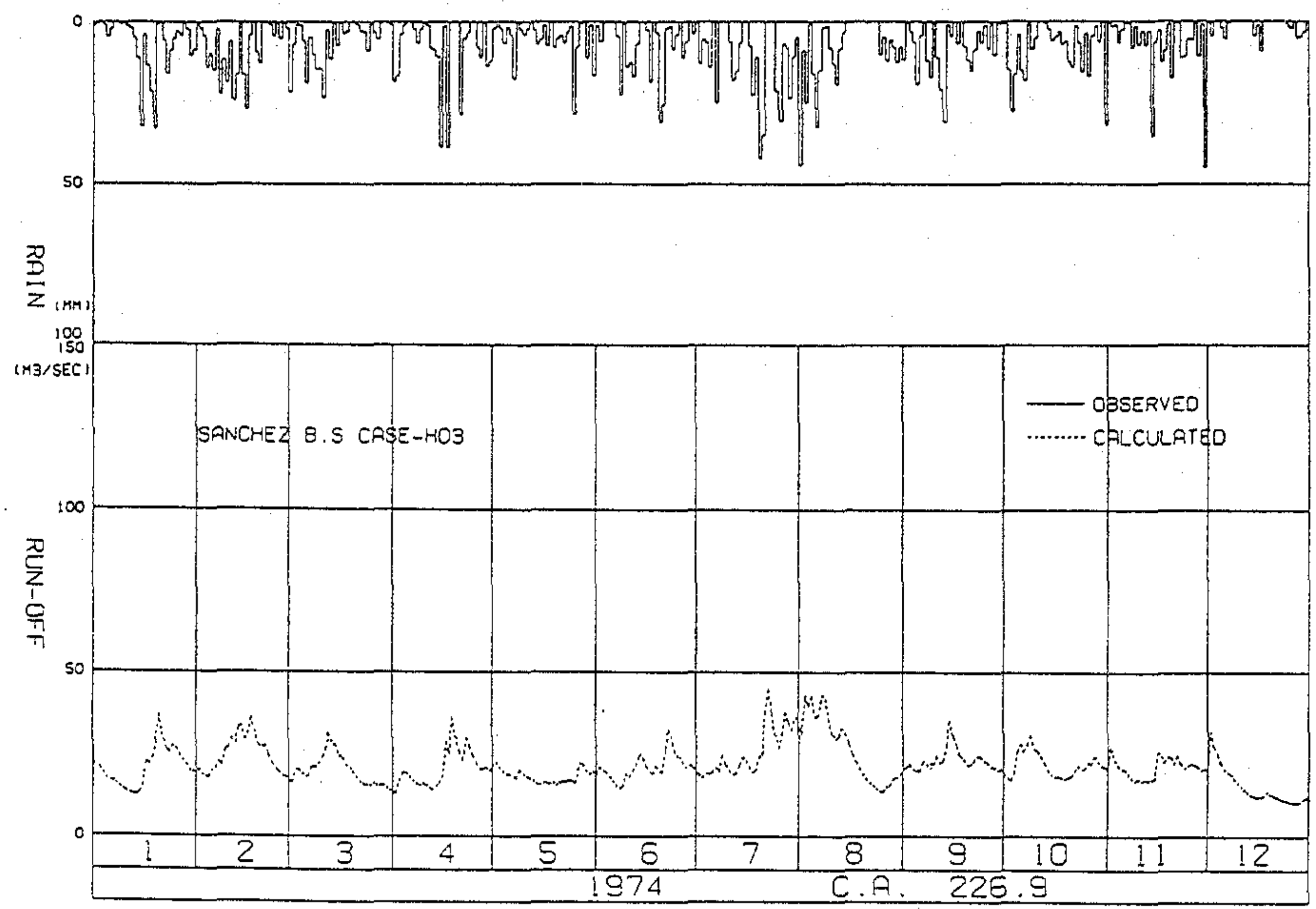


Fig. 8-7 (7)   Results of Run-off Analysis

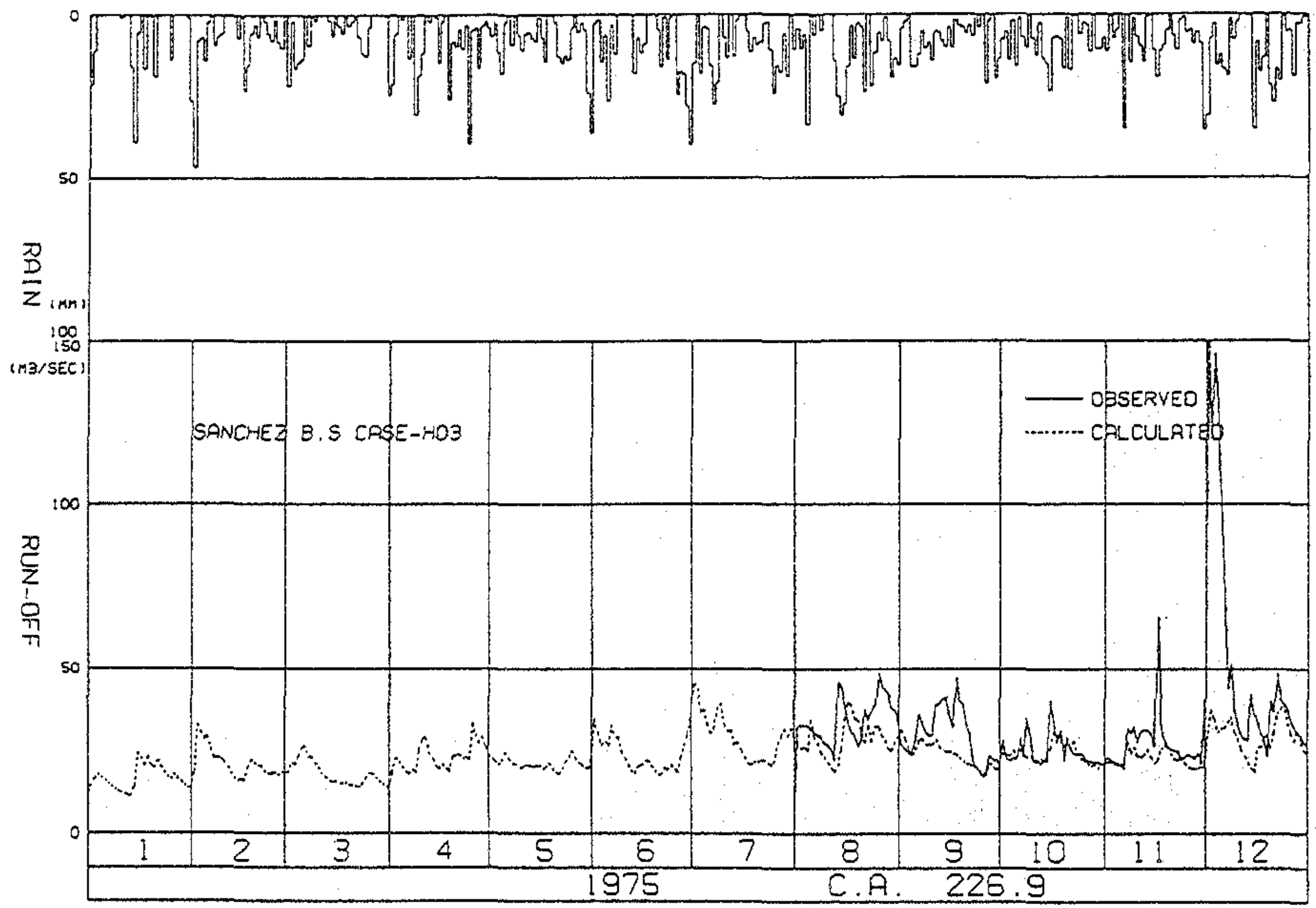


Fig. 8-7 (8)   Results of Run-off Analysis

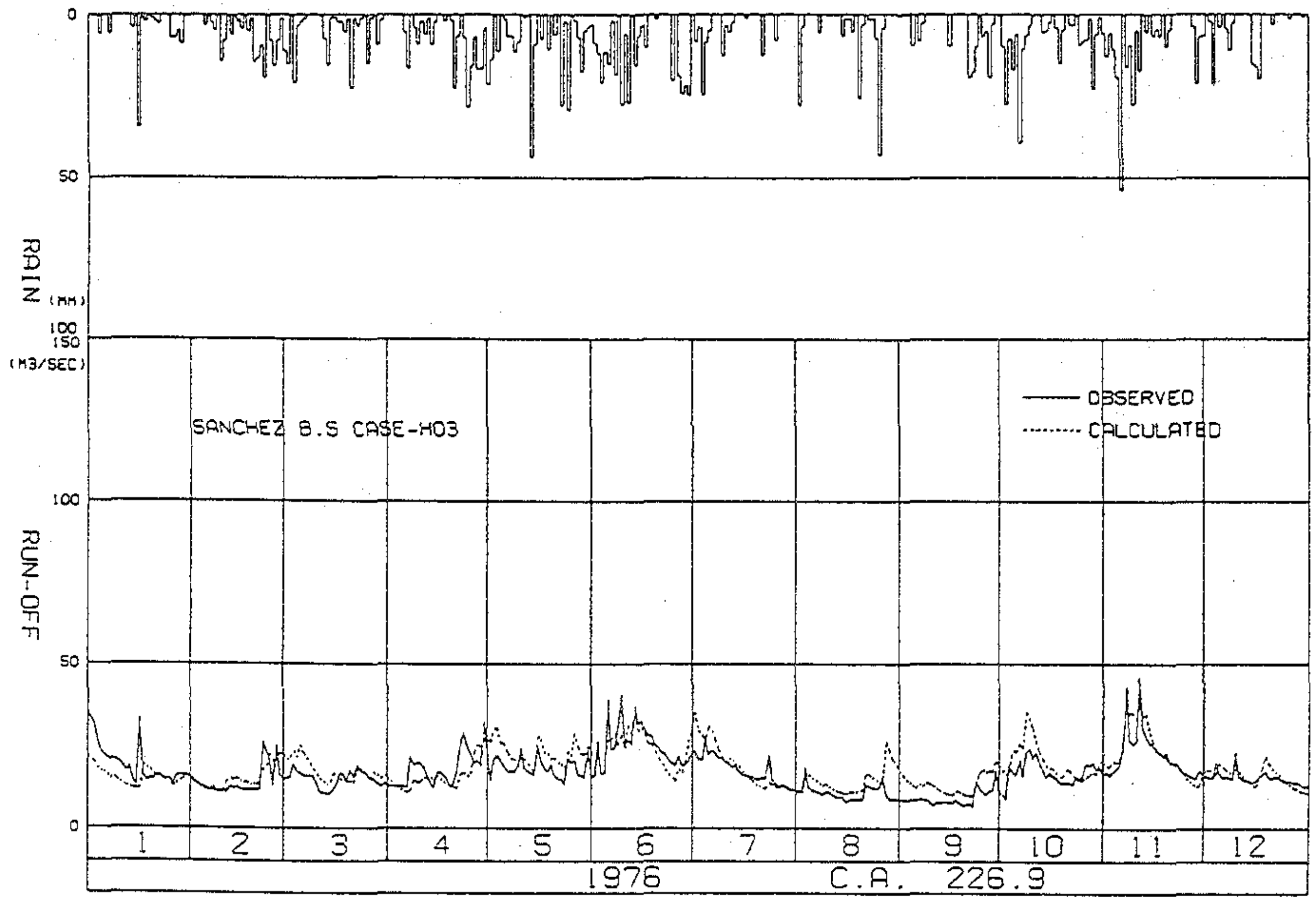


Fig. 8-7 (9) Results of Run-off Analysis

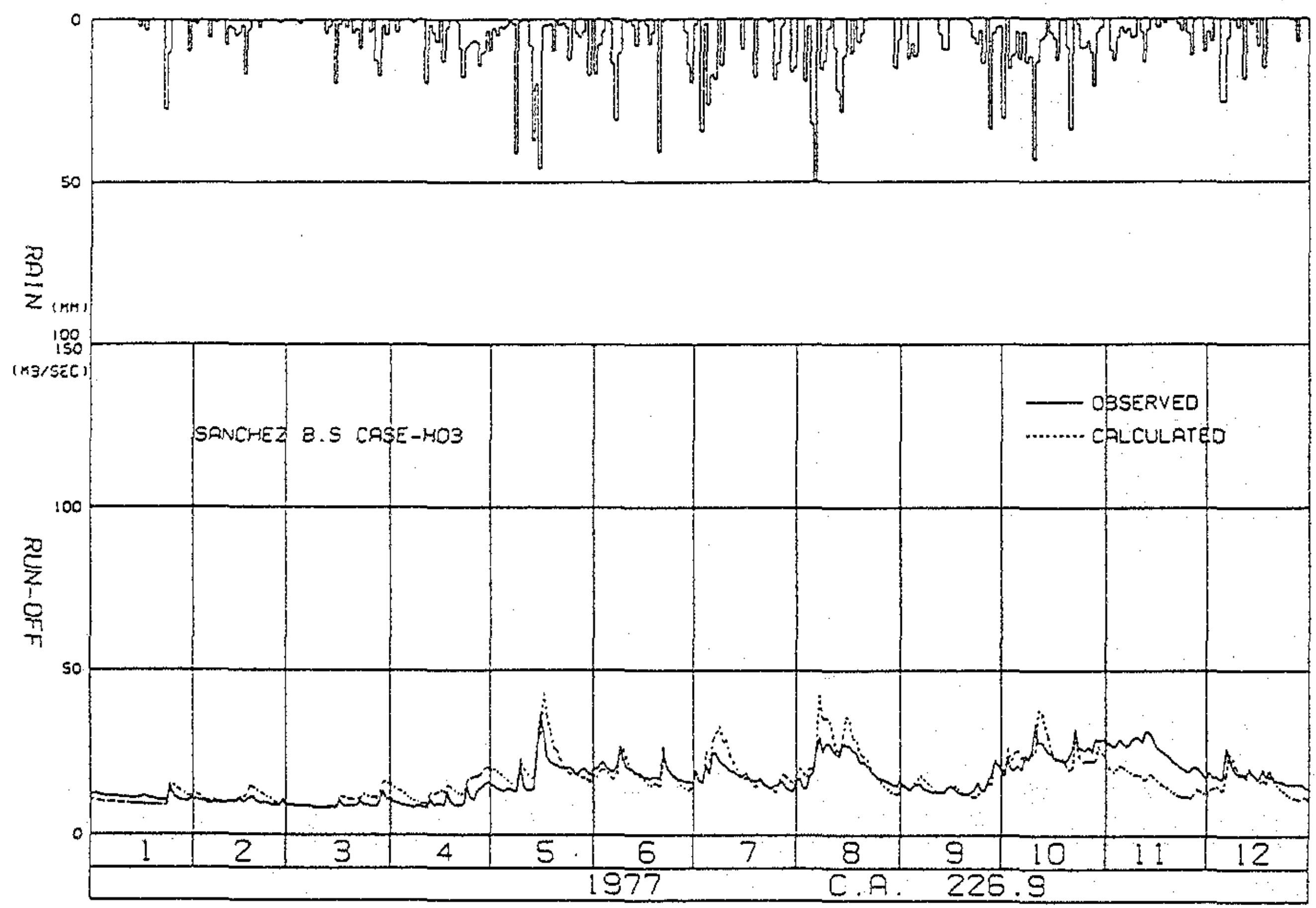


Fig. 8-7 (10) Results of Run-off Analysis

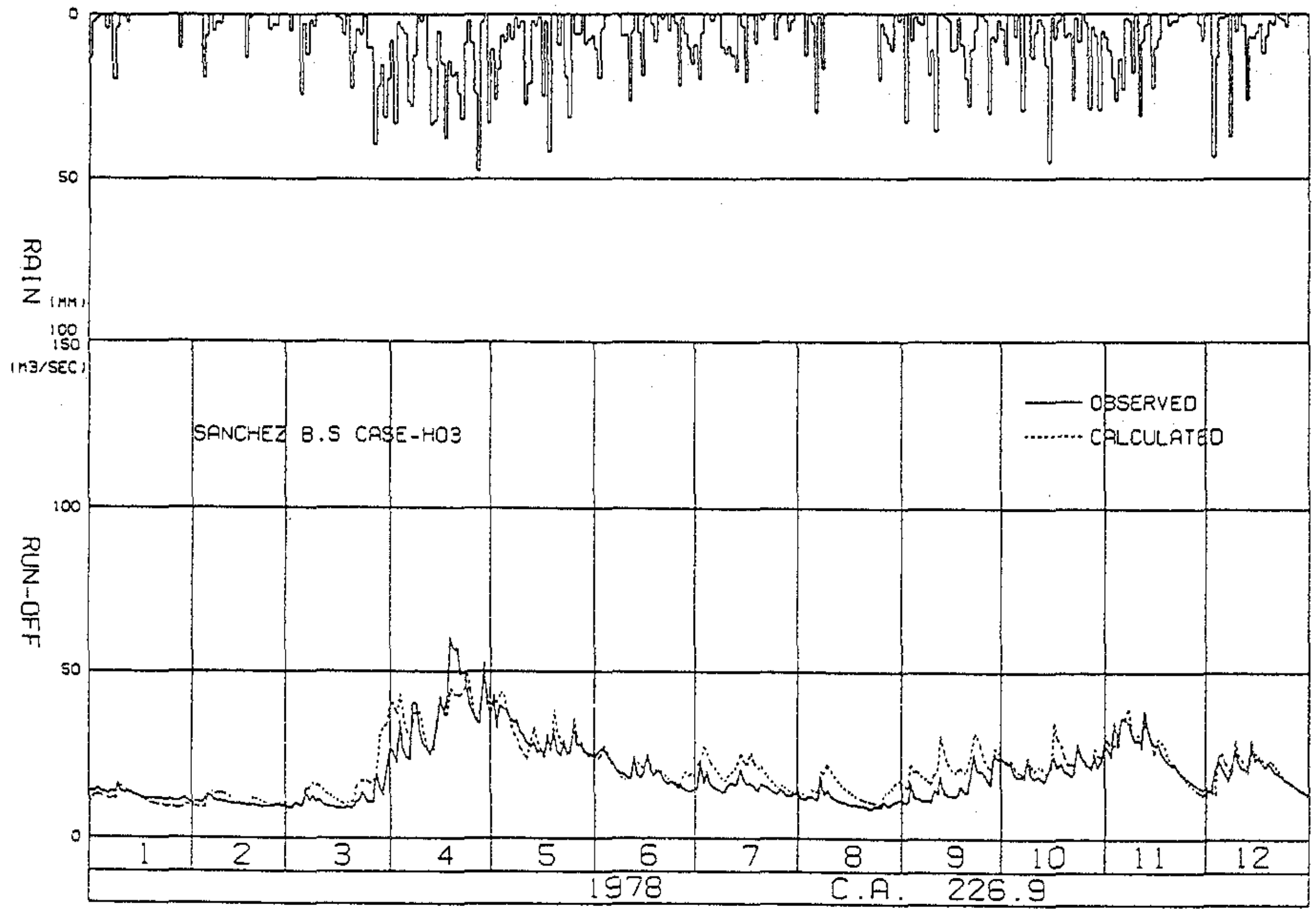


Fig. 8-7 (11) Results of Run-off Analysis

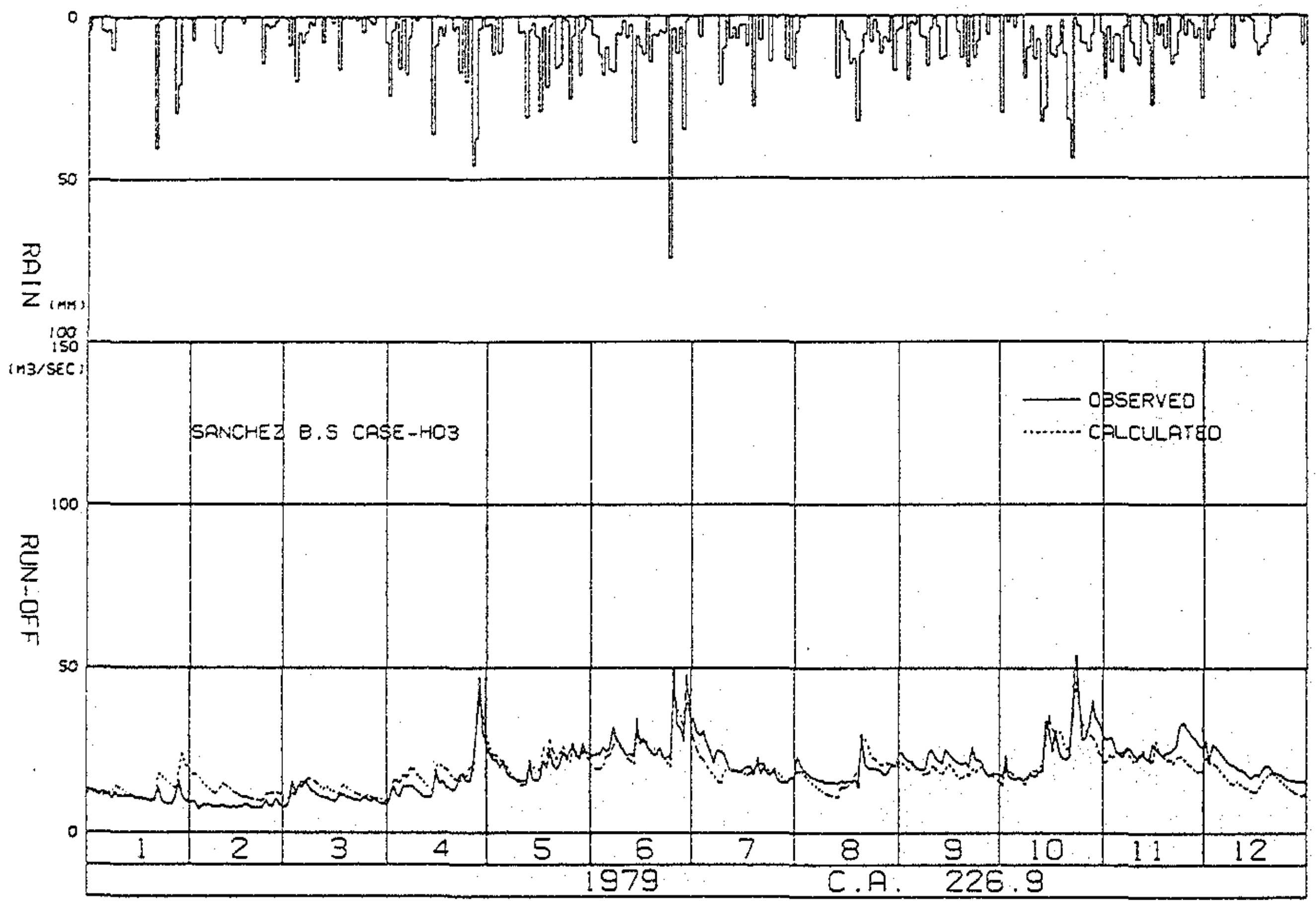


Fig. 8-7 (12) Results of Run-off Analysis

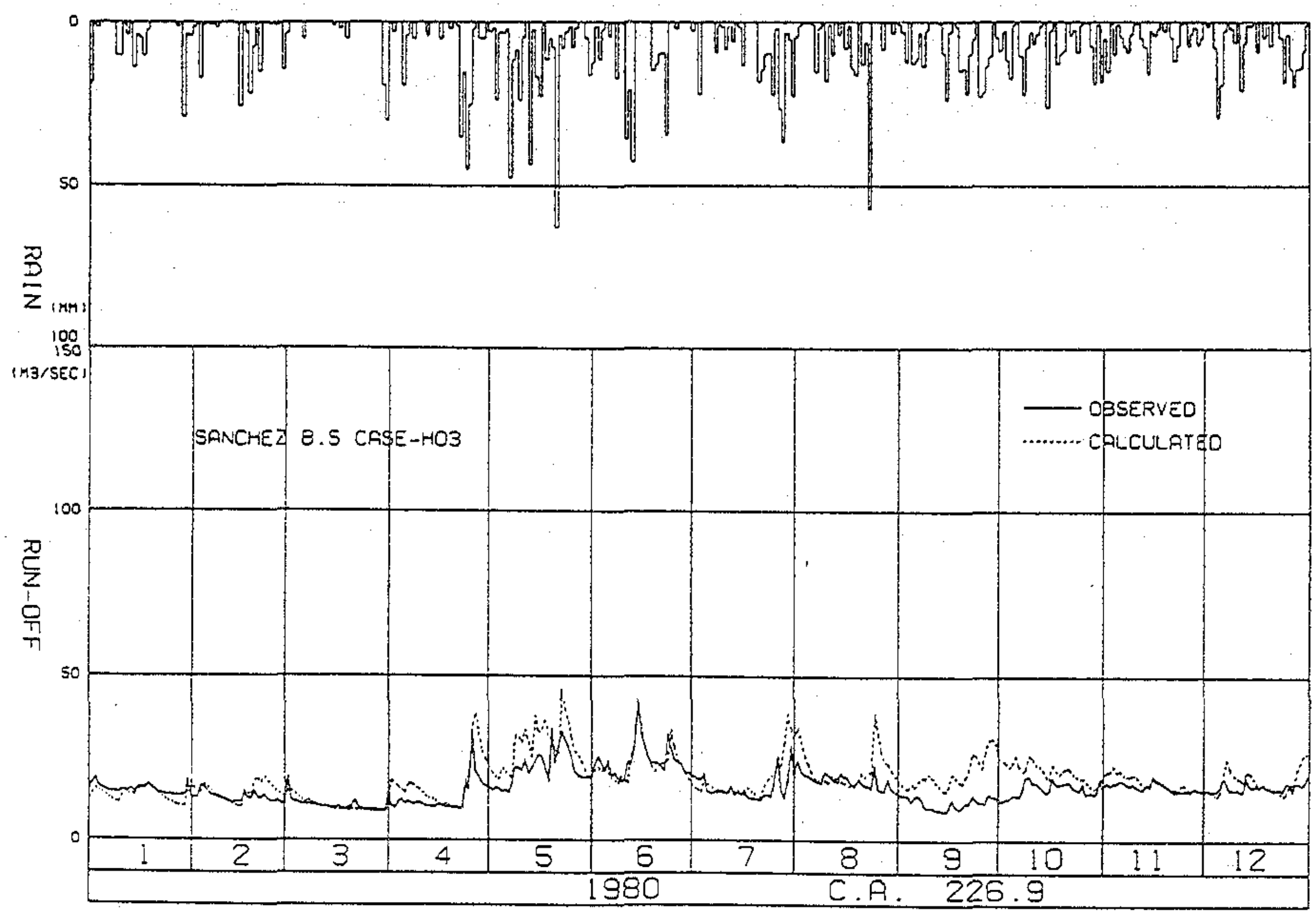


Fig. 8-7 (13) Results of Run-off Analysis

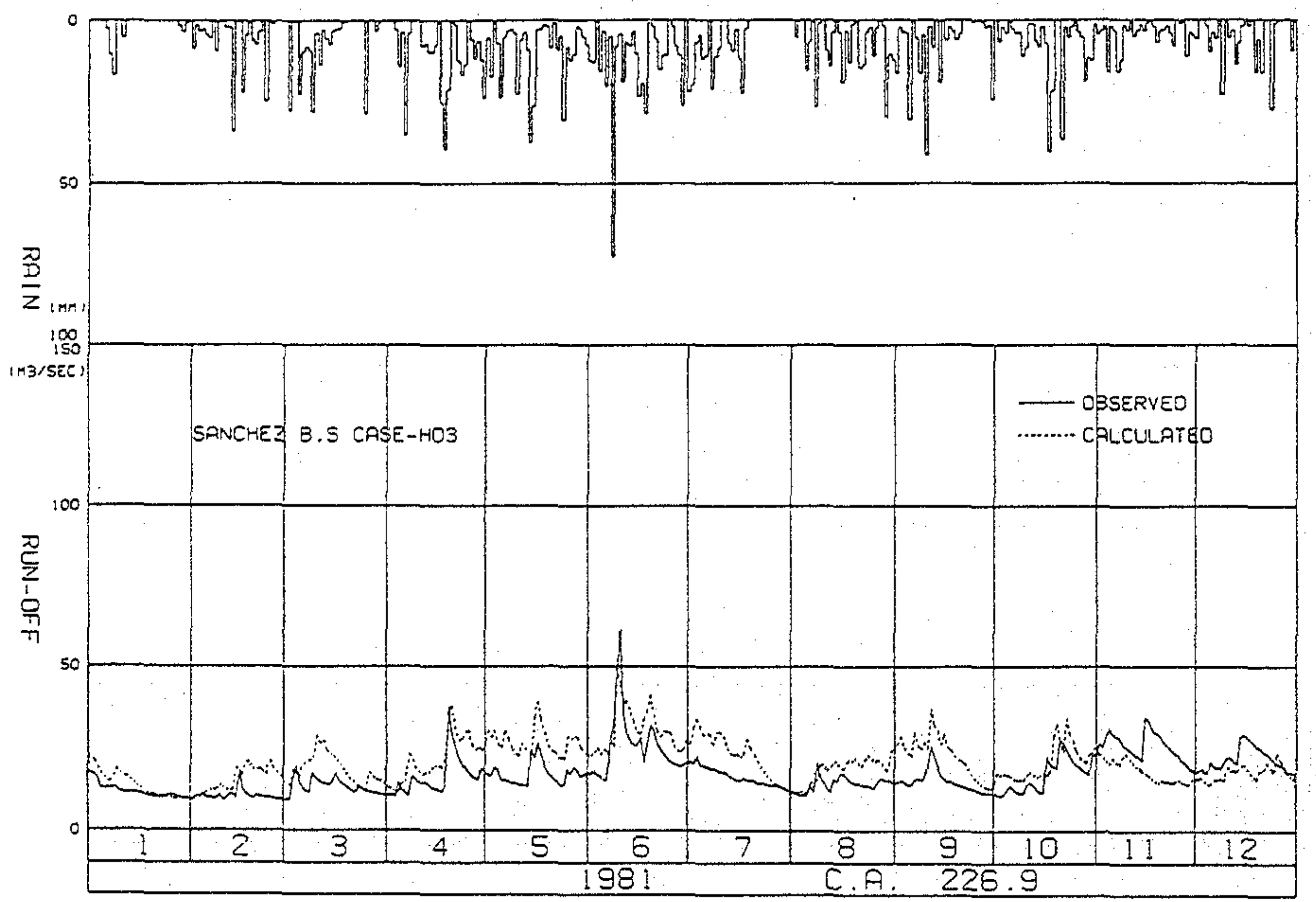


Fig. 8-7 (14) Results of Run-off Analysis

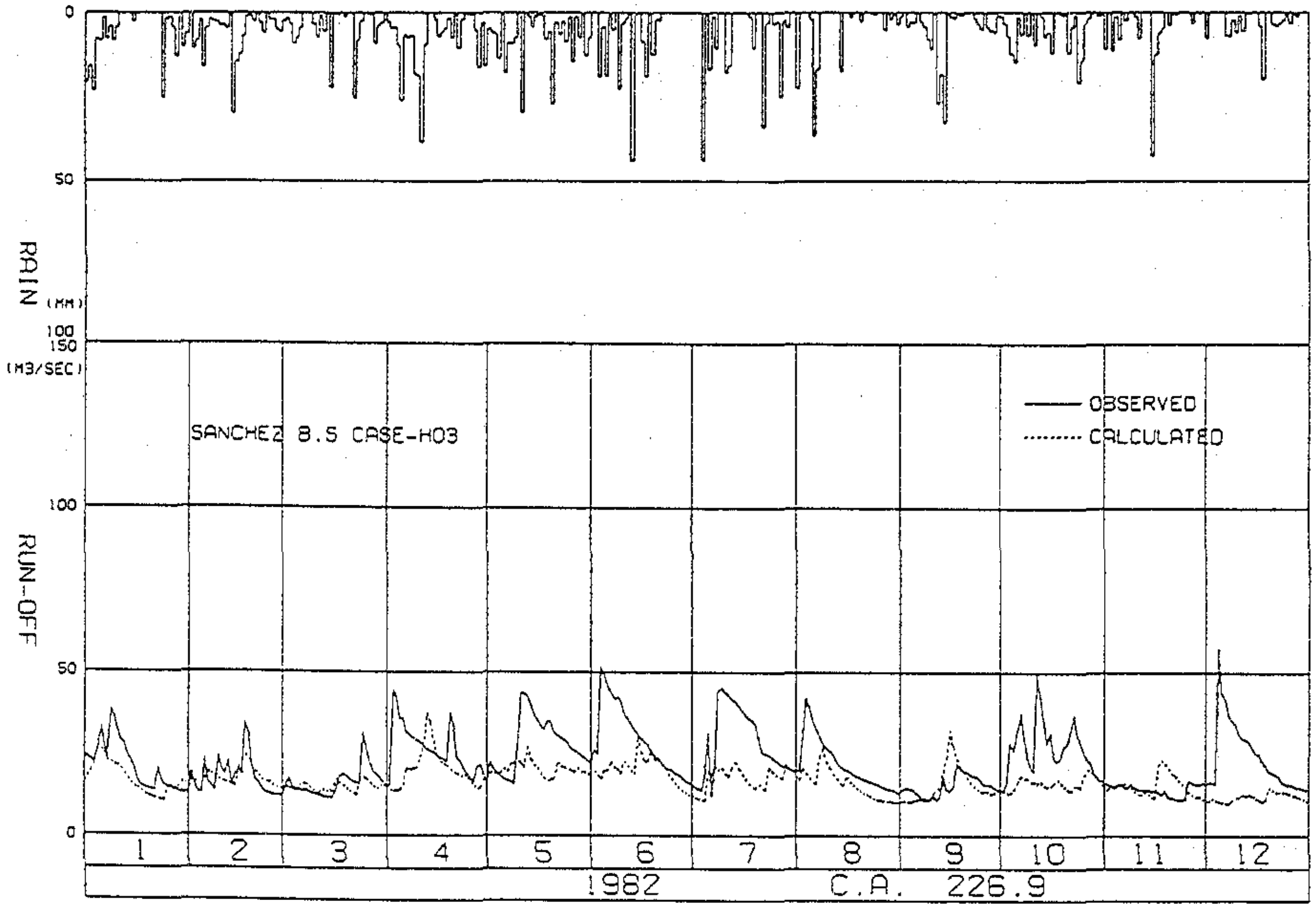


Fig. 8-7 (15) Results of Run-off Analysis

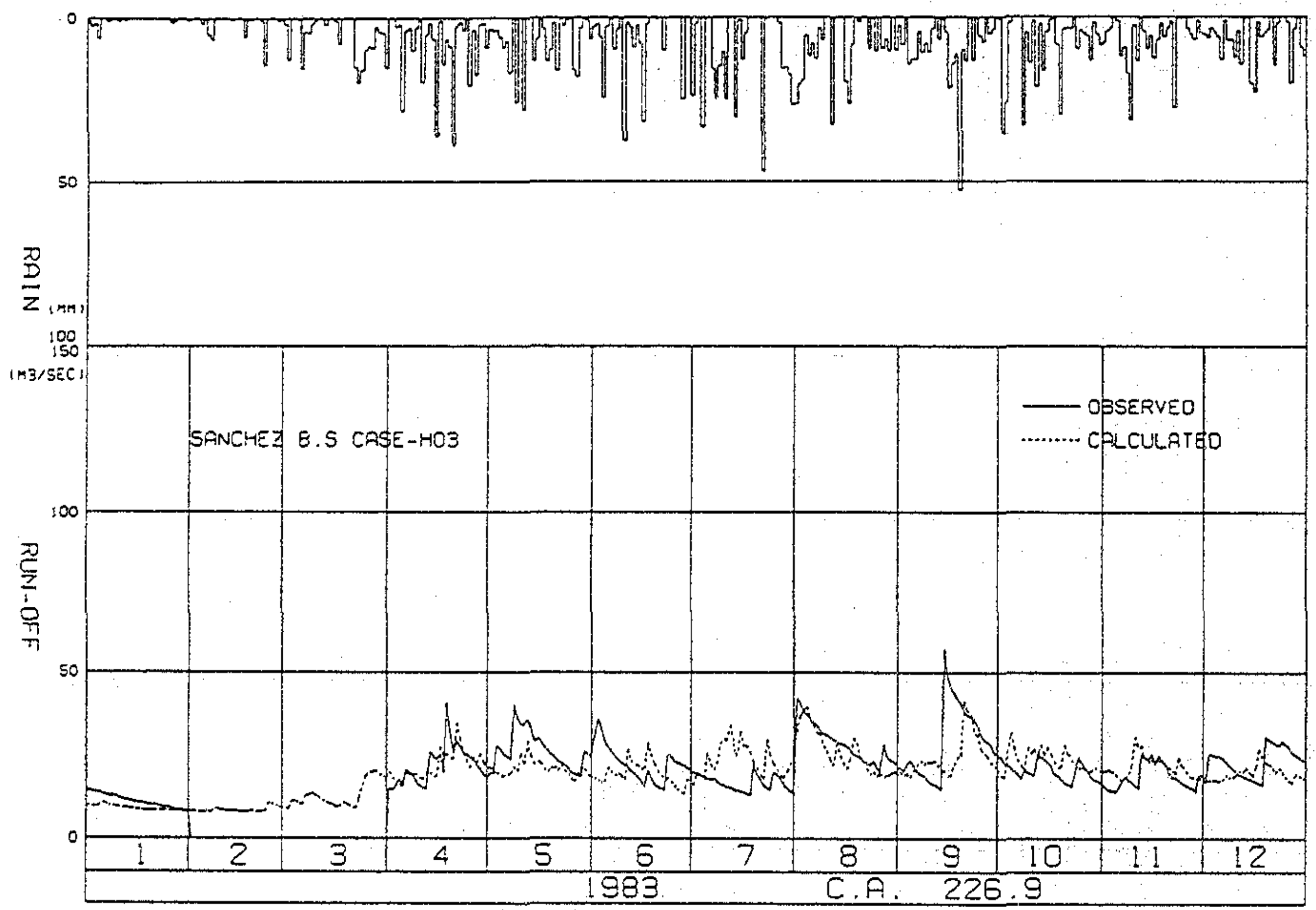


Fig. 8-7 (16) Results of Run-off Analysis

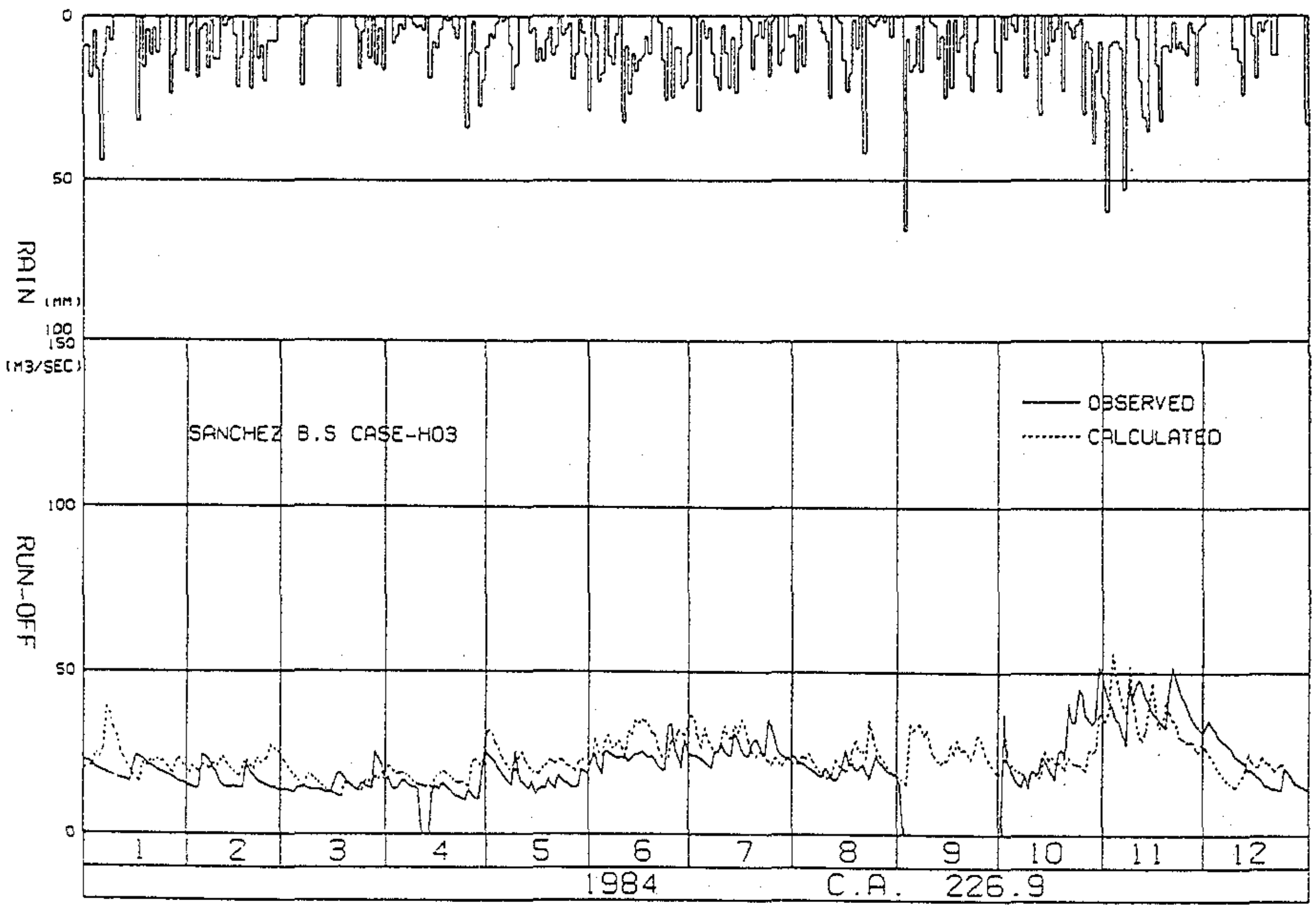


Fig. 8-8(1) Relation of Specific Discharge (El Siete vs Pte. Las Sánchez G.S)

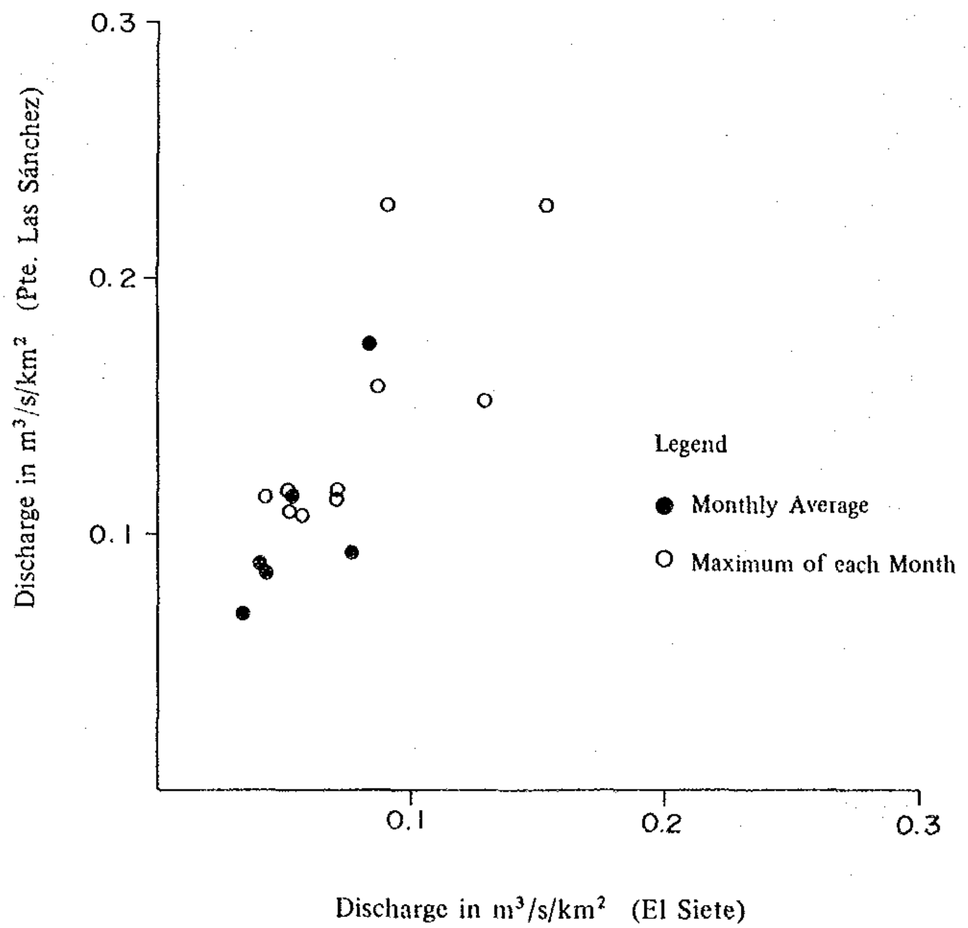


Fig. 8-8(2) Relation of Specific Discharge (Pte. Las Sánchez vs Girardot G.S)

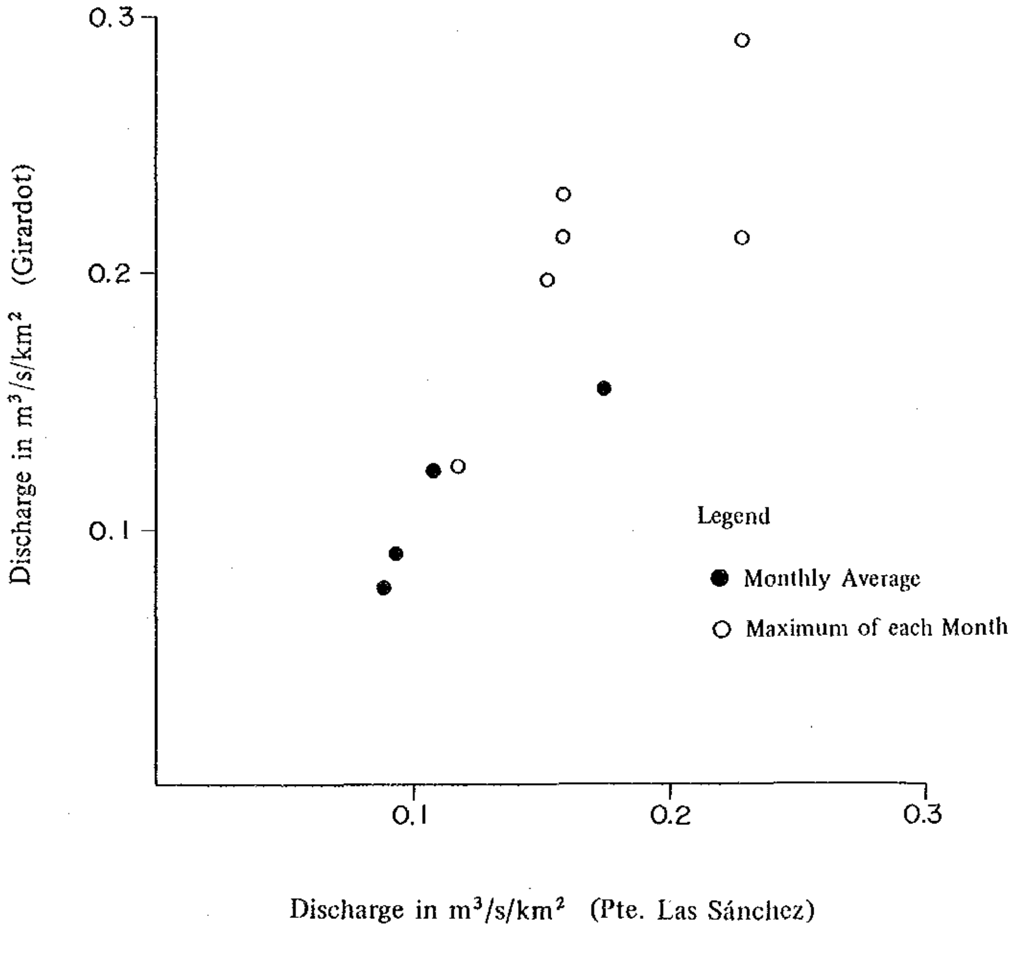


Fig. 8-8(3) Relation of Specific Discharge (Girardot vs El Piñon G.S)

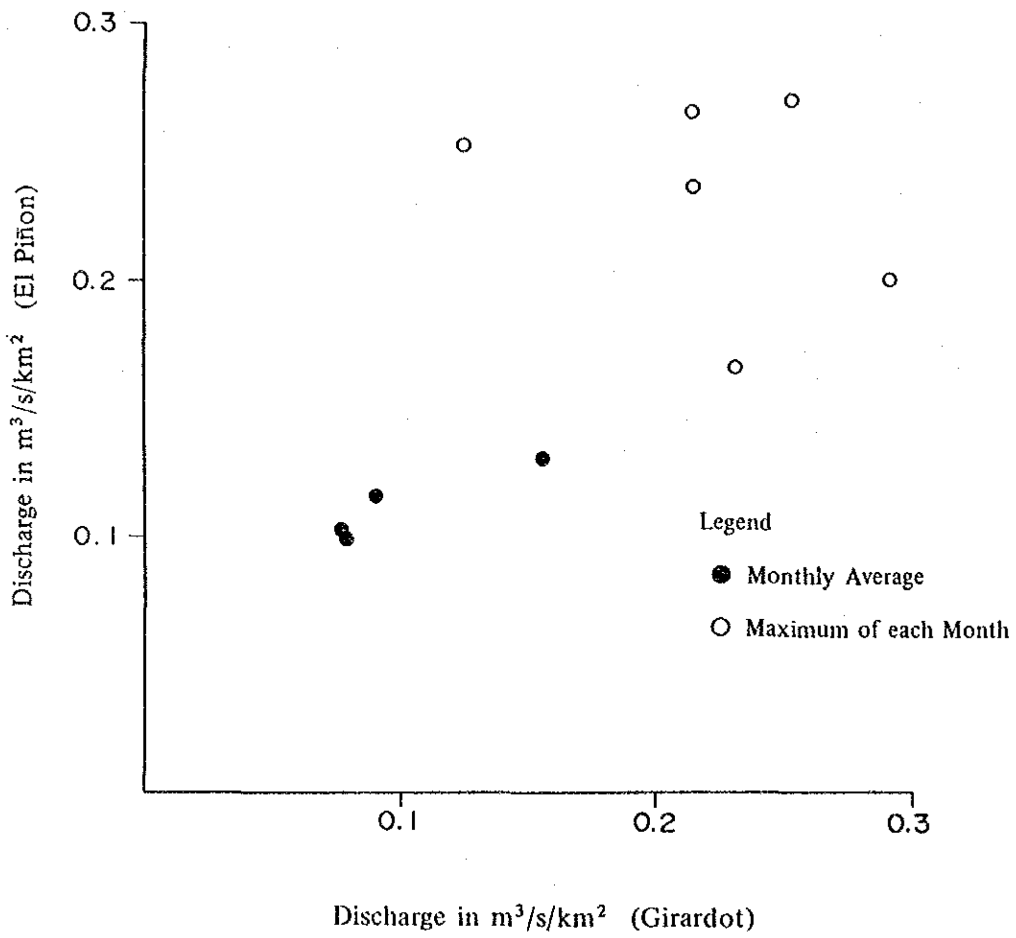
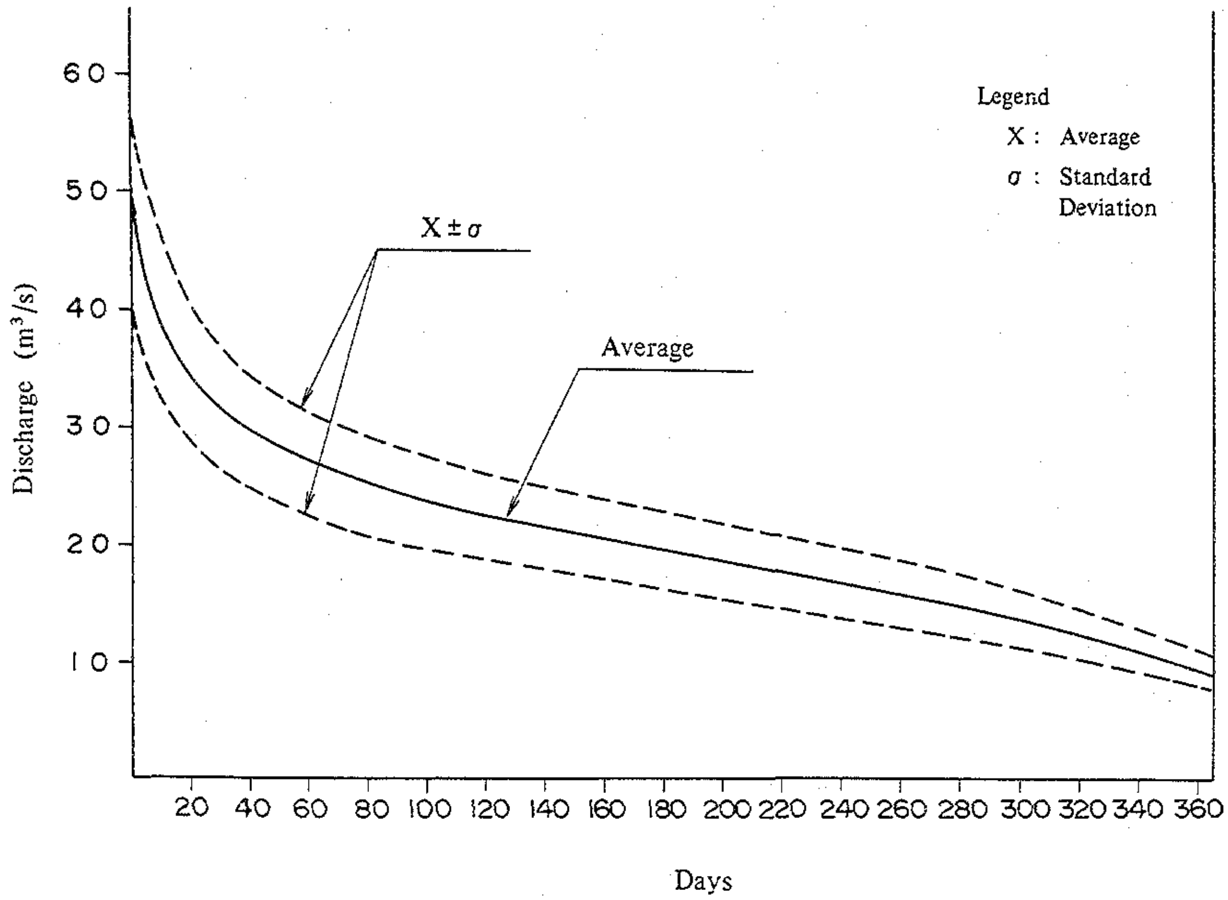


Fig. 8-9 Flow-Duration Curve at Pte. Las Sanchez G.S.



8.4 Flood Runoff Analysis

Flood discharge was estimated in the following procedure on the basis of precipitation records at La Mansa, Carmen de Atrato and El Piñon rainfall stations where the observation periods are comparatively long.

8.4.1 Stochastic Rainfall

Stochastic rainfall for various return periods was estimated from a series of maximum daily precipitation data for each year at La Mansa, Carmen de Atrato and El Piñon rainfall staions, assuming the extremal distribution (Gumbel and Log-Normal). The results are shown in Fig. 8-10 (1) - (3).

As the larger rainfall value was obtained when the Gumbel distribution was used, it was decided to adopt the stochastic rainfall based on the Gumbel distribution method for the following flood runoff analysis.

8.4.2 Probable Maximum Precipitation (PMP)[3]

Many methods to estimate PMP have been suggested and they are usually suitably selected according to obtainable data and the characteristics of the basin etc.

In the case of the the Atrato basin, the following two methods were applied and the larger PMP adopted, as the observation period for the necessary meteorological records is short and also very limited data to estimate PMP was obtained.

(1) PMP Estimated by Stochastic Method

The stochastic method is the simplest PMP estimate and the basic equation is as follows.

$$Xm = \overline{X}n + Km \cdot Sn$$

Where $\overline{X}n$: mean of the series of n annual maximum

Sn : standard deviation of the series

Km : constant

The value of Km=15 is usually used, but by Hershfield (1965), Km was found to be correlated with the raininess of the region, drier locations having a higher Km and vice versa. An example is seen in Colombia where Km=10 was adopted at a project. [8)]

Considering these points, the value Km=10 was used in this analysis. The results are tabulated in Table-8.2.

(2) PMP by the Maximization of Historical Storms

In this method, historical storms are first selected and then adjusted to the maximum limits physically possible (Maximization), using moisture or moisture inflow index. The enveloped value for these maximized historical storms gives PMP. This is one of the most reasonable and theoretical methods to estimate PMP, if the necessary meteorological data are obtained.

When major historical storms are observed for a long period, moisture adjustment alone is sufficient as there is a high possibility that the precipitation records of large rainfall efficiency (defined as a ratio of rainfall to the total moisture in the air) were obtained. But in cases where records are very limited, this adjustment is usually made by moisture inflow index which includes the wind effect. [4)]

As this case fits for the latter, maximization was performed by moisture inflow index adjustment as follows.

Adjustment factor:

$$= \frac{\text{The Maximum Moisture Inflow Index}}{\text{Moisture Inflow Index existing during the Storm}}$$

Where, moisture inflow index is defined as the product of precipitable water in the atmosphere and wind speed. Precipitable water is the maximum amount of moisture that can be retained in a vertical column of air and has been found by reliable research observations to vary almost directly with surface dewpoints, if saturation and pseudo-adiabatic conditions are assumed. Appendix I-6 shows this relation.

The maximum moisture inflow index for the project area was evaluated on the basis of the meteorological data (surface dewpoints and wind speed) at La Mansa and are shown in Fig. 8-11.

Table-8.2 PMP Estimated by Stochastic Method

(Unit: mm/day)

Station Year	La Mansa Annual Max.	La Mansa Date of Storm	Carmen de Atrato Annual Max.	Carmen de Atrato Date of Storm	El Piñon Annual Max.	El Piñon Date of Storm
1959	-	-	52.0	Aug. 17	134.0	Aug. 3
1960	-	-	94.0	Dec. 2	268.0	Aug. 11
1961	-	-	46.0	Jun. 11	180.0	Nov. 11
1962	-	-	80.0	Oct. 8	190.0	Oct. 29
1963	-	-	(60.0)	Nov. 7	153.0	Nov. 10
1964	-	-	62.0	Nov. 23	134.0	Apr. 23
1965	-	-	-		154.0	Jan. 16
1966	-	-	78.0	Jun. 19	120.0	May 24
1967	-	-	90.0	Feb. 6	100.0	Nov. 8
1968	-	-	(100.0)	Nov. 30	132.0	Oct. 24
1969	-	-	60.0	Jun. 10	(120.0)	Oct. 21
1970	-	-	61.0	Jun. 13	-	-
1971	-	-	65.0	Apr. 8	205.0	Jan. 4
1972	81.0	Oct. 10	47.0	Jun. 24	(104.0)	Jan. 16
1973	(137.0)	Feb. 7	50.0	Apr. 25	153.0	Oct. 5
1974	72.5	Aug. 1	51.0	Nov. 30	151.0	Oct. 5
1975	46.9	Apr. 18	57.0	Feb. 1	153.0	Aug. 24
1976	65.7	Oct. 6	61.0	Nov. 5	134.0	Oct. 2
1977	61.8	May 8	63.0	Oct. 10	154.0	May 14
1978	64.2	Mar. 27	48.0	Oct. 15	193.0	Oct. 19
1979	(73.2)	Jun. 24	(75.0)	Jun. 24	141.0	Oct. 25
1980	(69.3)	May 6	75.0	May 8	170.0	Sep. 22
1981	77.7	Jun. 8	70.0	Jun. 8	150.0	Apr. 18
1982	78.2	Sep. 12	(50.0)	Jun. 13	150.0	Jul. 19
1983	78.3	Nov. 9	61.0	Sep. 19	150.0	Oct. 15
1984	(71.2)	Aug. 21	66.0	Sep. 2	180.0	Mar. 17
Number of Data	13		25		25	
Average $\overline{X}n$	75.15		64.88		154.92	
Standard Deviation Sn	19.87		14.53		34.43	
PMP	273.9		210.2		504.1	$PMP=\overline{X}n+KmSn$ (km=10)

Note : ° Bracketed data mean partially defected measurement

° PMP = Probable Maximum Preciptation

Fig. 8-10 (1) Stochastic Point Rainfall (La Mansa)

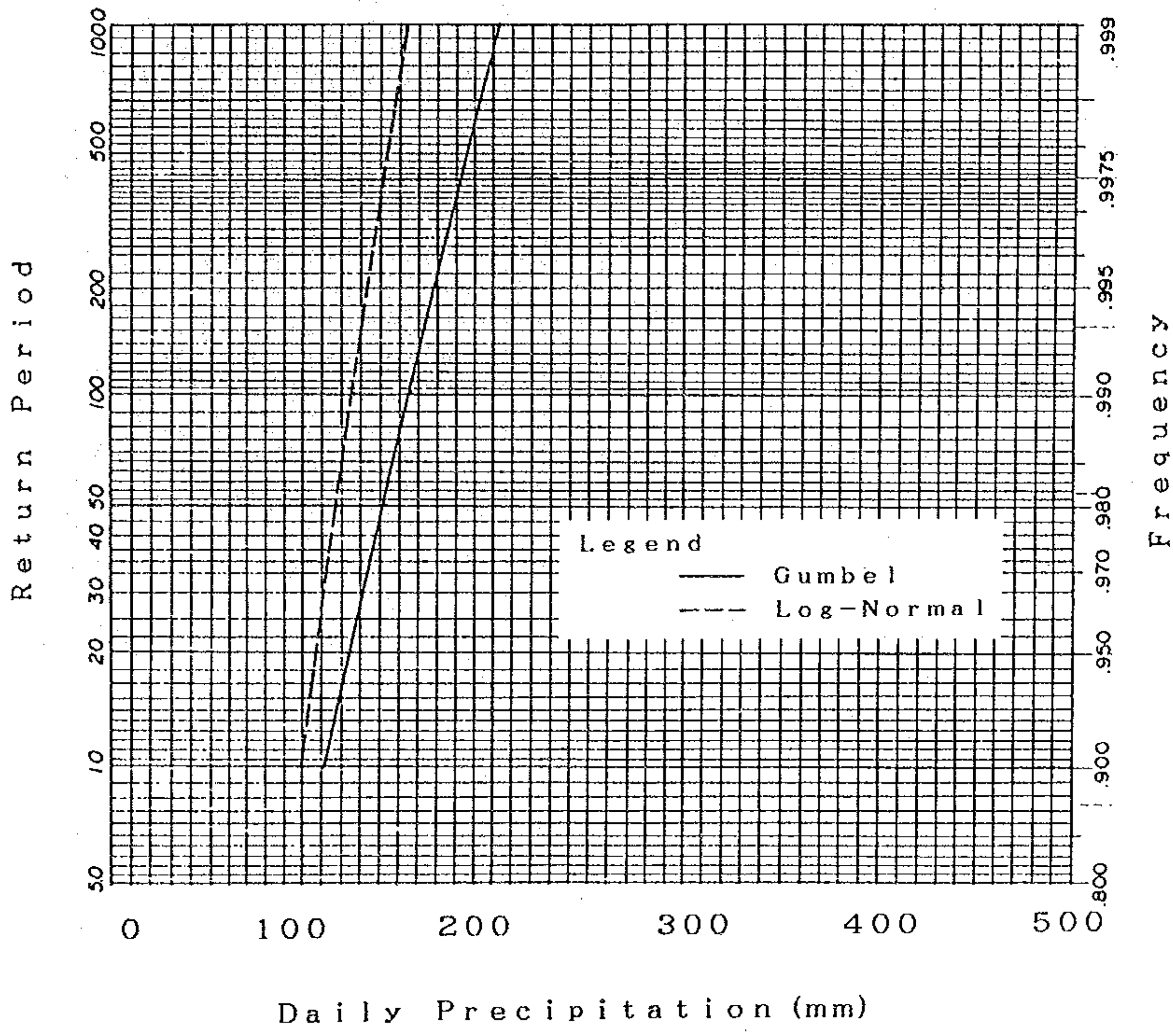


Fig. 8-10 (2) Stochastic Point Rainfall (Carmen de Atrato)

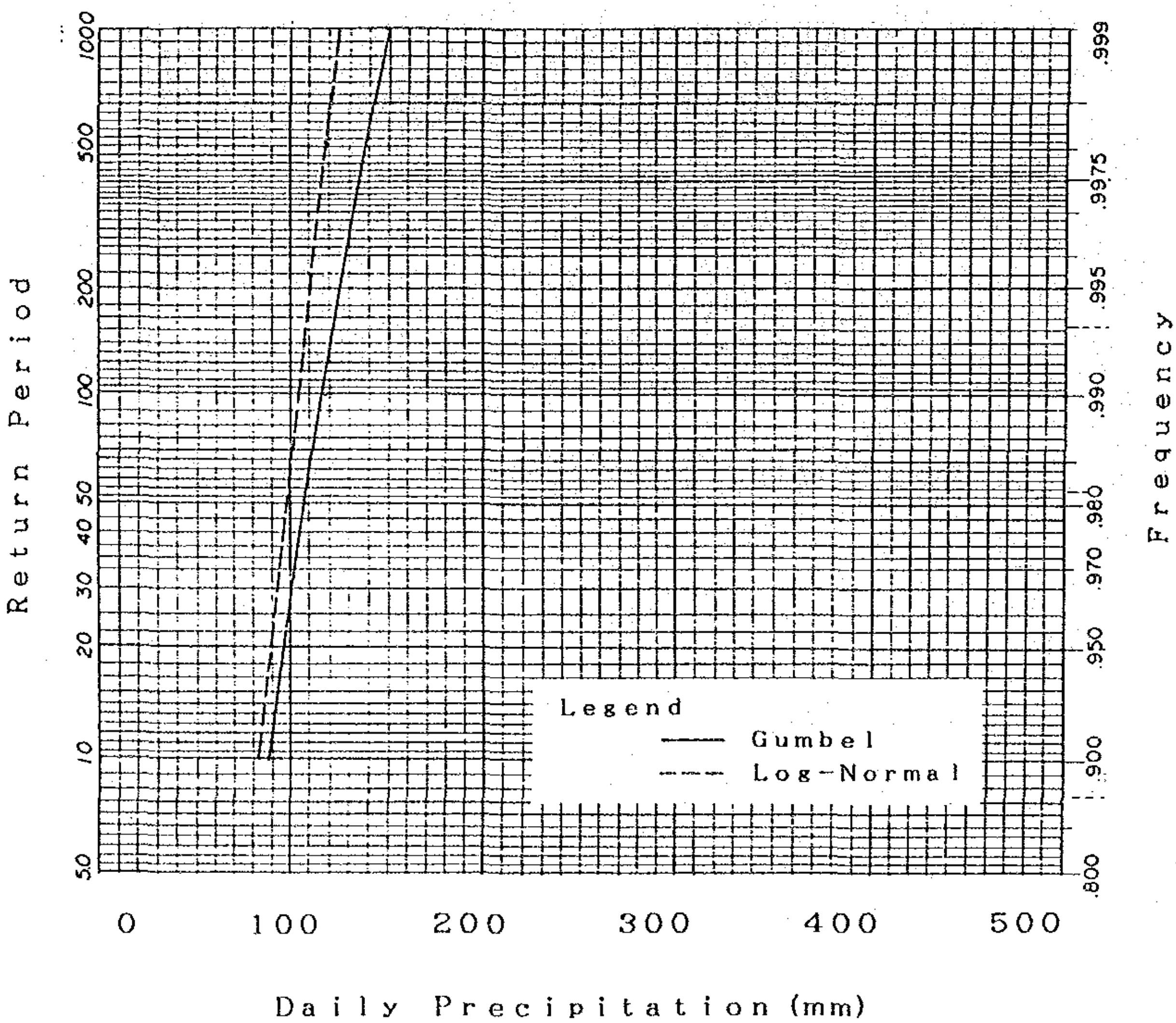


Fig. 8-10 (3) Stochastic Point Rainfall (El Piñon)

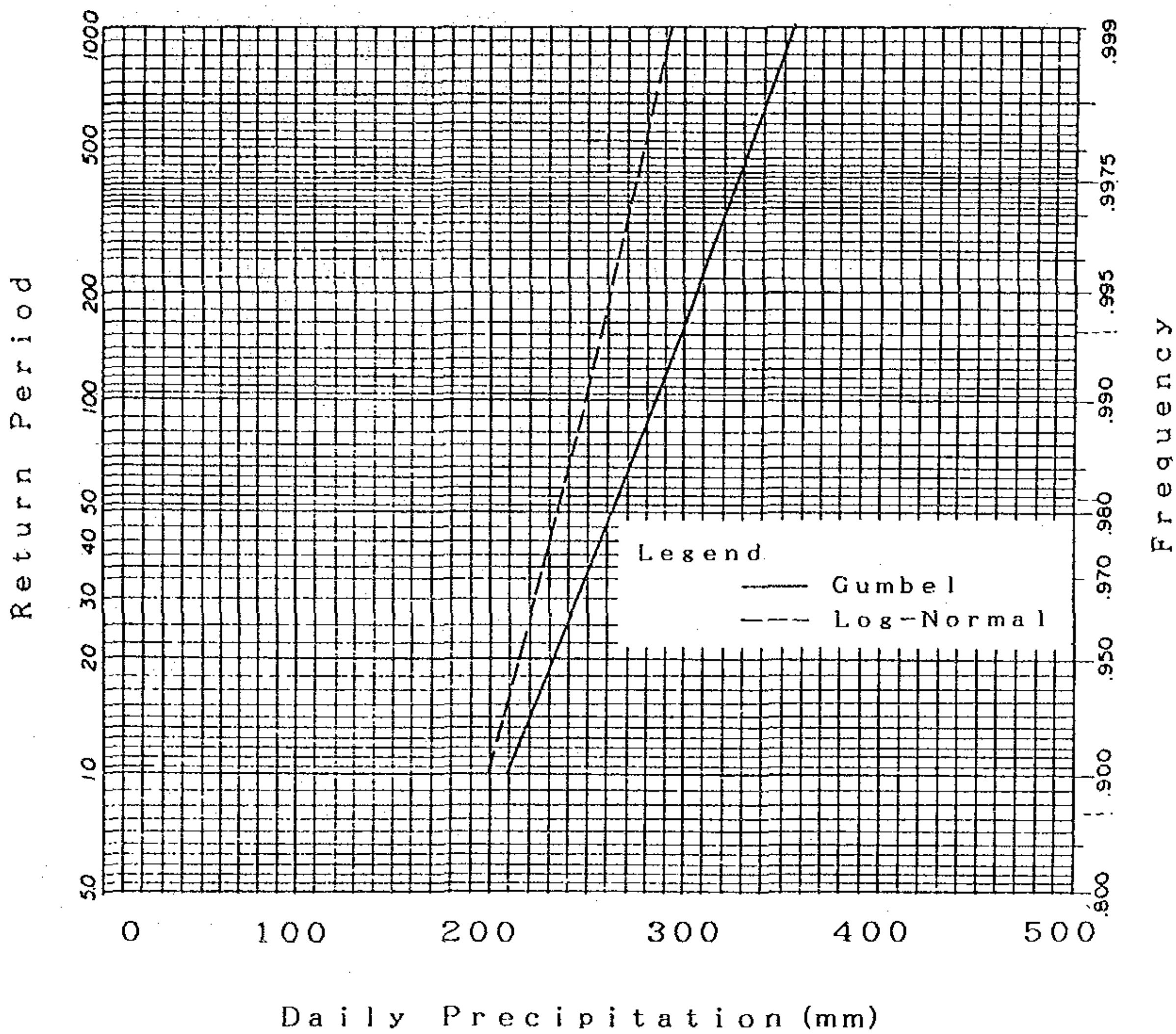


Fig. 8-11 Maximum Moisture Inflow Index

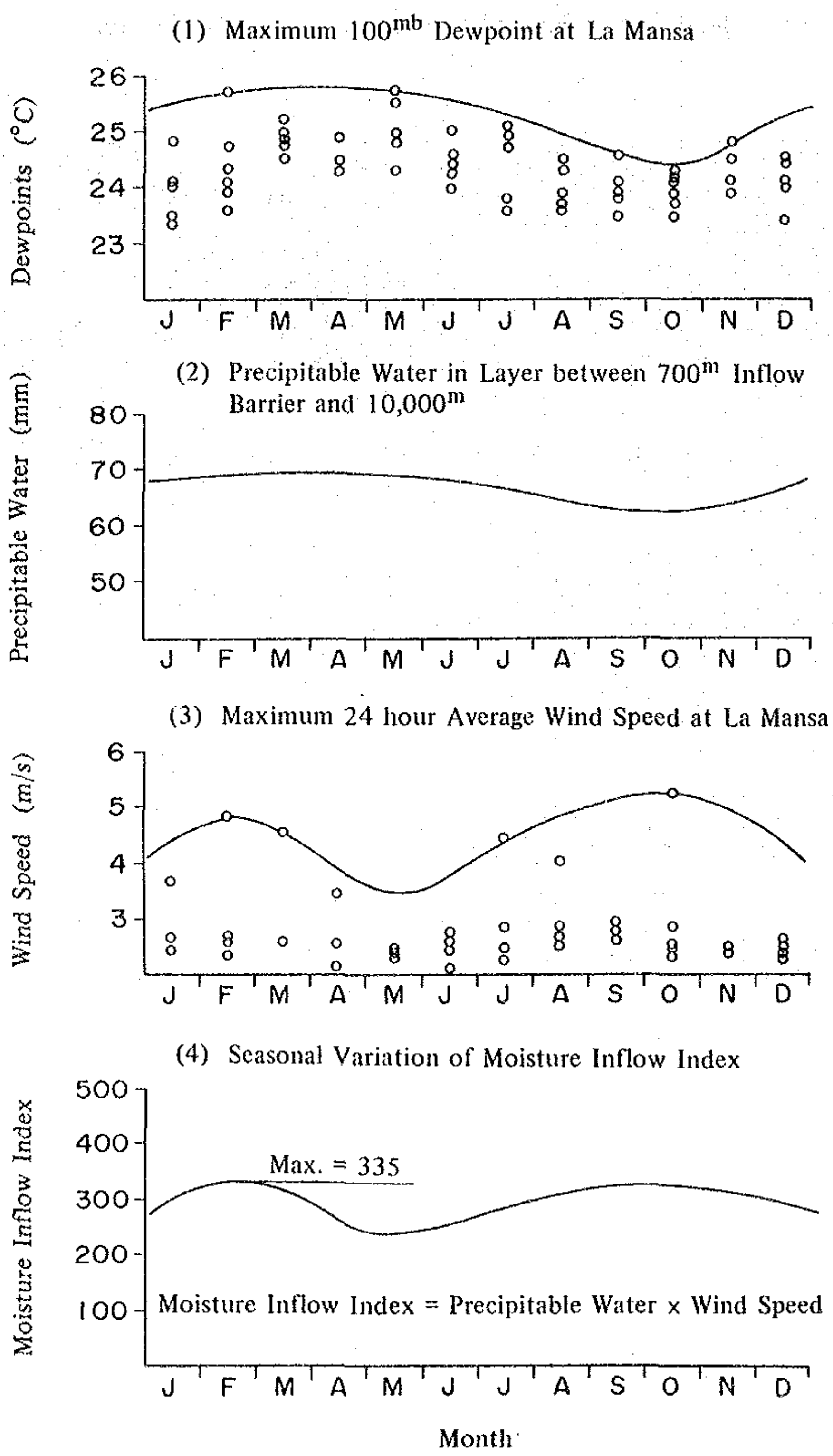


Table-8.3 (1) - (3) show the major historical storm rainfalls etc., for La Mansa, Carmen de Atrato and El Piñon rainfall stations. Although this estimation is based on the records of only those five years from 1978 to 1982, PMP for La Mansa, Carmen de Atorato and El Pinon rainfall stations was decided to be 260 mm, 235 mm and 592 mm respectively, which were the maximum of the maximized storm rainfalls for each station.

8.4.3 Average Rainfall Over Areas

The stochastic rainfall and PMP estimated in the section 8.4.1 and 8.4.2 respectively were spacially averaged using the weighted average method (Thiessen method). The weight for each station is shown in Fig. 8-3. The averaged stochastic rainfall and PMP are tabulated in Table-8.4.

Table-8.3 (1) Storms used in Deriving Probable Maximum Precipitation (La Mansa)

Storms				Representative Max. Dewpoint (°C)		Precipitable Water in 700 - 10,000^{m} Layer (mm)	Max. 24-hour Average Windspeed	Moisture Inflow Index	Max. Moisture Inflow Index	Maximi-zing Factor	PMP
No.	Date		Max. Daily Precipitation	Observed	at 1000^{mb}		m/s				(mm)
1	1978	Apr.27	62.1	15.2	23.8	59	1.99	117.4	335	2.85	177
2	1978	Dec. 3	62.7	14.7	23.3	56.5	1.52	85.9	"	3.90	245
3	1979	Jan.28	54.0	13.8	22.4	52.3	1.69	88.4	"	3.79	205
4	1979	Jun.13	56.0	14.4	23.0	55	1.60	88	"	3.81	213
5	1979	Jun.24	73.2	15.8	24.4	62	1.89	117.2	"	2.86	209
6	1980	May 6	69.3	15.9	24.5	62.5	1.94	121.3	"	2.76	191
7	1980	May 12	52.5	16.0	24.6	63	1.82	114.7	"	2.92	153
8	1980	Jul.27	54.7	15.2	23.8	59	2.23	131.6	"	2.55	139
9	1980	Aug.22	65.2	14.2	22.8	54.1	1.83	99	"	3.38	220
10	1981	Jun. 8	77.7	14.7	23.3	56.5	1.77	100	"	3.35	260
11	1981	Oct.21	58.7	14.8	23.4	57	2.01	114.6	"	2.92	171
12	1982	Sep.12	78.2	15.3	23.9	59.5	2.04	121.4	"	2.76	216

Table-8.3 (2) Storms used in Deriving Probable Maximum Precipitation (Carmen de Atrato)

Storms				Representative Max. Dewpoint (°C)		Precipitable Water in 700 - 10,000^{m} Layer (mm)	Max. 24-hour Average Windspeed	Moisture Inflow Index	Max. Moisture Inflow Index	Maximi-zing Factor	PMP
No.	Date		Max. Daily Precipitation	Observed	at 1000^{mb}		m/s				(mm)
1	1979	Jun.24	75.0	15.8	24.4	62	1.89	117.2	335	2.86	215
2	1979	Oct.22	54.0	14.3	22.9	54.5	1.89	103.0	"	3.25	176
3	1980	May 20	75.0	15.8	24.4	62	2.03	125.9	"	2.66	200
4	1980	Aug.22	53.0	14.2	22.8	54.1	1.83	99.0	"	3.38	179
5	1981	Apr.18	50.0	14.9	23.5	57.5	1.84	105.8	"	3.17	159
6	1981	May 14	51.0	14.9	23.5	57.5	1.83	105.2	"	3.18	162
7	1981	Jun. 8	70.0	14.7	23.3	56.5	1.77	100	"	3.35	235
8	1982	Jun.13	50.0	15.6	24.2	61	1.72	104.9	"	3.19	160

Table-8.3 (3) Storms used in Deriving Probable Maximum Precipitation (El Piñon)

Storms				Representative Max. Dewpoint (°C)		Precipitable Water in 700 - 10,000m Layer (mm)	Max. 24-hour Average Windspeed	Moisture Inflow Index	Max. Moisture Inflow Index	Maximizing Factor	PMP
No.	Date		Max. Daily Precipitation	Observed	at 1000mb		m/s				(mm)
1	1978	Apr.17	160.0	14.8	23.4	57	1.59	90.6	335	3.70	592
2	1978	Oct.19	193.0	14.0	22.6	53.2	2.27	120.8	"	2.77	535
3	1980	Sep.22	170.0	14.4	23.0	55	1.81	99.6	"	3.36	571
4	1980	Dec.25	150.0	14.1	22.7	53.6	1.84	98.6	"	3.40	510
5	1981	Apr.18	150.0	14.9	23.5	57.5	1.84	105.8	"	3.17	476
6	1982	Jul.19	150.0	14.7	23.3	56.5	1.57	88.7	"	3.78	567

Table-8.4 Specially Averaged Probable Rainfall

(Unit: mm/day)

Station	Return Period (Years)	La Mansa	Carmen de Atrato	El Piñon	Special Average
Pte. Las Sanchez	10	110.2	87.9	-	96
	20	124.3	97.4	-	107
	50	142.5	109.6	-	121
	100	156.1	118.8	-	132
	1,000	201.2	149.3	-	167
	10,000	246.2	179.6	-	203
	PMP	274	235	-	249
Girardot	10	110.2	87.9	-	94
	20	124.3	97.4	-	104
	50	142.5	109.6	-	118
	100	156.1	118.8	-	129
	1,000	201.2	149.3	-	163
	10,000	246.2	179.6	-	197
	PMP	274	235	-	245
El Piñon	10	110.2	87.9	209.4	113
	20	124.3	97.4	231.9	126
	50	142.5	109.6	261.0	142
	100	156.1	118.8	282.8	155
	1,000	201.2	149.3	354.9	195
	10,000	246.2	179.6	426.9	236
	PMP	274	235	592	303

8.4.4 Peak Discharge Prediction

Flood peak discharge was predicted by the rational formula [5]:

$$Qp = \frac{1}{3.6} fp.r.A$$

Where Qp : Flood peak discharge (m^3/s)

fp : Peak discharge coefficient

r : Rainfall intensity (mm/hour)

A : Drainage area (Km^2)

Rainfall intensity r can be evaluated by

$$r = \frac{P_{24}}{24} \left(\frac{24}{Ta}\right)^{\frac{2}{3}}$$

Where, R_{24} is a daily rainfall in mm/day and Ta is a flood concentration time, which can be calculated by

$$Ta = \frac{L}{20\left(\frac{H}{L}\right)^{0.6}} \quad \text{(hours)}$$

Where L : River length (m)

H : Elevation difference (m)

The peak discharge coefficient was analyzed by inversion using the above formula from the peak discharge data measured in 1980, 1981, 1983 and 1984 by the stage recorders at Las Sanchez and Girardot gauging stations (but measured only in 1984 at Girardot).

The results are plotted on Fig. 8-12, where the relations between the calculated peak discharge coefficient and the averaged daily rainfall over the basin are shown. This figure indicates that there is a tendency that the peak discharge coefficient decreases as the daily rainfall increases. Fig. 8-12 is not based on sufficient data, but closely examining this tendency, it was concluded that the comparatively small value of peak discharge coefficient fp=0.65 should be adopted for this basin.

The flood peak discharge estimation for Las Sanchez, Girardot and El Piñon basin are summarized in Table 8-5.

The relation between the specific peak discharge and the drainage area is shown in Fig. 8-13. In Fig. 8-13, Creager curves [6]

$$g = 46C \cdot A^{(0.894A^{-0.048} - 1)}$$

Where, C : Constant

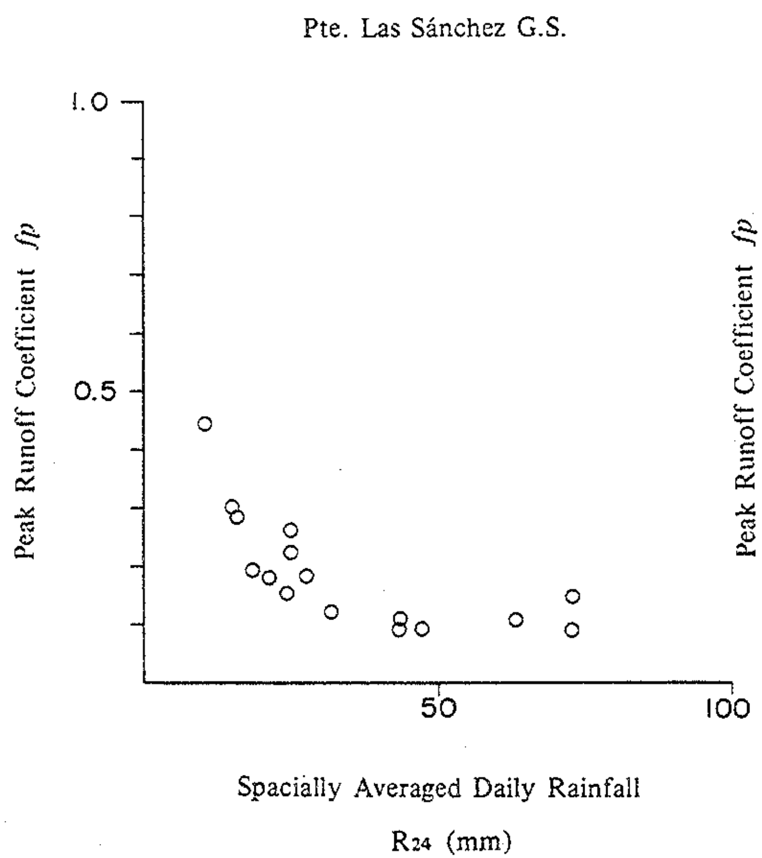
A : Drainage area ($mile^2$)

Q : Specific peak discharge ($ft^3/sec/mile^2$)

calculated in the case C=26, 33, 50 are also plotted, and it is clear that these curves correspond to the flood of return period 100, 1000 in years and PMF (Probable Maximum Flood) respectively. Hence, from these Creager curves, the design flood discharges at various project sites can be estimated.

For example, the design floods at El Siete No.1 Dam, El Siete No.2 Intake Dam, El Siete No.2 Power Station etc. are obtained as shown in Table-8.6.

Fig. 8-12 Peak Runoff Coefficient vs. Daily Precipitation



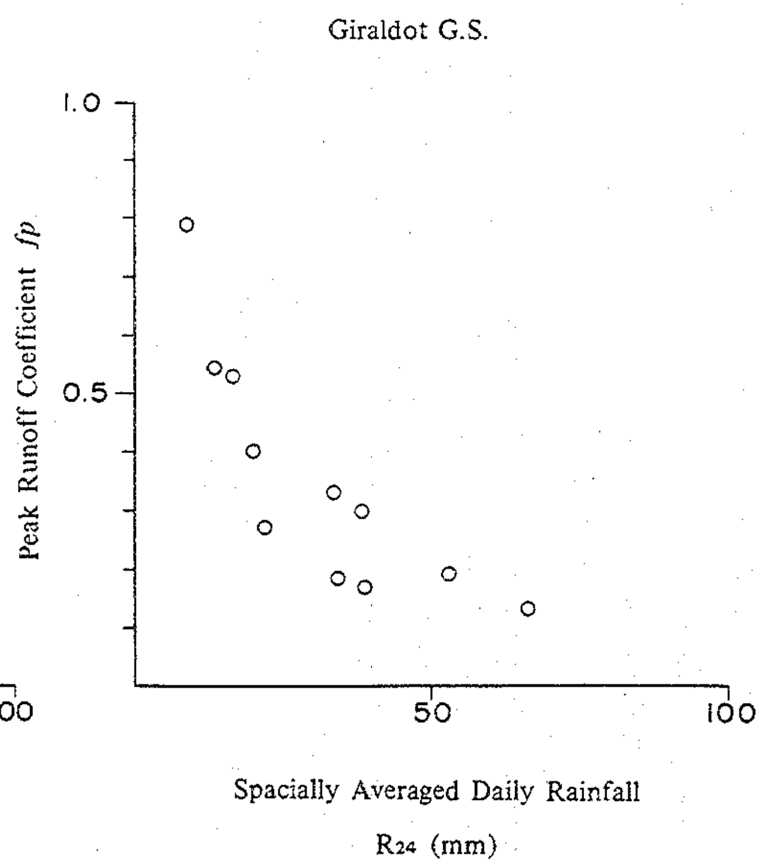


Fig. 8-13 Design Flood for Atrato Project

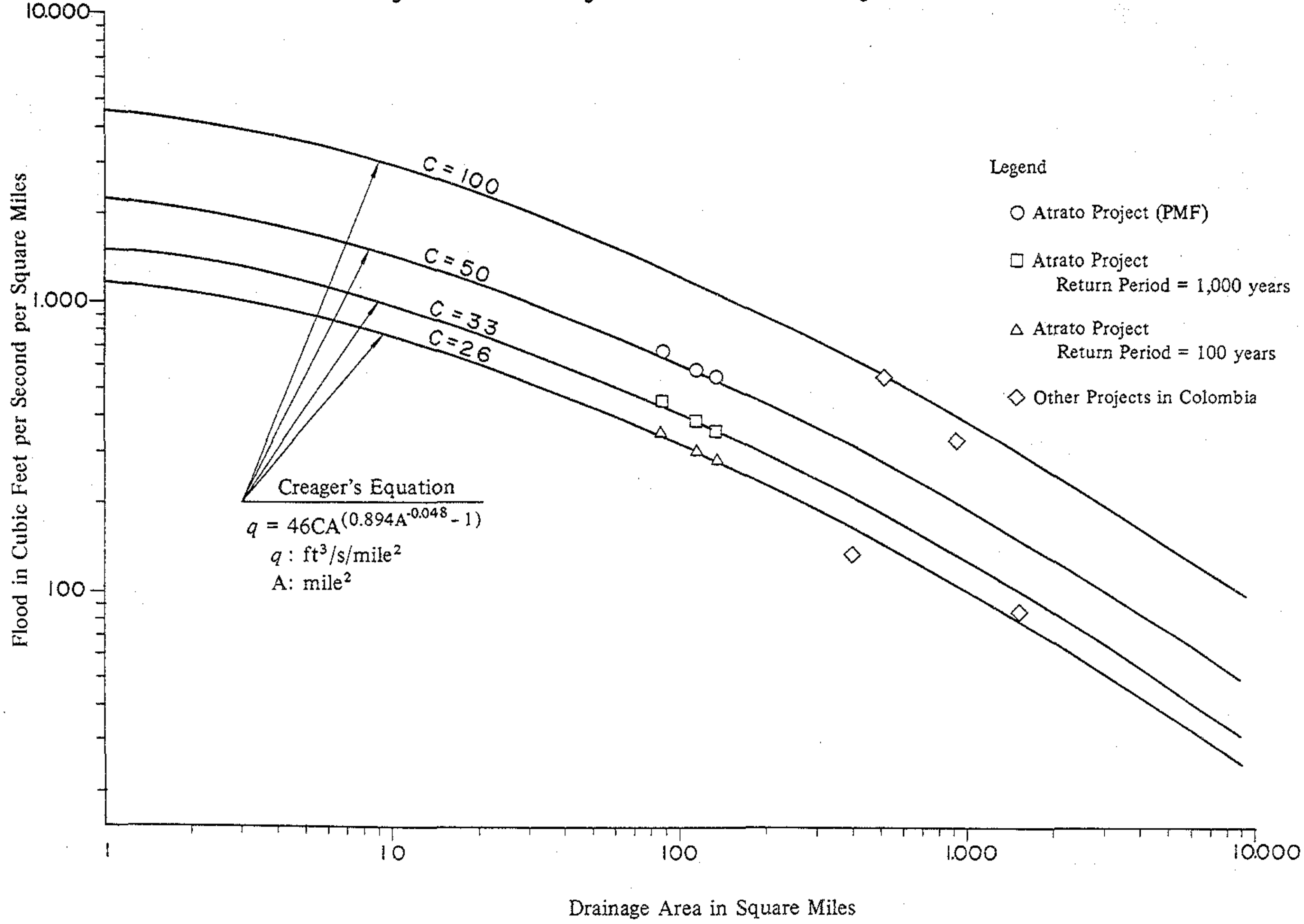


Table-8.5 Estimation of Flood Discharge

Site	Return Period (Year)	Catchment Area A(km^2)	Difference of Elevation H (m)	River Length L (m)	Maximum Daily Rainfall R_{24} (mm/day)	Intensity of Rainfall r (mm/hr)	Flood Concentration Time Ta (hr)	Flood Discharge Qp (m^3/s)	Specific Flood Discharge per km^2 q($m^3/s\ km^2$)
Pte. Las Sanchez	20	226.9	940	28,500	107	17.4	3.1	713	3.14
	50	"	"	"	121	19.7	"	807	3.56
	100	"	"	"	132	21.5	"	881	3.88
	1,000	"	"	"	167	27.2	"	1,114	4.91
	10,000	"	"	"	203	33.1	"	1,356	5.98
	PMP	"	"	"	249	40.6	"	1,663	7.33
Girardot	20	297.9	1,350	37,300	104	14.8	3.8	796	2.67
	50	"	"	"	118	16.8	"	904	3.03
	100	"	"	"	129	18.4	"	990	3.32
	1,000	"	"	"	163	23.2	"	1,248	4.19
	10,000	"	"	"	197	28.0	"	1,506	5.06
	PMP	"	"	"	245	34.9	"	1,877	6.30
El Piñon	20	347.4	1,790	52,700	126	13.9	5.6	872	2.51
	50	"	"	"	142	15.6	"	979	2.82
	100	"	"	"	155	17.0	"	1,066	3.07
	1,000	"	"	"	195	21.4	"	1,342	3.86
	10,000	"	"	"	236	25.9	"	1,625	4.68
	PMP	"	"	"	303	33.3	"	2,089	6.01

Remarks

Adopted formula is as follows.

$$Ta = \frac{L}{20(\frac{H}{L})^{0.6}}$$

$$r = \frac{R_{24}}{24} (\frac{24}{Ta})^{\frac{2}{3}}$$

$$Qp = \frac{1}{3.6} f_p r A$$

where,

- Ta : Flood concentration time (hr.)
- L : River length (m)
- H : Difference of elevation (m)
- R_{24}: Max. daily rainfall (mm/day)
- r : Intensity of rainfall (mm/hr.)
- fp : coefficient of discharge
- A : Catchment area (km^2)
- Qp : Flood discharge (m^3/sec.)
- fp = 0.65

Table-8.6 Design Flood Discharge at Each Project Site

(Unit: m^3/s)

Project Site	Drainage Area (km^2)	Return Period		PMF
		100 years	1000 years	
No.1 Auxiliary Intake Dam	235.7	870	1,110	1,680
El Siete No.1 Dam	256.3	910	1,160	1,760
El Siete No.2 Intake Dam	297.9	990	1,260	1,910
El Siete No.2 P/S	343.1	1,070	1,360	2,060

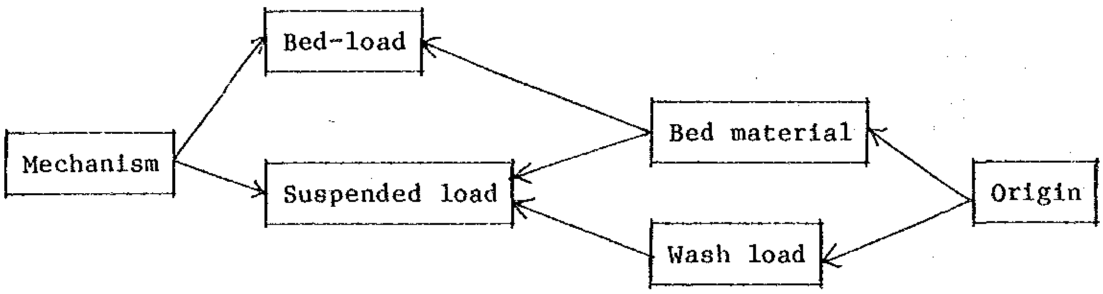
8.5 Sediment Discharge Analysis

Generally, the sediment load of streams is divided into bed-load and suspended load by the difference in transport mechanisms. Bed-load is the sediment discharge transported near the river bed due to the tractive force of the stream in rolling, sliding and saltation forms. Suspended load is transported in suspension over the cross section of the stream channel by the turbulent diffusion phenomena.

Stream-borne sediment is also classified into bed material and wash load by its sources. Bed material is the fraction of sediment consisting of the river bed materials. Wash load is the fraction of sediment composed of smaller particles transported from the upstream region.

The relation of these classified sediment fraction is shown in the following figure.

Sediment Classifications



8.5.1 Suspended Load Estimation

Suspended load was estimated using the observed concentration data of the suspended sediment at the gauging stations. Measurements were made by two methods: 1 direct measurement of the concentrations in river water sampled by a depthintegrating type sampler and 2 turbidity measurement by turbidimeter. As is well known, method 2 is not directly applicable for measurement of sediment concentrations because turbidity generally depends on the size, shape, etc. of the suspended particles and differs from the concentration value. Therefore, the relation between the turbidity and the concentration was calibrated using artificial muddy water and water sampled from the Atrato River in advance of the turbidity measurement. The results are shown in Fig. 8-14. From this figure, the concentration was obtained by doubling the turbidity records where method 2 was used.

The relations between the suspended sediment concentrations and the daily discharge are shown in Fig. 8-15 (1) ~ (4). Using these relations, annual sediment discharge can be estimated by the following equation.

$$Qsus = \sum_{i=1}^{365} Qi \times Ci \times 86,400 \quad (mg)$$

Where Qsus : Annual sediment discharge (mg)

Qi : Daily discharge (m^3/sec)

Ci : Suspended sediment concentration

Annual suspended load estimated by the above equation on the basis of the daily discharge records for 15 years at las Sanchez obtained in section 8.3.4 (1), is tabulated in Table-8.7.

8.5.2 Bed Load Estimation

Direct measurement of bed load is very difficult and an effective method has not yet been established. As measurements have not been performed in Atrato basin, bed-load was predicted from the percentage of bed-load to suspended load. It is said that the maximum value of this percentage is 25% and the large value is obtained for mountaneous region 7). The value 25% was adopted in this analysis. The predicted bed-load is also shown in Table-8.7.

8.5.3 Total Stream Sediment Load

Total stream sediment load is calculated by the sum of suspended load and bed load. The annual total sediment load at Las Sanchez gauging station averaged for 15 years from 1969 to 1984 (except 1971) is estimated to be 1,654,000 ton/year. If sediment density is assumed as 1.2 ton/m^3, this sediment volume is elaborated as 1,378,000 m^3/year (see Table-8.7).

Fig. 8-14 Concentration vs. Turbidity

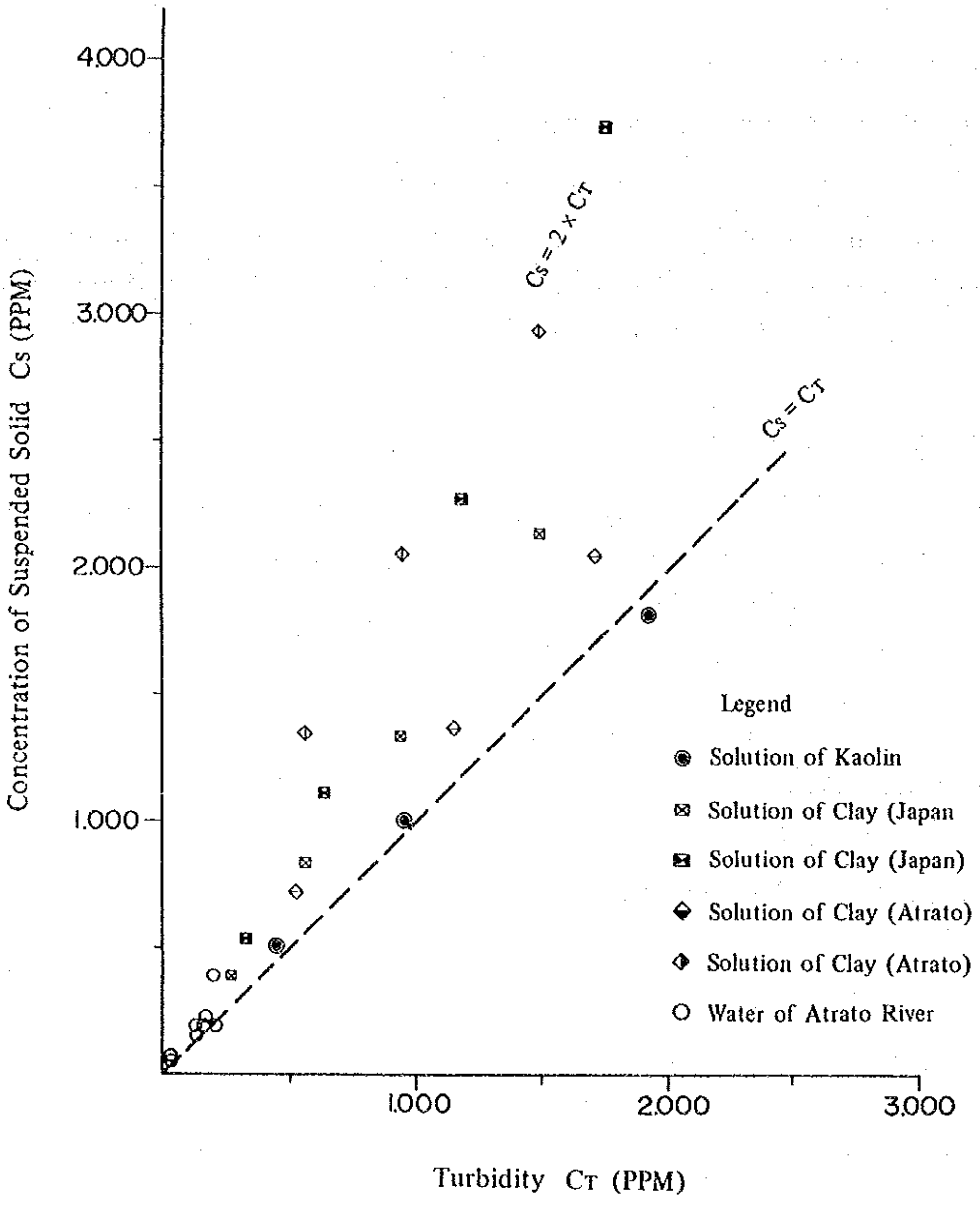


Fig. 8-15(1) Water Discharge vs Concentration of Suspended Sediment

(El Siete Gauging Station)

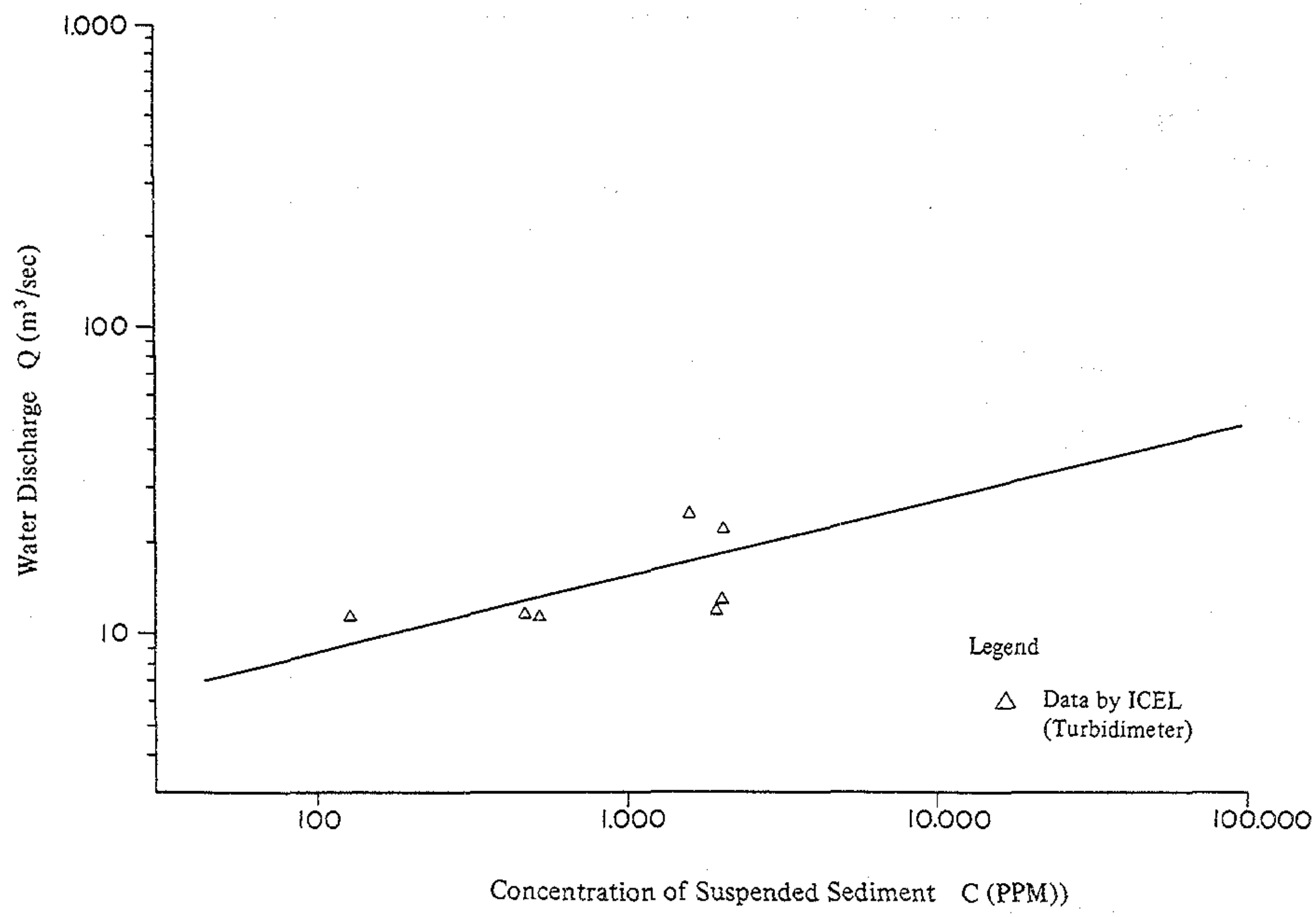


Fig. 8-15(2) Water Discharge vs. Concentration of Suspended Sediment
(Pte. Las Sánchez Gauging Station)

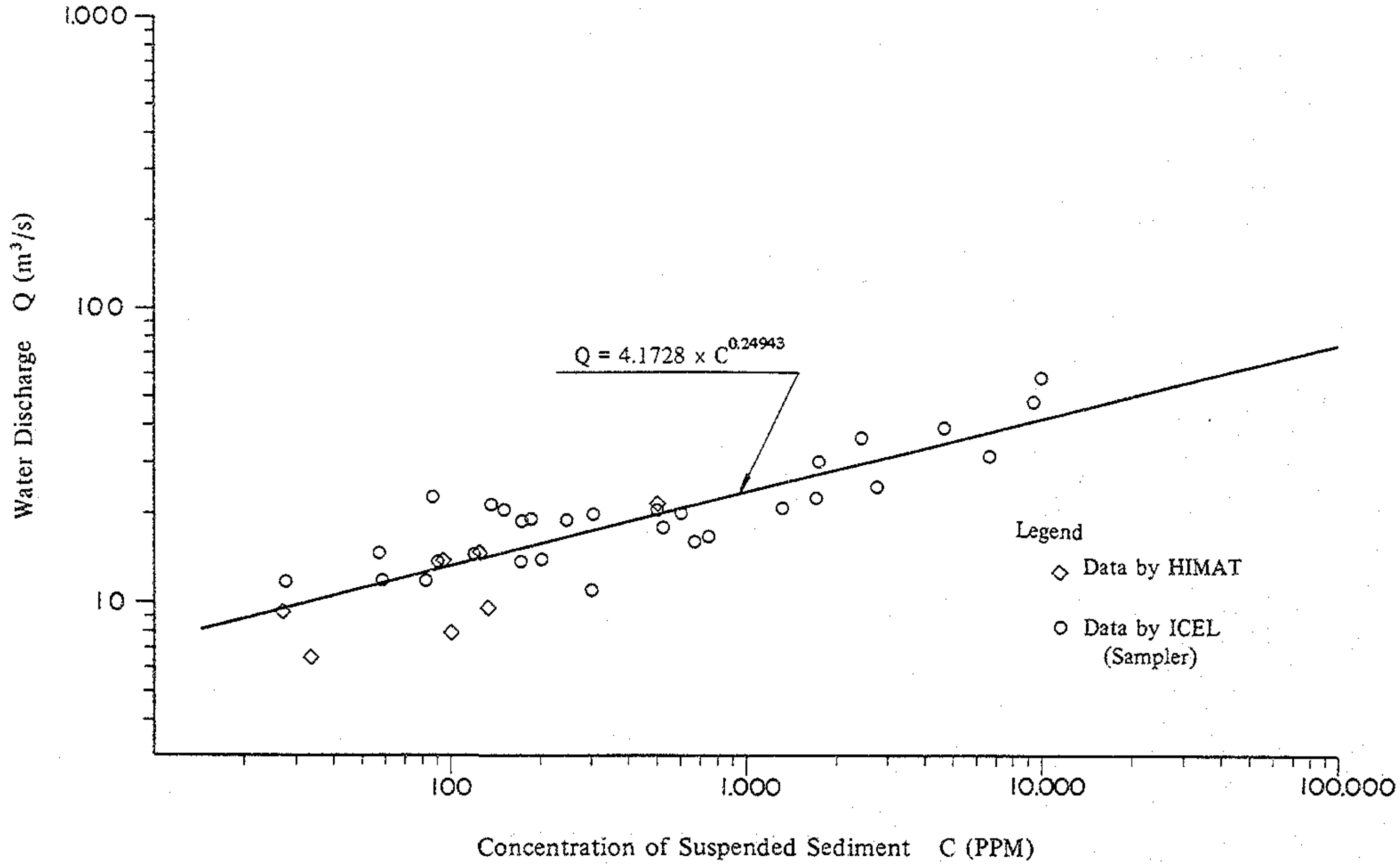


Fig. 8-15(3) Water Discharge vs. Concentration of Suspended Sediment

(Girardot Gauging Station)

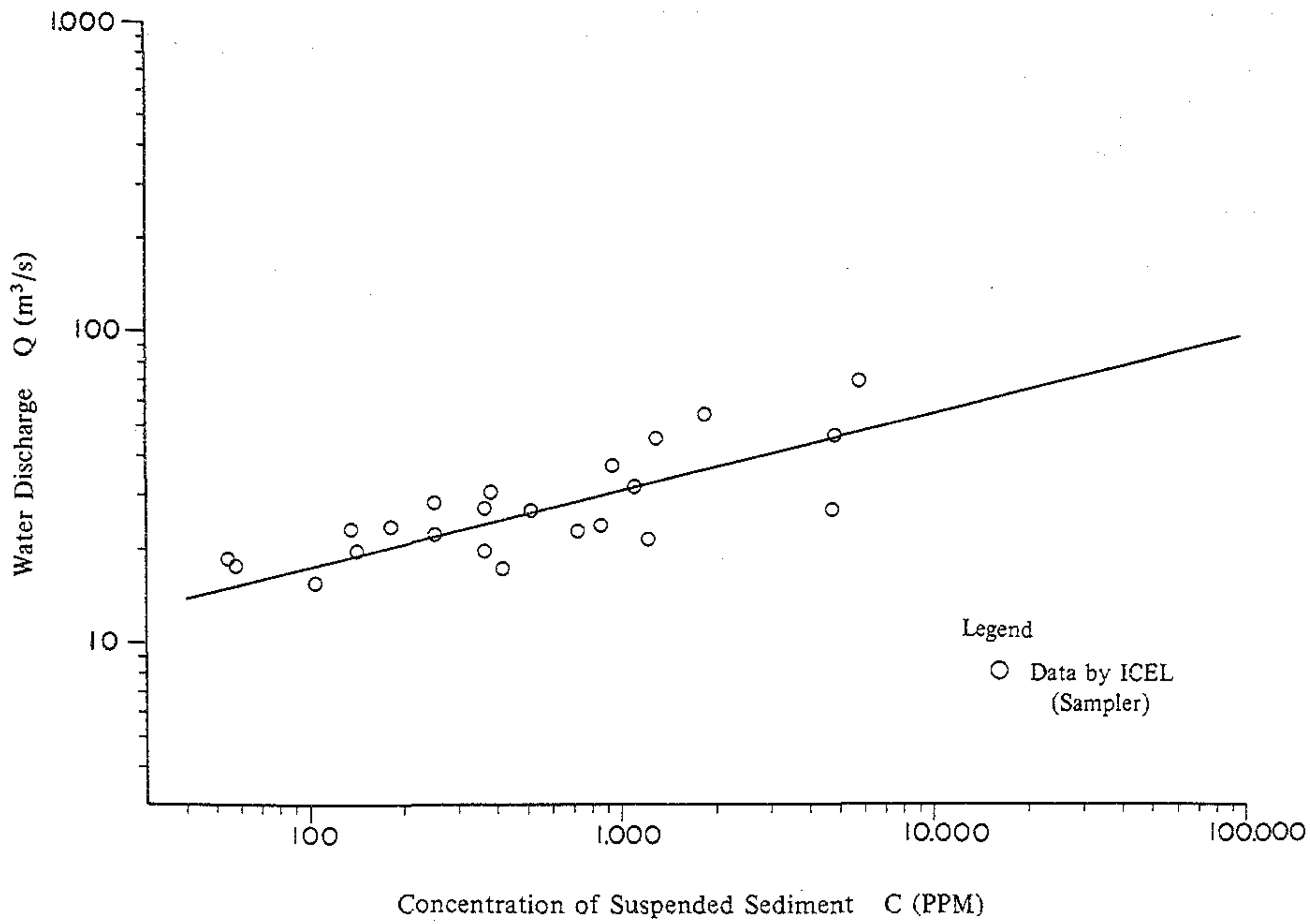


Fig. 8-15(4) Water Discharge vs. Concentration of Suspended Sediment
(El Piñon Gauging Station)

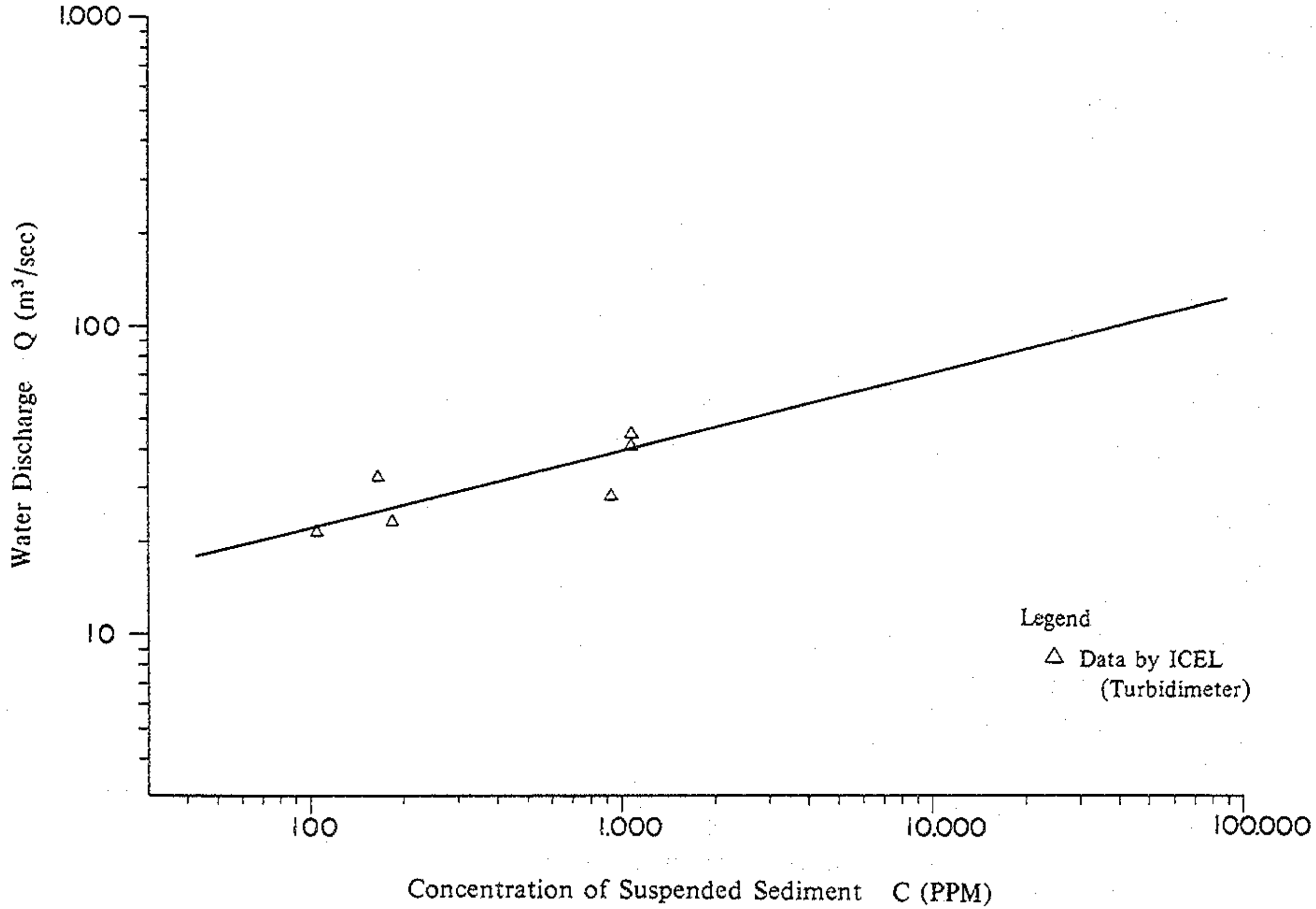


Table-8.7 Annual Inflow of Sedimentation

(Pte. Las Sanchez Ganging Station A = 226.9 km^2)

Year	Suspended Load	Bed Load	Total
1969	1,878,000	470,000	2,348,000
1970	3,234,000	809,000	4,043,000
1971	-	-	-
1972	3,309,000	827,000	4,136,000
1973	981,000	245,000	1,226,000
1974	1,097,000	274,000	1,371,000
1975	1,383,000	346,000	1,729,000
1976	497,000	124,000	621,000
1977	403,000	101,000	504,000
1978	1,849,000	462,000	2,311,000
1979	1,079,000	270,000	1,349,000
1980	312,000	78,000	390,000
1981	709,000	177,000	886,000
1982	272,000	68,000	340,000
1983	743,000	186,000	929,000
1984	2,096,000	524,000	2,620,000
Average	1,323,000	331,000	1,654,000

(Unit: ton/year)

Bed Load = 0.25 x Suspended Load

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CHAPTER 9. INSTALLED CAPACITY AND ANNUAL ENERGY PRODUCTION

CHAPTER 9 INSTALLED CAPACITY AND ANNUAL ENERGY PRODUCTION

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CHAPTER 9. INSTALLED CAPACITY AND ANNUAL ENERGY PRODUCTION

9.1 Installed Capacity

Installed capacity was selected as follows based on the results of hydrological analysis in Chapter 8 and studies of development mode and development scale in Chapter 11.

(1) Runoff

The annual average runoff at the El Siete No.1 dam site is 23.0 m^3/s, the maximum runoff 54.3 m^3/s, and the minimum runoff 10.4 m^3/s.

The annual average runoff of the remaining catchment area at the EI siete No.2 intake dam site is 3.7 m^3/s, the maximum runoff 8.8 m^3/s, and the minimum runoff 1.7 m^3/s.

(2) Maximum Available Discharge at Each Power Station

With 25 m^3/s, double the 95-percent dependable discharge of 12.3 m^3/s (discharge for 50-percent load factor), as the basis, economic comparisons were made for cases from 20 m^3/s to 30 m^3/s, and as a result, the case of 25 m^3/s was highest in both annual surplun benefit (B-C) and the benefit - cost ratio (B/C). (See 11.3.1) Consequently, the maximum available discharge of El Siete No.1 Power Station was selected to be 25 m^3/s.

The greater part of inflow at El Siete No.2 Power Station will consist of discharge from El Siete No.1 Power Station. Therefore, it was decided that the maximum 25 m^3/s discharge of the No.1 Power Station would be received through a conduit going through the No.2 Intake Dam while further adding the discharge from the remaining catchment area to obtain the maximum available discharge of the No.2 Power Station.

Economic studies were made for the cases of 1 m^3/s, 2 m^3/s, 4 m^3/s, and 5 m^3/s as the maximum intake quantity from the remaining catchment area, and as a result, it was judged that the maximum intake of 3 m^3/s would be most economical.

(3) Effective Head

The normal water level for the El Site No.1 Regulating Pondage was made 1,445 m considering daily water level fluctuation from the high water level of 1,450 m and low water level of 1,440 m, (available drawdown 10 m) with the median water level of the available drawdown as the normal water level.

Loss of head was taken to be 21 m adding friction losses, bending losses, and reduction and enlargement losses at the intake, headrace tunnel, surge tank, and penstock, and the freeboard of 3 m from the Pelton turbine center to the discharge water level. Therefore, the effective head of the No.1 power station is to be 353 m, deducting 21 m loss of head from the total 374 m head.

The normal intake water level of the No.2 Power Station was taken to be 1,068.5 m, the water level at the end of the sedimentation basin provided appurtenant to the No.2 Intake Dam.

The loss of head was taken to be 24 m adding friction losses, bending losses, and reduction and enlargement losses at the headrace tunnel, surge tank, and penstock.

Regarding the tailwater level, the water level for the discharge, adding the average discharge from the remaining catchment area to the maximum 28 m^3/s discharge used for power generation, was obtained from the rating curve of the Atrato River mainstream at the outlet point of the No.2 Power Station, and was made 687 m.

Consequently, the effective head of the No.2 Power Station was taken to be 357.5 m, deducting loss of head from the total 381.5 m head.

9.2 Annual Energy Production

(1) Annual Energy Production Calculations

El Siete No.1 and No.2 Power Stations are facilities with daily regulating capabilities, and to calculate energy production it is necessary to make computations of daily inflow on a daily basis. Accordingly, the discharge obtained in Chapter 8 was applied to daily inflow.

The period on which the calculations were based were the 15 years from 1969 through 1984 (except year of 1971), calculating electric energy on a daily basis and adding annual energy production by year.

The effective heads applied in computing electric energy were the 353 m and 357.5 m of the El Siete No.1 and El Siete No.2 Power Stations, respectively.

Regarding the generating factor, the factor at maximum output under the condition of continuous operation at maximum output through daily regulation for both power stations was applied.

The results of computing monthly and annual energy productions based on the fundamental conditions above are as given in Tables-9.1 and -9.2.

(2) Firm Energy and Secondary Energy Computations

Both power stations are to be developed as daily regulating types with firm discharges to be obtained from the duration curves of various runoff gauging stations determined in Chapter 8, and the 95-percent dependable discharges of the project sites were taken.

The firm discharges of El Siete No.1 and No.2 Power Stations are 12.3 m^3/s and 14.3 m^3/s, respectively. Firm energy is energy produced with firm discharge, and the calculation results are as shown in Tables-9.1 and -9.2.

(3) Anual Energy Production Applied to Project

On examination of the annual energy production figures for the 15 years from 1969 through 1984 (except year of 1971), the maximum annual energy production was, in 1975, 579.6 GWh/yr for the No.1 power station, and 665.9 GWh for the No.2 power station, a total of 1,245.5 GWh annually.

On the other hand, the minimum was, in 1977, with 456.9 GWh for the No.1 power station and 530.6 GWh for the No.2, a total of 987.5 GWh annually.

Looking at the average values for the 15-years period, they are 508.0 GWh/yr for the No.1 Power Station, and 588.3 GWh/yr for the No.2, a total of 1,096.3 GWh/yr.

These results show a 14% increase for the maximum value, and a 10% decrease for the minimum.

This degree of variation between wet and dry years is on the small side compared with the cases of many other rivers, and it will be reasonable to use the average value as the energy production to be applied in the Project.

Accordingly, energy productions applied to the Project are as given in Table-9.3 and Fig.-9.1.

Fig. 9-1 Annual and Monthly Energy Production in Average

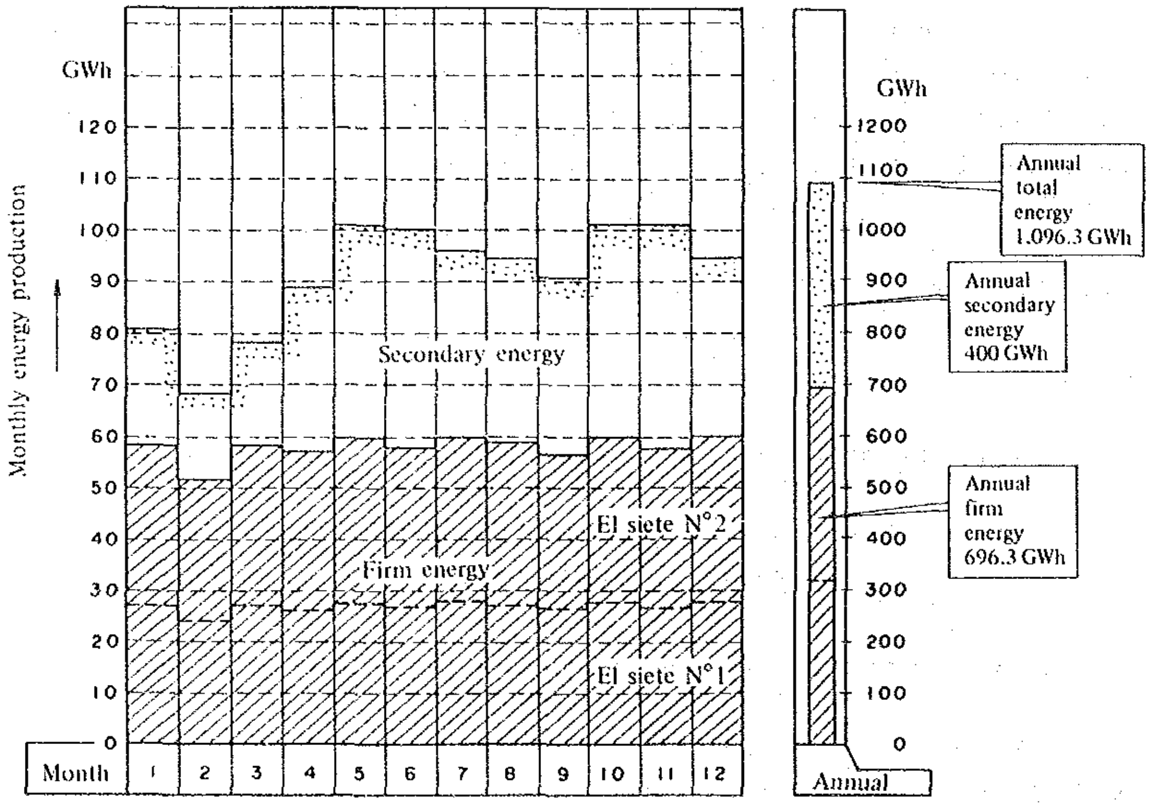

Table-9.1 Firm Energy and Annual Total Energy in El Siete No.1 Power Station

Unit : GWh

Month	Year	1 1969	2 1970	1971	3 1972	4 1973	5 1974	6 1975	7 1976	8 1977	9 1978	10 1979	11 1980	12 1981	13 1982	14 1983	15 1984	Average GWh	Average MW	P/F	Remarks
1	Firm	27.2	27.5		27.5	26.6	27.5	27.5	27.4	26.9	27.4	26.2	27.5	26.7	27.4	22.7	27.4	26.9	36.2	0.48	P/F: plant utility factor
	Total	38.2	47.9	-	48.5	29.9	45.5	39.1	43.3	28.1	31.8	28.1	38.5	29.5	38.9	19.5	37.0	31.5	42.3	0.56	
2	Firm	24.7	24.8	-	25.7	23.9	24.8	24.8	25.7	22.2	23.1	18.9	25.7	23.1	24.8	19.5	25.7	23.8	35.4	0.47	
	Total	32.6	29.7	-	42.6	32.3	45.0	43.2	31.0	22.2	23.5	18.9	31.4	23.9	38.9	19.5	37.0	31.5	46.9	0.63	
3	Firm	27.5	27.3	-	27.5	27.5	27.4	27.5	27.4	22.4	25.6	25.8	25.6	27.2	27.5	26.3	27.5	26.7	35.9	0.48	
	Total	40.7	41.3	-	39.7	47.2	46.3	43.1	37.6	22.4	28.6	28.0	26.5	33.6	36.8	32.7	38.1	36.2	48.7	0.65	
4	Firm	26.6	26.6	-	26.6	26.6	26.6	26.6	26.6	23.1	26.6	26.5	25.7	26.5	26.6	26.6	26.5	26.3	36.5	0.49	
	Total	49.0	46.3	-	48.1	50.6	44.9	48.4	40.4	25.2	41.8	35.4	30.6	36.6	43.8	47.5	34.4	41.5	57.6	0.77	
5	Firm	27.5	27.5	-	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	37.0	0.49	
	Total	46.3	50.2	-	51.9	50.6	44.8	50.0	42.4	43.8	53.1	46.8	46.2	41.1	47.7	49.8	40.9	47.0	63.2	0.84	
6	Firm	26.6	26.6	-	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	36.9	0.49	
	Total	44.1	50.8	-	49.6	45.3	47.0	48.5	48.0	43.3	43.8	51.1	48.7	44.8	44.1	43.7	49.8	46.8	65.0	0.87	
7	Firm	26.7	27.5	-	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.4	27.5	27.5	27.4	36.8	0.49	
	Total	31.1	46.9	-	48.5	45.5	48.5	50.7	41.1	42.9	38.2	48.1	37.9	40.3	43.3	49.1	53.6	44.4	59.7	0.80	
8	Firm	27.5	27.5	-	27.5	27.5	27.5	27.5	24.9	27.5	26.2	27.5	27.5	27.4	27.2	27.5	27.5	27.2	36.6	0.49	
	Total	44.5	51.4	-	52.1	47.5	46.9	52.2	26.7	47.0	28.1	42.8	44.8	36.0	37.4	50.3	48.0	43.7	58.7	0.78	
9	Firm	26.6	26.6	-	26.6	26.6	26.6	26.6	21.4	26.6	26.6	26.6	25.6	26.6	26.4	26.6	26.6	26.1	36.2	0.48	
	Total	46.0	47.5	-	49.4	50.6	48.8	50.7	22.5	34.9	36.0	47.3	28.5	35.5	35.1	49.2	49.3	42.1	58.5	0.77	
10	Firm	27.5	27.5	-	27.5	27.5	27.5	27.5	27.3	27.5	27.5	27.5	27.5	27.4	27.5	27.5	27.5	27.4	36.8	0.49	
	Total	47.9	51.9	-	47.9	51.5	48.8	52.8	41.6	52.3	46.7	46.3	41.3	39.1	39.8	51.0	44.4	46.9	63.0	0.84	
11	Firm	26.6	26.6	-	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	36.9	0.49	
	Total	44.4	48.4	-	47.6	50.1	46.9	49.7	44.9	51.1	48.0	52.7	41.2	50.9	35.7	48.1	44.1	46.9	65.1	0.86	
12	Firm	27.5	27.5	-	27.5	27.5	27.4	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.0	27.5	27.5	27.4	36.8	0.49	
	Total	42.2	51.7	-	39.8	47.4	35.8	51.2	37.9	43.4	44.7	46.9	42.6	49.2	29.3	48.1	46.4	43.8	58.9	0.78	
Annual	F	322.2	323.1	-	324.2	321.6	323.2	323.3	316.2	311.7	318.4	314.4	320.5	320.4	322.3	312.1	324.1	319.8	36.5	0.49	
	T	507.2	563.9	-	565.6	548.3	549.3	579.6	457.6	456.9	464.3	492.5	458.2	460.5	472.5	511.7	523.4	508.0	58.0	0.77	
Average	F	26.9	26.9	-	27.0	26.8	26.9	26.9	26.3	26.0	26.5	26.2	26.7	26.7	26.9	26.0	27.0	-			
	T	42.3	47.0	-	47.1	45.7	45.8	48.3	38.1	38.1	38.7	41.0	38.2	38.4	39.4	42.6	44.4	-			

Table-9.2 Firm Energy and Annual Total Energy in El Siete No.2 Power Station

Unit : GWh

Month	Year	1 1969	2 1970	1971	3 1972	4 1973	5 1974	6 1975	7 1976	8 1977	9 1978	10 1979	11 1980	12 1981	13 1982	14 1983	15 1984	Average GWh	Average MW	P/F	Remarks
1	Firm	32.0	32.3	-	32.3	31.4	32.3	32.3	32.3	31.7	32.2	30.9	32.3	31.4	32.2	26.8	32.3	31.7	42.6	0.37	P/F: plant utility factor
	Total	44.7	55.3	-	55.9	35.2	52.6	45.7	50.4	33.1	37.5	33.1	45.2	34.8	47.1	26.8	53.6	43.4	58.3	0.51	
2	Firm	29.1	29.2	-	30.2	28.1	29.2	29.2	30.2	26.1	27.2	22.2	30.2	27.2	29.2	22.9	30.2	28.0	41.7	0.33	
	Total	38.4	34.9	-	49.1	37.8	51.7	49.9	36.5	26.2	27.7	22.2	36.9	28.1	45.4	22.9	43.4	36.7	51.0	0.43	
3	Firm	32.3	32.1	-	32.3	32.3	32.3	32.3	32.2	26.4	30.2	30.4	30.2	32.0	32.3	31.0	32.3	31.4	42.2	0.37	
	Total	47.4	47.9	-	46.3	54.5	53.5	50.2	44.1	26.7	33.6	32.9	31.2	39.5	43.3	38.2	44.7	42.3	56.8	0.50	
4	Firm	31.3	31.3	-	31.3	31.3	31.3	31.3	31.3	27.2	31.3	31.1	30.3	31.2	31.3	31.3	31.2	30.9	42.9	0.36	
	Total	56.2	53.3	-	55.3	57.8	51.9	55.6	47.0	29.7	48.9	41.5	36.0	42.8	50.7	54.6	40.5	48.1	66.8	0.57	
5	Firm	32.3	32.3	-	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	43.4	0.38	
	Total	53.6	57.7	-	59.2	58.0	52.1	57.4	49.6	50.7	60.5	54.2	53.6	48.0	55.1	57.2	47.8	54.3	73.0	0.64	
6	Firm	31.3	31.3	-	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	43.4	0.37	
	Total	51.0	58.0	-	56.8	52.5	54.1	55.7	55.1	50.4	50.8	58.3	55.8	51.9	51.0	50.7	57.0	53.9	74.9	0.63	
7	Firm	31.5	32.3	-	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	43.4	0.38	
	Total	36.6	54.2	-	55.9	52.6	56.0	58.2	47.9	50.0	44.8	55.4	44.5	47.1	50.2	56.4	61.0	51.4	69.1	0.60	
8	Firm	32.3	32.3	-	32.3	32.3	32.3	32.3	29.3	32.3	30.8	32.3	32.3	32.3	32.0	32.3	32.3	32.0	43.0	0.38	
	Total	51.7	58.9	-	59.6	54.8	54.1	59.6	31.5	54.3	33.0	49.9	52.0	42.3	43.7	57.7	55.4	50.6	68.0	0.59	
9	Firm	31.3	31.3	-	31.3	31.3	31.3	31.3	25.2	31.3	31.3	31.3	30.1	31.3	31.1	31.3	31.3	30.8	42.8	0.36	
	Total	53.1	54.7	-	56.6	57.8	56.0	57.9	26.5	41.0	42.2	54.5	33.6	41.7	41.0	56.4	56.5	48.6	67.5	0.57	
10	Firm	32.3	32.3	-	32.3	32.3	32.3	32.3	32.1	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.3	43.4	0.38	
	Total	55.3	59.3	-	55.3	58.9	56.2	60.3	48.5	59.7	54.1	53.7	48.2	45.6	46.7	58.5	51.7	54.1	72.8	0.64	
11	Firm	31.3	31.3	-	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	43.4	0.37	
	Total	51.5	55.5	-	54.8	57.3	54.1	56.8	52.0	58.3	55.1	60.0	48.2	58.1	41.8	55.3	51.2	54.0	75.0	0.64	
12	Firm	32.3	32.3	-	32.3	32.3	32.2	32.3	32.3	32.3	32.3	32.3	32.3	32.3	31.8	32.3	32.3	32.3	43.4	0.38	
	Total	49.1	59.1	-	46.6	54.7	41.8	58.6	44.6	50.6	51.8	54.3	49.9	56.6	34.5	55.5	53.5	50.8	68.2	0.60	
Annual	F	379.3	380.3	-	387.6	378.5	380.5	380.6	372.2	366.9	374.9	370.1	377.3	377.1	379.4	367.4	382.5	376.6	43.0	0.51	
	T	588.5	648.8	-	651.3	631.8	634.1	665.9	533.8	530.6	540.2	570.1	535.0	536.4	550.5	590.3	616.4	588.3	67.2	0.79	
Average	F	31.6	31.7	-	31.8	31.5	31.7	31.7	31.0	30.6	31.2	30.8	31.4	31.4	31.6	30.6	31.9	31.4			
	T	49.0	54.1	-	54.3	52.7	52.8	55.5	44.5	44.2	45.0	47.5	44.6	44.7	45.9	49.2	51.4	49.0			

Table-9.3 Average Energy Production (Average from 1969 to 1984)

Unit : GWh

Month	El Siete No.1			El Siete No.2			Total		
	Firm E	Second E	Total E	Firm E	Second E	Total E	Firm E	Second E	Total E
1	26.9	10.3	37.2	31.7	11.7	43.4	58.6	22.0	80.6
2	23.8	7.7	31.5	28.0	8.8	36.8	51.8	16.5	68.3
3	26.7	9.5	36.2	31.4	10.9	42.3	58.1	20.4	78.5
4	26.3	15.2	41.5	30.9	17.2	48.1	57.2	32.4	89.6
5	27.5	19.5	47.0	32.3	22.0	54.3	59.8	41.5	101.3
6	26.6	20.2	46.8	31.2	22.7	53.9	57.8	42.9	100.7
7	27.4	17.0	44.4	32.3	19.1	51.4	59.7	36.1	95.8
8	27.2	16.5	43.7	32.0	18.6	50.6	59.2	35.1	94.3
9	26.1	16.0	42.1	30.8	17.8	48.6	56.9	33.8	90.7
10	27.4	19.5	46.9	32.3	21.8	54.1	59.7	41.3	101.0
11	26.5	20.4	46.9	31.3	22.7	54.0	57.8	43.1	100.9
12	27.4	16.4	43.8	32.3	18.5	50.8	59.7	34.9	94.6
Ann.	319.8	188.2	508.0	376.5	211.8	588.3	696.3	400.0	1,096.3

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10.1 Investigation Works

The investigation works for the El Siete No. 1 and No. 2 project sites were carried out by ICEL from November 1983 to April 1985 based on the recommendations in "Master Plan Report on Rio Atrato Hydroelectric Power Project, March 1982, Japan International Cooperation Agency," and with technical cooperation in the investigation works by a JICA Survey Mission on five occasions.

The investigation works performed by ICEL, as shown in Table 10-1, included field geological survey together with subsurface geological investigations by drilling, and trench and pit excavation, and by seismic prospecting. The results of these investigations are contained in the following reports.

° Aprovechamientos Hidroelectricos del Rio Atrato, Informe Finel, Estudios Geologicos; April 1985, ICEL

° Aprovechamientos Hidroelectricos del Rio Atrato, Informe Final, Estudios Geotecnicos Tomo 1; Abril 1985, ICEL

° Aprovechamientos Hidroelectricos del Rio Atrato, Informe Final, Estudios Geotecnicos Tomo 2; Abril 1985, ICEL

° Aprovechamientos del Rio Atrato, Informe Final, Estudios Sismologicos, Abril 1985, ICEL

Surface geological surveys of the entire project area, using rough topographical maps of approximately 1/25,000 scale (prepared by JICA, 1981), and geological reconnaissances of principal project sites utilizing 1/1,000 topographical maps and aerial photographs of approximately 1/2,000 scale were made by a geologist of the JICA Mission on three occasions between November 1983 and February 1985 (aggregate approximately 1 month) as a part of the Feasibility Study. In Tokyo, besides performing photogeological interpretations of the project area, physical tests, X-ray analyses, and microscope observations of rocks were also carried out.

All geological studies in this Report were made based on the results of the various works and field geological surveys in Colombia and photogeological interpretations, laboratory tests, and analytical work in Japan.

Table-10.1 Geological Investigation Works Up to Date

Project	Locality	Drillhole: Number of Drillholes (Total Length)	Drillhole: Standard Penetration Test (Total Times)	Drillhole: Water Pressure Test (Total Sections)	Drillhole: Monitor by Piezometer	Trench and Pit: Number of Trenches or Pits (Total Length)	Seismic Prospecting: Number of Lines (Total Length)	Vertical Electrical Sounding: Number of Measuring Points	Remarks
EL SIETE NO. 1	Auxiliary Damsite	-	-	-	-	3 trenches (37.15 m)	-	-	0.9 km upstream of El Siete No. 1 Damsite.
	Damsite	9 holes (310.39 m)	7 holes (59 times)	9 holes (70 sections)	5 holes	13 trenches (95.02 m) 3 pits (3.5 m)	1 line with 2 spreads (220 m) *	-	* Right bank of Damsite. Dwg.-08 shows locality of Investigation works at Damsite.
	Penstock and Powerhouse Sites	-	-	-	-	16 trenches (173.43 m) 2 pits (3.65 m)	3 lines with 7 spreads (770 m)	3 points	
	Sub-total	9 holes (310.39 m)	7 holes (59 times)	9 holes (70 sections)	5 holes	32 trenches (305.6 m) 5 pits (7.15 m)	4 lines (990 m)	3 points	Dwg.-06 shows locality of vertical electrical soundings.
EL SIETE NO. 2	Intake Damsite and Intake Tunnel Site	2 holes (79.4 m)	1 hole (5 times)	-	1 hole	-	4 lines with 12 spreads (1310 m)	-	
	Penstock and Powerhouse Sites	2 holes (68.68 m)	2 holes (18 times)	2 holes (7 sections)	2 holes	5 trenches (70.95 m)		3 points	
	Sub-total	4 holes (148.08 m)	3 holes (23 times)	2 holes (7 sections)	3 holes	5 trenches (70.95 m)	4 lines (1310 m)	3 points	
No.1 and No.2	Borrow Area for Concreat Aggregate	-	-	-	-	1 trench (6.2 m) 14 pits (20.05 m)	-	-	Puente de Sanchez and Quebrada La Borasca. Borrow area
No.1	Borrow Area for Earth Material	-	-	-	-	11 trenches (145.25 m)	-	2 points	Terraza de Sanchez. Borrow area
Total		13 holes (458.47 m)	10 holes (82 times)	11 holes (77 sections)	8 holes	49 trenches (528.00 m) 19 pits (27.20 m)	8 lines (2300 m)	8 points	

10.2 Topography and Geology of Project Area

10.2.1 Topography

Whereas the eastern half of Colombia is a plain of elevation 100 to 200 m, the western half consists of three branches of the Andes Mountains having elevations of 3,000 to 5,000 m running south to north. From east to west, the three Andean branches are respectively called Cordillera Oriental, Cordillera Central, and Cordillera Occidental (see Dwg.-01). There is also a mountain range of elevation 1,000 m and under extending north to south between the Cordillera Occidental and the Pacific Ocean coast (the northern part of the mountain range called Serrania de Los Saltos, the southern part, Serrania de Baudo). The midstream and downstream areas of the Rio Atrato flow north through the lowland between this mountain and the Cordillera Occidental to enter the Caribbean Sea.

The fountainhead of the Rio Atrato is at the western slope of the Cordillera Occidental from which it first flows south to southwest down the steep slope to Quibdo City at an elevation of approximately 35 m. Here the Rio Atrato changes course drastically to the north in the vicinity of Quibdo from where it flows north for approximately 300 km to the Caribbean Sea.

The El Siete No. 1 and No. 2 project sites are located at elevations from 1,000 to 600 m at the uppermost area of the Rio Atrato. The El Siete No. 1 project area covers a stretch from river-bed elevation of 1,460 m to 1,050 m where the Rio Atrato turns from a westerly to a southerly course. The El Siete No. 2 project area lies downstream of the No. 1 project area from a river-bed elevation of 1,100 m to 700 m where the Rio Atrato flows approximately southward. The Rio Atrato is joined at the left-bank side by a comparatively large tributary, the Rio Grande, approximately 17 km downstream of the No. 2 project damsite. This confluence is at a point approximately 100 km upstream from Quibdo City.

The Rio Atrato in the two project areas forms V-shaped valleys of relative heights 50 to 100 m in many places. At parts other than the V-shaped valleys where the valley widths are comparatively large, there are some flat areas. Parts of these flat areas are terraces, while the remaining parts were formed by mudflows as described later.

Accordingly to field geological surveys and photogeological interpretations made up to this time, there are no large-scale landslide terrains in the two projects areas, but small-scale slope collapses can be seen in many places.

Considered from the fact that there are many hanging valleys in parts of the Rio Atrato and at tributaries in the project area, from the topographic point of view this is an area with severe erosional agencies.

10.2.2 General Geology

Colombia is situated along the northwest fringe of the Guayana Shield, and therefore, the eastern half of the country has a simple and stable geological structure influenced by this shield. In sharp contrast, the western half consists of complex fold mountains extending in a north-south direction, and these geological structures are reflected in the topography.

In the Rio Atrato basin at the west slope of the Cordillera Occidental where the project area is located, there are the KSV Formation consisting of sedimentary rocks and volcanic rocks and the KV Formation of volcanic rocks and intrusive rocks of the late Cretaceous Period, and diorite (the TD Formation) which intruded the above two formations during the Tertiary Period. In the vicinity of Quibdo City downstream of the project area there is the T_{S5} Formation consisting of Pliocene-Oligocene marine sedimentary rocks unconformably overlying the abovementioned formation.

(1) Stratigraphy and Lithology of Project Area

The formations comprising the basement rocks of the El Siete No. 1 and No. 2 project sites are the KSV Formation and the Td Formation. Quaternary mudflow deposits, terrace deposits, slopewash, and river deposits are distributed overlying the basement rocks in unconformity. In this Report, the KSV Formation was subdivided into five formations in order from the bottom of K_{1A}, K_{1B}, K_{2A}, K_{2B}, and K_3 based on the lithofacies features.

The features of the stratigraphy and lighology are as given in Table-10.2, and can be summarized as follows:

1) K_{1A} Formation (Upper Cretaceous)

This formation is widely distributed in the Rio Atrato basin upstream of El Siete No. 1 auxiliary dam, that is, the catchment area of the No. 1 project, and is a formation surmised to correspond to the bottommost part of the strata making up the basement of this project site.

This formation consists of alternations of dark gray, hard sandstone layers 10 to 50 cm thick and black to dark gray, slightly fissile shale layers from 3 to 10 cm thick.

With the exception of those areas along the rivers and valleies where erosion is extreme, the surfaces in the distribution area of this formation are severely weathered and there are many small slope collapses of weathered parts of basement rocks on the mountainsides.

2) K_{1B} Formation (Upper Cretaceous)

This is a formation which grades to the K_{1A} Formation and is featured by intercalation of calcareous beds. This is distributed from the El Siete No. 1 auxiliary dam foundation to the downstream No. 1 Dam regulating reservoir.

The lower position of this formation consists of alternations of gray to black shale layers 2 to 3 cm thick, and gray calcareous shale layers 5 to 10 cm thick. These grade upward to black chert layers 2 to 10 cm thick, and further grade to

Table-10.2 Geologic Sequence of Project Area

Era	Period	Stratigraphic Unit			Rock Type	Characteristic	Main Distribution
Cenozoic	Quaternary	Quaternary System			River deposit	Unconsolidated deposit consists of gravel, sand and silt.	Along the Atrato River
					Slopewash	Unconsolidated deposit consists of rock fragments and silt.	On slope in whole area
					Terrace deposit	Unconsolidated deposit consists of gravel, sand and silt.	Both banks of main river
					Mudflow deposit	Unconsolidated, but compact deposit consists of basaltic fragements with silty matrix, poorly sorted.	Flat area on hillsides along the Atrato River
	Tertiary	Td	Intrusive rock Intrusion		Diorite	Medium-to coarse-grained, massive, hard and compact. Granodioritic in part.	El Siete No.2 penstock area
Mesozoic	Upper Cretaceous	KSV Formation	K_3		Diabase (With amphybolite, in local)	Dark green colored, hard but somewhat cracky.	El siete No.2 waterway route
			K_2	K_{2B}	Alternation of Sandstone, shale and conglomerate (With basaltic rock, in local)	Mainly alternation of sandstone and shale with frequent intercalations of basaltic rock.	El Siete No.1 penstock and powerhouse
				K_{2A}	Basalt (With basaltic pyroclastic rocks)	Black to purplish grey colored basalt, massive and hard with occasional intercalations of basaltic tuff breccia.	El Siete No.1 damsite and No.1 headrace tunnel route
			K_1	K_{1B}	Alternation of chert and limestone and/or calcareous shale	Beds of chert and limestone are 3 to 10 cm thick, intensly folded. No karstic phenomena.	El Siete No.1 reservoir area
				K_{1A}	Alternation of sandstone and shale	Bed of sandstone is 10 to 50 cm thick and bed of shale is 5 to 30 cm thick. Sandstone is hard but shale is somewhat brittle.	Upstream of El Siete No.1 auxiliary damsite

alternations of black chert or shale layers 5 to 40 cm thick and gray to grayish white limestone layers 5 to 30 cm thick. The chert and limestone are hard. This formation shows a severe fold structure in this area.

The alternations of black chert and limestone are featured by isoclinal folds of wavelengths approximately 10 to 30 m.

Karstification is not recognizable in the area where these alternations of calcareous and noncalcareous rocks are distributed.

3) K_{2A} Formation (Upper Cretaceous)

This formation is distributed from the El Siete No. 1 dam foundation to approximately 2.5 km downstream, and is estimated to be conformable with the K_{1B} Formation.

This formation is composed of basalt and basaltic pyroclastic rocks, but partially, there is also andesitic rock. The basalt is a massive, hard rock presenting a purplish gray to dark gray color and petrographically would be classified as fine-grained to coarse-grained augite basalt. This basalt has intercalations here and there of hard, massive brecciated tuff or autobrecciated lava beds.

The basaltic pyroclastic rocks have dark gray, massive and hard parts containing subrounded and/or angular gravels from 3 to 10 cm in diameter in a matrix of basaltic tuff and parts containing finer gravels.

4) K_{2B} Formation (Upper Cretaceous)

This formation is distributed from downstream of the El Siete No. 1 headrace to the No. 1 powerhouse site and further down to the El Siete No. 2 intake dam, and has a transitional relationship with the underlying K_{2A} Formation.

This formation consists mainly of alternations of hard, gray sandstone layers 2 to 20 cm thick and slightly brittle black shale layers 0.5 to 3 cm thick with intercalations of unbedded hard conglomerate, while thick interbeds of hard basalt or basaltic pyroclastic rock, and infrequently, hard diabase in which joints are developed.

5) K_3 Formation (Upper Cretaceous)

This formation is distributed at the upstream section of the El Siete No. 1 headrace, and is conformable or fault contact with the K_{2B} Formation.

This formation consists mainly of a diabase presenting a greenish gray color, but this has been metamorphosed into medium-grained and schistose amphibolite near the contact with diorite, or there are parts that have been subject to mylonitization. The diabase is a hard rock in which joints are developed, while parts that have become amphibolite or mylonite are slightly brittle.

6) Intrusive Rock Td (Tertiary)

This rock is diorite intruded in the K_3 Formation and is distributed from the downstream section of the El Siete No. 2 project headrace to the El Siete No. 2 powerhouse site.

This diorite petrographically is classified as hornblende-biotite granodiorite and is generally massive and hard where fresh, but the rock at the surface layers of these project sites is brittle and easily crumbled due to weathering.

7) Quaternary Deposits

a) Mudflow Deposits

It is surmised that these deposits were formed by mudflows or debris flows of the Quaternary Period. They are thickly distributed mainly at the right bank of the El Siete No. 1 damsite and the right bank of the El Siete No. 2 powerhouse site along the Rio Atrato channel, both being unconsolidated.

The composition of the mudflow deposits is nonuniform and differs according to location, but a typical composition would be as described below. These deposits consist mainly of subangular to subrounded gravels of hard basalt and sandy silt filling the interstices, contain wood fragments here and there, and are generally well-compacted. The content of gravels is from 30 to 80 percent in terms of volumetric ratio.

b) Terrace Deposits

These are loose terrace deposits seen along the Rio Atrato consisting of sand and gravel and are distributed locally at places such as the El Siete No. 1 auxiliary dam site.

These deposits mainly consist of pebble and cobble gravels of basalt, sandstone, chert, etc., with the intersitices filled by sand and silt. The gravels are mostly subrounded or subangular.

c) Slopewash

These deposits are distributed commonly at mountainsides near the mouths of valleies.

Talus deposits and alluvial cone deposits are handled collectively in this Report as slopewash.

These deposits consist of rock fragments derived from basement rocks in the hinterland and silt matrix, and are generally loose.

d) River Deposits

These deposits consist of pebble and cobble gravels with the interstices filled by sand and silt distributed at the present river bed. The deposits are loosely compacted with large boulders several meters in diameter contained at places.

e) Topsoil

This is a soil containing a brown clay and has high water retentivity. The surface layer is in the form of a humus soil in which pasture grass is mixed.

(2) Geological Structure

The various formations comprising the basement of this project area, as shown in Dwg.-06, shows a belt-like distribution extending in a north-south direction. Both bedding planes in the individual formations and intrusion planes of intrusive rocks often show north-south strikes. The beds dip 45 to 70° west in the area upstream of El Siete No. 1 Dam, while in the area downstream of the dam, the beds dip mostly 50 to 80° east. The waterway alignment of the El Siete No. 1 Project is planned to cross this belt-like structure while that of the El Siete No. 2 Project is planned in a direction parallel to it.

It was confirmed that there is extreme folding of the K_{1B} Formation at the Rio Toro immediately upstream of the dam. It was also confirmed that the planes of other formations dip steeply and are overturned at some formations.

With regard to faults in the project area, air photo lineaments in the north-south direction coinciding with the formations belt-like distribution were interpreted in aerial photographs. Air photo lineaments in the northwest-southeast direction were interpreted for the El Siete No. 2 project site.

10.3 Geology of EL Siete No. 1 Project

The El Siete No. 1 Project consists of constructing a dam approximately 55 m in height (high water level elevation 1,450 m) at a point about 19 km upstream from the previously-mentioned confluence of the Rio Atrato and the Rio Grande, taking in water from the left-bank side of the dam, conducting the water by a headrace tunnel of approximately 3.1 km and a penstock of approximately 1.3 km to the No. 1 powerhouse site at the left bank to generate a maximum 75 MW of electric power.

10.3.1 El Siete No. 1 Regulating Reservoir Area

Up to the present, geological mapping has been done of the regulating reservoir area using a 1/1,000-scale topographical map. The result is shown in Dwg.-08.

(1) Topographical Conditions

This reservoir is extended in roughly an east-west direction. The total length (at high water level elevation 1,450 m) is approximately 0.9 km and the total storage capacity approximately 926 x 10^3 m^3 to constitute a daily regulating reservoir.

This reservoir is fed from both sides by two tributaries with permanent flows, the Rio Toro at the right-bank side and the Qda. Sta Lucia at the left-bank side, slightly upstream of the reservoir's midpoint.

The slopes at both banks contacting the reservoir high water level are inclined 30 to 45°. There are gradual slopes (10 to 20°) consisting of mudflow deposits described later at parts above high water level at the middle part of the right-bank side of the reservoir and at the dam foundation.

There is one small slope collapse at the skirt of the previously-mentioned mudflow deposits around the reservoir.

(2) Geological Conditions

Alternations of chert and limestone or calcareous shale belonging to the K_{1B} Formation are distributed at the upstream part of the regulating reservoir area and basalt of the K_{2A} Formation at the downstream part. These formations both have strikes of N20°E-N10°W orthogonal to the Rio Atrato and dips very close to vertical. Alternations of chert and limestone are folded along the Rio Atrato tributary Rio Toro, with the fold axis plunging 40 to 60° to the north or to the south.

In the investigations up to the present, it was pointed out that there is a possibility of faults (roughly in a north-south direction) which intersect this regulating reservoir existing, but these faults will not have any serious effects on the reservoir. These faults will be described later in the section related to the El Siete No. 1 auxiliary connecting tunnel.

The previously mentioned basement rocks are overlain at the right-bank side by unconsolidated, loose river deposits, terrace deposits, slopewash and an unconsolidated but comparatively well-compacted mudflow deposit.

As described it is known that a mudflow deposit exists from the middle part of the right bank of this regulating reservoir to the damsite, and at present a highway passes through this distribution area at a height slightly below the projected high water level of the reservoir. At surfaces of road-cuts along this highway in the vicinity of the right-bank middle portion of the reservoir, basement rocks (K_{1B} Formation, K_{2B} Formation) underlying the mudflow deposit are exposed here and there. This fact indicates that, with the exception of the dam foundation portion described in 10.3.2, the mudflow deposit is comparatively thin at just around the regulating reservoir high water level.

It was previously mentioned that a part of this mudflow deposit where it comes into contact with the regulating reservoir presents a form of slope collapse, but the scale is small and at present the deposit is stable and it is thought there is little possibility of the collapse area to increase.

Generally, the reservoir left-bank slope has little of unconsolidated and loose deposit distribution, while there is no distribution of mudflow deposits.

(3) Geological Engineering Assessments

The geological engineering assessments of this regulating reservoir area based on the topographical and geological conditions disclosed by the investigations up to this point may be summarized as follows:

1) Watertightness of this regulating reservoir is thought to be no problem at all, judging by the topographical and geological conditions.

2) Regarding to the stability of the reservoir rim, it is considered that although there may be some small collapses occurring at certain parts, there will be no collapse to a degree which could greatly impair the reservoir function.

3) Sedimentation inside the reservoir is expected to be comparatively substantial judging by the site's topographical and geological conditions, and it will naturally be necessary to provide measures against this in the design. (See Paragraph 5, Chapter 8 for more detailed discussions of sedimentation.)

10.3.2 El Siete No. 1 Damsite

Two dam axis (A-A and A'-A' in Dwg.-08) were initially compared and studied for the El Siete No. 1 damsite, and it was concluded that the downstream dam axis (A-A) is optimum. Accordingly, the results of investigation of the A-A axis will be explained herein, but the geological profile of the A'-A' axis is also given in Dwg.-08 for reference. Presently, construction of a concrete gravity dam (crest elevation, 1,455 m, height approximately 55 m) is planned at the A-A axis.

9 drillholes totalling 310.39 m in depth, 13 trenches totalling 95.02 m in length, 3 pits totalling 3.5 m in depth, and seismic prospecting on one traverse line, 220 m in length, as shown in Table-10.1, have been provided. Measurements of water levels and water pressure tests have been carried out at all of these drillholes. Of these, the boring done at the dam axis (Section A-A) consisted of Drillholes AD-1, AD-2, and AD-5, a total of 110 m in length.

(1) Topographical Conditions

The damsite (A-A axis) is located where the Rio Atrato flows west roughly in a straight line with a channel width of approximately 20 m, at a valley with a tableland at midheight of the slope on the right-bank side. The tableland has a relative height of approximately 50 m, and the dam crest will be slightly below the surface of the tableland. The slopes at the both abutments of the damsite are inclined approximately 45° topographycally as shown in Section A-A in Dwg.-09. The tableland at the right-bank was formed by a mudflow deposit, to be described later, and the mudflow deposit portion will be excavated and removed when the dam is constructed.

(2) Basement Rock Types and Lighologies

Basalts (K_{2A} Formation) are distributed at the dam foundation and overlain by Quaternary river deposits, slopewash, and mudflow deposits.

Outcrops of the basement rock in the vicinity of the dam axis are generally seen in larger number at the left-bank side, there being few at the right-bank side. The K_{2A} Formation near the damsite consists mainly of dark gray to reddish brown basalt and dark gray basaltic tuff. Basalt, thought to be autobrecciated lava, is also seen in part. These rocks generally have few cracks and are hard where fresh. The bedding plane of the basaltic tuff breccia layer at the damsite river bed has a strike (N20°W) intersecting the dam axis slightly askew and dips steeply (85°E) to the upstream side.

The predominant strikes and dips of the joint sets seen in this basement rock are in three directions, N80°W-25°NE, N70°E-85°SE, and N10°W-85°NE as shown in Fig.-10.1. The first two strike roughly parallel to the Rio Atrato, while the third has a strike diagonally crossing the river. These are seen at river-bed outcrops as joints with tight clefts at 10 to 50 cm intervals.

Physical laboratory tests on drilled cores of AD-1, AD-2, and AD-5 collected from the damsite were carried out in Tokyo. The test items and locations of sample collection are given in Table-10.3. Of these drilled cores, the unconfined compressive strength representative of the rock distributed deeper than the estimated sound rock line will be between 730 kg/cm^2 to 1,633 kg/cm^2, (the test values of the samples obtained from Drillholes AD-2 and AD-5).

Fig. 10-1 Contour Diagram of Joints in El Siete No.1 Damsite

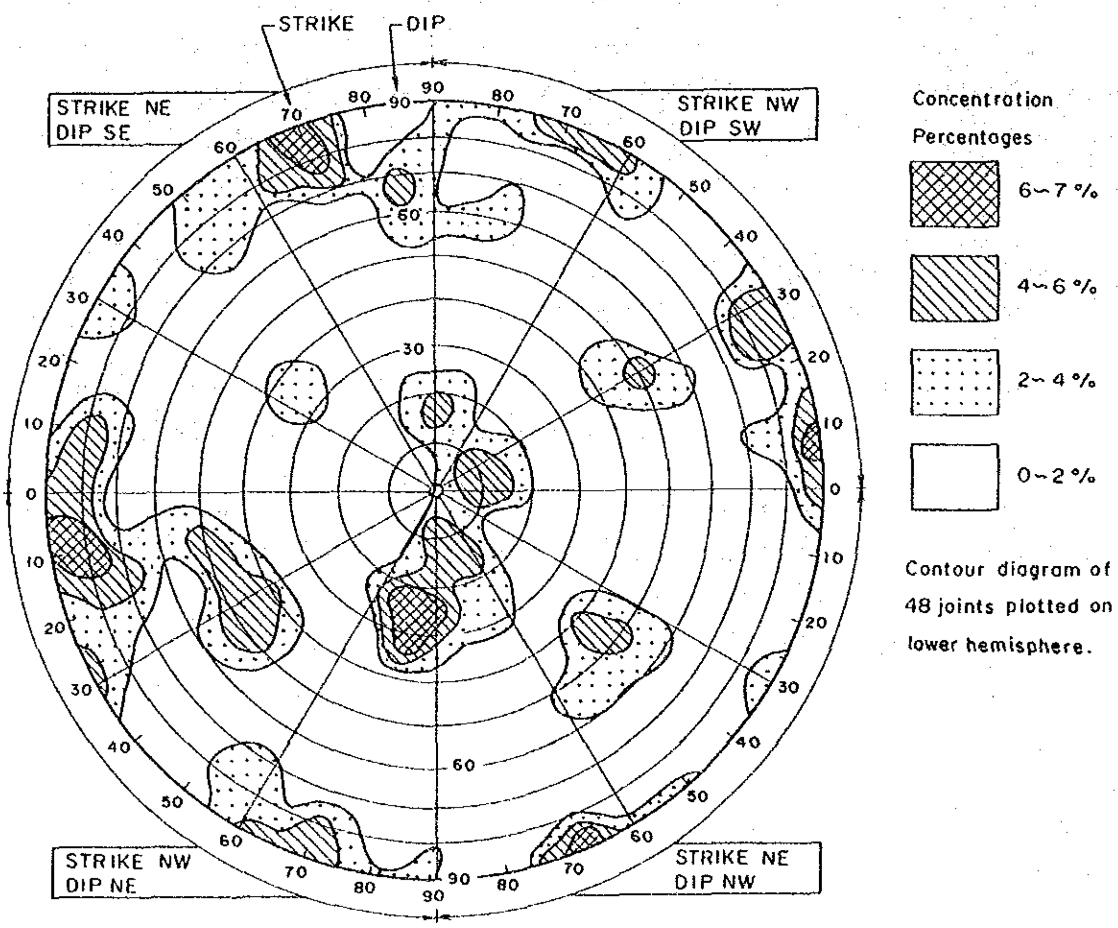

Table-10.3 Physical Properties of Drilled Cores

Borehole No.	Depth (m)	Rock Name	Apparent Specific Gravity	Absorption (%)	Uniaxial Compressive Strength (kgf/cm^2)	Stastic Modulus of Elasticity (kgf/cm^2)	Elastic Wave Velocity P Wave (km/s)
AD - 1	25.0	Basalt	2.81	2.67	426	9.5 x 10^4	2.69
AD - 2	38.6	Basalt	2.92	1.14	730	46.4 x 10^4	5.45
					1633	36.5 x 10^4	5.32
AD - 5	19.1	Basalt	2.85	1.72	884	40.9 x 10^4	4.75

(3) Faults

Regarding faults in the foundation rock, none which would pass directly through the dam foundation have been found in investigations up to the present.

(4) Weathering

With respect to basement rock weathering, basalt outcrops at the right-bank mountainside in the vicinity of the dam axis and the left-bank mountainside above an elevation of approximately 1,500 m are extremely weathered, present a brownish color, and have become very brittle (to the degree that they can be crushed between the fingers). Observations of drilled cores showed that core recovery of this strongly weathered portion was poor, with practically all having become slime, and there were parts that could not be differentiated from the mudflow deposit overlying the basement.

According to the results of drilling carried out so far, the thickness of extremely weathered parts is generally around 5 m at the midheights of the slopes at both banks, and the thickness of parts weathered to an intermediate degree is 10 m or under. Fresh, hard basement rock is generally exposed in the vicinity of the river bed. However, at Drillhole AD-9 on the left-bank slope upstream of the dam axis, strong weathering reaches into about 27 m, indicating that there are local spots where weathering has progressed to considerable depths.

(5) Groundwater

The condition of groundwater at the damsite was checked utilizing drillholes. Water levels were measured in all drillholes (9 holes) drilled at the damsite and at five holes (AD-3, AD-4, AD-5, AD-6, and AD-9) water levels were measured by piezometer for several days to about 10 days after completion of drilling. As a result, it was learned that there were groundwater tables at a depth of approximately 15 m from the ground surface at the right-bank side near the dam crest, and at a depth of about 30 m from the ground surface at the left-bank side similarly near the dam crest. The groundwater levels in the drillholes are shown in the core logs in Dwg.-09.

(6) Lugeon Value

Water pressure tests were carried out in drillholes made at the damsite at parts of comparatively little weathering of basement rock, and Lugeon values were obtained. The results, as shown in Table-10.4 and Dwg.-09, show that many parts in the weathered basement rock generally were 20 Lu (maximum 38 Lu), and that fresh parts mostly had values less than 10 Lu.

(7) P-wave Velocity

In order to determine the P-wave velocities of the right-bank mudflow deposit and the basement, seismic prospecting (one traverse line) was performed using the refraction method. The results are shown in Table-10.5 and Appendix-III-3(1). It was determined that the P-wave velocity of the mudflow deposit at the El Siete No. 1 dam site was around 1.4 km/s, while the velocities of basement rocks were from 1.9 to 4.0 km/s.

Concerning velocities of basement rocks, the parts showing 1.9 to 2.1 km/s are thought to be strongly weathered portions and those showing 2.9 to 4.0 km/s to be fresh rock.

(8) Overburden

1) Mudflow Deposit

The mudflow deposit at the damsite is ununiform at places and occasionally contains basalt boulders several meters in diameter, but in general consists of subangular to subrounded basalt gravels of 1 to 100 cm in diameter with interstices filled by sandy silt, the matrix being well-compacted. The gravel content ranges from about 30 to 80 percent, and bedding is not generally recognized.

At the dam axis, the tableland at the right-bank side is formed by this mudflow, and a mudflow deposit approximately 35 m thick was confirmed at Drillhole AD-2 provided up to the present.

Table-10.4 Lugeon Value of Bedrock at El Siete No.1 Damsite

Hole Name	Test Section (m)	Water Table (m)	Effective Maximum Pressure (kg/cm²)	Lugeon Value (ℓ/min/m/10kg/cm²)	Remarks
AD-1	12.55 - 17.55	14.00	4.5	20	*
	17.55 - 22.55	14.60	6.6	13	*
	22.55 - 27.55	16.00	11.7	9	
	27.00 - 30.00	17.00	11.8	13.5	
AD-2	38.10 - 41.00	15.55	11.7	9	
	41.00 - 44.00	15.55	11.7	18.5	
	44.00 - 47.00	15.55	11.7	11.5	
	47.00 - 50.00	15.55	11.7	13	
AD-3	7.20 - 10.20	6.45	3.8	3.5	*
	9.00 - 12.00	6.45	3.8	3.5	*
	12.00 - 15.00	6.45	5.8	3	*
	15.00 - 18.00	6.45	5.8	3	*
	18.00 - 21.00	6.45	8.8	1	*
	21.00 - 24.00	6.45	8.8	0.5	*
	24.00 - 27.00	6.45	8.8	1.5	*
	27.00 - 30.00	6.45	9.8	0	*
AD-4	24.00 - 27.00	4.00	9.4	8	Inclined drillhole *
	27.00 - 30.00	4.50	8.4	6	*
AD-5	12.33 - 15.33	14.90	5.5	25	*
	17.50 - 22.50	-	4.6	17	*
	22.50 - 27.50	24.00	5.5	12	*
	27.00 - 30.00	24.77	6.6	10	*

Hole Name	Test Section (m)	Water Table (m)	Effective Maximum Pressure (kg/cm²)	Lugeon Value (ℓ/min/m/10kg/cm²)	Remarks
AD-6	15.70 - 20.70	12.40	6.4	18	*
	20.70 - 25.70	12.40	6.4	12	*
	25.00 - 30.00	12.40	11.4	7	Inclined drillhole
AD-7	12.00 - 15.00	1.92	10.3	5	
	15.00 - 18.00	2.5	10.3	10	
	18.00 - 21.00	2.5	10.3	10.5	
	21.00 - 24.00	2.5	10.3	8	
	24.00 - 27.00	2.5	10.3	10	
	27.00 - 30.00	2.5	5.3	16	*
AD-8	11.69 - 14.69	8.25	4.9	38	*
	15.23 - 18.23	10.55	5.1	13	*
	18.00 - 23.00	10.55	8.1	10	*
	23.00 - 28.34	10.87	11.2	3	
	28.00 - 30.39	11.12	11.2	6	
AD-9	28.98 - 31.98	27.00	8.8	3.5	*
	31.98 - 34.98	27.00	8.8	0.5	*
	33.98 - 36.98	27.00	8.8	0.1	*
	36.98 - 39.98	27.00	8.8	5	*
	39.98 - 42.98	27.00	10.3	5	
	42.98 - 46.98	29.10	11.1	5	
	46.58 - 50.00	19.11	10.1	13	

* Lugeon value is calculated at maximum pressure.

Table-10.5 Velocity Layers of Seismic Wave in Project Area (Seismic Refraction Method)

Location		Measuring-Line	Velocity of P-wave (km/s)					Remarks
			1st layer	2nd layer	3rd layer	4th layer	5th layer	
EL SIETE NO.1	Damsite	SA - 1	0.3	0.5	1.4	1.9 - 2.1	2.9 - 4.0	Right bank of damsite.
	Penstock and Powerhouse Sites	SB - 7	0.3 - 0.4	0.5	-	1.6 - 1.7	2.8	Left bank of the Atrato River.
		SB - 8	0.3 - 0.4	0.5 - 0.7	1.1 - 1.4	-	2.8 - 4.2	
		SB - 9	0.4 - 0.6	-	1.2	1.6	2.2 - 2.3	
EL SIETE NO.2	Intake Damsite and Sedimentation Baisn Site	SB - 1	0.3 - 0.6	-	1.1	1.9	2.3 - 3.2	Right bank of the Atrato River.
		SB - 2	0.3 - 0.5	0.6 - 0.9	1.1 - 1.3	1.7 - 2.1	2.4 - 3.8	
		SB - 3	0.5	-	1.2 - 1.4	2.6	2.4 - 4.0	
		SB - 5	0.3 - 0.4	0.6 - 0.9	1.2 - 1.8	2.6 - 2.7	3.3 - 4.6	

2) Slopewash

The slopewash at the damsite is an unconsolidated deposit consisting mainly of angular basalt fragments and a silty matrix. It is not more than several meters thick.

3) River Deposits

River deposits are chiefly cobble gravels with interstices filled by fine-grained sand, but there are also numerous bouldes 1 to 3 m in diameter. The cobbles are subrounded and/or subangular shale, sandstone, and basalt. The boulders are mostly subangular and/or angular basalt.

Drillholes were not provided at the river-bed part of the dam axis, but the thickness of the river deposits is approximately 10 m, according to a drillhole upstream of the dam axis. The river-bed sand-gravel layer at the dam axis is estimated to be about 2 to 3 m thick judging by the shape of the river bed and the geological conditions of the surroundings.

(9) Geological Engineering Assessments

Geological engineering assessments made based on the topographical and geological features of this damsite described in (1) to (8) above are as follows:

1) Dam Foundation Excavation

A concrete gravity dam with a 1,455 m crest elevation is planned at this site (present river-bed surface elevation approximately 1,410 m). According to the results of geological investigations, it will be necessary for the foundation of the dam with the above mentioned scale to be on basalt with comparatively little weathering, and for that purpose, river-bed sand-gravel, mudflow deposits and basalt, weathered strongly or to a medium degree to be excavated and removed. The estimated sound rock line to be the dam foundation is shown on Dwg.-09 attached, and at the dam axis (A-A), it is expected that excavation and removal of approximately 10 m, approximately 5 m, and about 20 to 35 m in depth from the ground surface (perpendicular to the surface) at the left-bank abutment, the river bed, and the right-bank abutment, respectively.

2) Dam Foundation Treatment

It was found that the permeability of the basement rock at parts 20 to 30 m in depth from the bedrock surface is mostly around 10 Lu. Consequently, it will be necessary at least to provide a water barrier along the dam axis to secure the water-tightness of the dam foundation, and a grout curtain will be the most reasonable as the water barrier.

To design a proper grout curtain, additional investigations will need to be executed, but it will be necessary to provide a grout curtain bringing permeability down to several Lugeons and under a range from the surface of the dam foundation to a depth equal to the dam height.

3) Cut Slope Stability in Dam Vicinity

The mudflow deposit at the damsite's right-bank side will be removed at the dam foundation, but will be exposed at the slope of a cut upstream of the dam. It will be necessary to study the stability of the mudflow deposit exposed at this cut slope.

4) Supplemental Investigation

It will be necessary to carry out drilling investigations concurrently serving as water pressure tests at midheight on the left-bank abutment of the dam and the river-bed poriton to confirm the ultimate excavation line and the extent of foundation treatment (water barrier) to be provided.

It will be also necessary to provide test adits at both abutments to ascertain the directions of lines of weakness in the foundation rock and the condition of the fundation rock, and to utilize these adits to carry out in-situ rock tests to determine the deformation and strength characteristics of the rock.