Chapter 1

GENERAL

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1.1 Introduction

This Final Report is prepared and submitted to the Manabi Rehabilitation Center (CRM) of the Government of the Republic of Ecuador (GOE) in accordance with the contract for the Detailed Design Study on the Water Transbasin Schemes for Chone-Portoviejo River Basins in the Province of Manabi (the Study) concluded between the Japan International Cooperation Agency (JICA) and Nippon Koei Co. Ltd.

The study consists of two phases: Phase 1 for preparation of basic designs including detailed field investigations and Phase 2 for detailed engineering study including preparation of tender documents and other documents necessary for the implementation of the Project on the Water Transbasin Schemes for Chone-Portoviejo River Basins in the Province of Manabi (the Project). The Study period is programmed to extend over a period of 18 months from early October 1993 till March 1995.

The specific objective of the Study is to prepare a detailed engineering design of the Project, based on the feasibility study report on the Project prepared in December 1992.

It is also one of the important objectives to realize transfer of technology to the Ecuadorian counterparts during the Study by the JICA Study Team.

The Final Report presents the results and evaluation of the detailed field investigations and detailed designs prepared during the study period from October 16, 1993 to March 31, 1995. The Study includes (i) Review of Previous Studies including water demands and water transbasin plan, (ii) Studies and Investigations including hydrology, sediment and water quality study, topographic survey, geological and material investigations, environmental study and institutional study, (iii) Detailed Designs of the proposed three water transbasin schemes with access roads, and (iv) Construction Plan and Cost Estimates including construction schedule and fund disbursement schedule.

1.2 Background of the Study

The Province of Manabi has long been suffering from a habitual water shortage problem. In 1986, CRM started a master plan study on the integrated water resources development in the Manabi Province (PHIMA) in cooperation with the Ecuadorian Governmental Institutions (CONADE and INERHI). The Organization of the American States (OAS) and JICA joined PHIMA during the master plan study. The PHIMA final report prepared by JICA in January 1990 recommended to conduct a feasibility study on the water resources development for Chone-Portoviejo river basins in the central part of the Manabi Province.

JICA, at the request of GOE, conducted a feasibility study on the Project from March 1991 to December 1992, which concluded that the Project is technically and environmentally sound, economically feasible and financially viable. GOE requested a detailed design study on the Project to the Government of Japan (GOJ), and the scope of work for the detailed design study was agreed upon between JICA and CRM in July 1993.

The Study commenced in October 1993 in accordance with the agreed scope of work.

1.3 Project Related to the Study

(1) General

In the Study area, a central part of Manabi province consisting of the Chone and Portoviejo river basins, various water resources development projects have been studied, and some of them were constructed, some are under construction and the others are waiting for further studies for implementation.

The following projects are closely related with the Study.

- (i) Poza Honda Multipurpose Project in the Portoviejo river basin.
- (ii) Daule - Peripa Dam project on the Daule river, located immediate east of the study area.
- (iii) La Esperanza Dam Project on the Carrizal river, a major tributary of the Chone river.
- (iv) Water Transbasin Project from the Daule to the Poza Honda and La Esperanza reservoirs.
- (v) Carrizal - Chone Multipurpose Project in the Chone river basin

(2) Daule-Peripa Dam Project

The first comprehensive study on the water resources development of the Guayas river basin was conducted by OAS in 1964 at the master plan level, in which the construction of the Daule-Peripa dam was proposed as a master reservoir for basin development. The United Nations Development Program (UNDP) made a preliminary study on the Daule-Peripa Dam Project in 1972. A feasibility study on the Daule-Peripa Project was conducted in 1978. The Committee for Guayas River Basin Development (CEDEGE) started the construction of the Daule-Peripa dam in September 1982 and completed it in December in 1987 with the IDB financing.

Main functions of the Daule-Peripa dam are as follows.

(1) flood control,
(2) domestic water supply,
(3) irrigation water supply, and
(4) hydroelectric power supply.

The Daule-Peripa dam is located on the Daule river at about 15 km upstream of Pichincha. Out of the effective reservoir capacity of 4,000MCM, a quantity of 500MCM/year is reserved for use in the Manabi Province through water transabasin with a maximum discharge of $18m^3/s$.

General features of Daule-Peripa Dam are shown in Table 1.3.1.

(3) La Esperanza Dam Project

A feasibility study on La Esperanza Dam Project was started in 1970 and completed in 1975. A definite design was prepared in 1976 and the construction was commenced in 1978 by Daewoo, a Korean contractor. CRM was the executing agency of this project and the cost was financed by the GOE.

During the initial stage of construction, however, the construction work was obliged to be suspended due to a geotechnical difficulty of the dam foundation, and the contract with Daewoo was terminated in 1980. A complete revision of the design including some more geotechnical investigations was started in September 1982 and completed in June 1984. The dam construction, however, had been suspended up to 1991 due to financial problem.

The financial problem was solved in 1991. Out of the total construction cost of US$ 80 million, US$ 30 million was agreed to be financed by the Spanish government, US$ 30 million by Spanish banks and the remaining US$ 20 million by the GOE.

CRM awarded a contract for construction to Dragados y Construcciones, a Spanish contractor, who had started the construction work since early 1992, and cofferdam embankment was completed. At present, the main dam is under construction. Relocation of houses and various structures in proposed reservoir area was completed at the end of December 1993. Construction of the dam is scheduled to be completed in 1996.

The Objectives of La Esperanza dam are flood control in the Carrizal river, irrigation water supply to the Carrizal-Chone irrigation area of about 15,000 ha and domestic water supply in the Chone river basin.

The general features of La Esperanza dam are shown in Table 1.3.2.

(4) Poza Honda Dam Project

UNDP conducted a feasibility study on the water resources development project of the Portoviejo river basin in 1963 and GOE prepared a definite design of the Poza Honda dam in October 1965.

With an agreement on technical and financial cooperation between GOE and the Government of West Germany, CRM made a revision of definite design, employing a consortium of West German consultants in January 1967. A revised definite design of the dam was completed by the consortium in August 1968.

The Poza Honda Multipurpose Project has been developed in the Portoviejo river basin in the following stages.

Stage 1: Construction of the Poza Honda dam in the upper reach of the Portoviejo river in 1971. It is capable to secure water supply of 107 MCM/year. General features of the dam are shown in Table 1.3.3.

Stage 2: Construction of the Guarumo water treatment plant in 1974 with a capacity of 43,000 m^3/day.

Stage 3: Construction of Santa Ana irrigation system along the middle reaches of the Portoviejo river in 1984, commanding a net irrigation area of 3,300 ha with annual water requirement of 60 MCM in average years and 74 MCM in dry years.

Stage 4: Construction of Cuatro Esquinas treatment plant at Portoviejo and El Ceibal treatment plant at Rocafuerte with a total capacity of 180,000 m^3/day, to be completed in 1995.

(5) Water Transbasin Project from Daule-Peripa to Manabi

CRM started a study on the water transbasin project from Daule-Peripa to Manabí in 1984, when the Daule-Peripa dam was under construction. A definite design for the project was prepared in 1987, which involved the following two transbasin schemes.

- Transbasin from Daule-Peripa to La Esperanza with a capacity of 12 m^3/s through a 8.3 km long diversion tunnel by gravity.

- Water diversion from the Daule river at about 30 km downstream of the Daule-Peripa dam to Poza Honda with a final capacity of 12 m^3/s by pumping.

The PHIMA study in 1989, however, did not recommend these two transbasin schemes because of high pumping requirement. CRM, in line with the PHIMA recommendation, requested CEDEGE to construct an inlet structure of the transbasin tunnel in the Daule-Peripa reservoir area with a capacity of 18 m^3/s, instead of 12 m^3/s, and CEDEGE constructed the tunnel entrance accordingly in 1990.

CRM also revised the tunnel design from Daule-Peripa to La Esperanza to have a capacity of 18 m^3/s in 1989.

General features of the diversion tunnel are as follows.

(1) Type of Tunnel	:	Semi-circular section
(2) Diameter	:	4.6 m
(3) Inlet sill EL.	:	64 m
(4) Outlet sill EL.	:	58.5 m
(5) Lining	:	Shotcrete

(6) Carrizal-Chone Multipurpose Project in the Chone River Basin

During the years from 1986 to 1989, in parallel with the financial arrangement for construction of the La Esperanza dam, CRM conducted a feasibility study on the Carrizal-Chone Multipurpose Project including river training and irrigation and drainage system over a net irrigation area of 16,720 ha in the Carrizal-Chone plain and the Guarango-Amarillos plain. The Guarango plain is located in the lower basin of the Portoviejo river and, therefore, the proposed irrigation system involves the water transbasin of 5.0 m^3/s from Chone to Portoviejo through a diversion tunnel of 5.1 km in length and with a diameter of 3.0 m at a level of EL. 72 m, including pumping of about 53 m. The total construction cost was estimated to be US$ 65.4 million at a price level of September 1989.

A head reach canal with a capacity of 23 m^3/s starts from the La Esperanza dam at EL. 32 m for a distance of 10 km and the left main canal is branched off from the head reach canal. At a point 18.1 km from the beginning point of the left main canal, a canal with a capacity of 5 m^3/s is further branched off at EL. 21.4 m for irrigation of the Guarango-Amarillos plain. A level of the diversion tunnel was optimized to be at EL. 72 m with regard to a tunnel length and a pumping head, though the Guarango-Amarillos irrigation area is lower than EL. 60 m.

This idea of water transbasin from Chone to Portoviejo was first adopted by the PHIMA Study and included in various alternative transbasin schemes, but, in later stage of the feasibility study, it was abandoned due to technical difficulty in constructing a tunnel through the Tosagua formation consisting of soft mudstone with considerable slaking tendency, resulting in a high tunnel construction cost.

The Carrizal-Chone Irrigation Project is directly connected with the La Esperanza Dam Project because water is planned to be supplied from La Esperanza. Since the construction of the La Esperanza dam was under way with a financial cooperation of Spain, CRM has a strong desire to proceed with the project. It is said that CAF (Corporación Andina de Fomento) accepted to finance US$ 4 million for the detaild design work of the project in late 1994.

Chapter 2

REVIEW OF PREVIOUS STUDIES

Chapter 2 REVIEW OF THE PREVIOUS STUDIES

2.1 General

The present detailed engineering study is a continuation of the feasibility study completed in December 1992. Data and information collected and analyzed in the feasibility study as well as during the water resources development master plan study in Manabi Province, so called the PHIMA study completed in January 1990, are fully utilized in the present study. Recent data and reports related to the project are also collected and reviewed, such as La Esperanza dam design and construction reports, Daule Peripa reservoir enviromental management and monitoring plan, designs of the Daule Peripa-La Esperanza transbasin project, etc.

A detailed filed reconnaissance survey is carried out to confirm the actual site conditions with respect to topography, geology, environment and reservoir sedimentation.

Among others, the integrated reservoir operation and water balance study is fully reviewed to confirm the proposed water transbasin capacities as well as the inlet and outlet elevations of the proposed three diversion tunnels, based on fully revised river runoff series at various important points for 29 years from 1964 to 1992 generated by the rainfall data.

2.2 Water Demands

Annual water demands are summarized below and monthly fluctuations of water demands are described in the following subsections for each purpose.

Summary of Water Demands

(1) Carrizal-Chone River Basins

Purpose	Annual Water Demand (MCM)	Remarks
River maintenance	16	Equivalent to 0.5m^3/s throughout the year from La Esperanza dam
Water supply	45	Chone-La Estancilla water supply system in 2020
Irrigation	272	Carrizal-Chone irrigation system (15,000 ha) and Amarillos system (1,000 ha) in dry years
Shrimp farm	99	At estuary of Chone river
Dilution water	54	Equivalent to 20% of irrigation water

(2) Portoviejo River Basin

Purpose	Annual Water Demand (MCM)	Remarks
River maintenance	8	Equivalent to 0.25 m^3/s throughout the year from Poza Honda dam
Water supply	89	Poza Honda water supply system in 2020
Irrigation	268	Poza Honda irrigation system in dry years
Shrimp farm	3	At estuary of Portoviejo river
Dilution water	54	Equivalent to 20% of irrigation water

(3) Chico River Basin

Purpose	Annual Water Demand (MCM)	Remarks
River maintenance	Varied	Min. flow of 0.12 m^3/s to be maintained
Water supply	63	El Ceibal water supply system in 2020
Irrigation	31	Chico irrigation system (1,700 ha) in dry years
Dilution water	6	Equivalent to 20% of irrigation water

2.2.1 River Maintenance Flow

Under the regulation, a dam should release a constant discharge as a river maintenance flow. The regulation requires that La Esperanza dam should release a constant discharge of 0.5 m^3/s and that Poza Honda dam should release a constant discharge of 0.25 m^3/s, both as a river maintenance flow.

According to the above policy, the Chico river is decided to maintain the minimum flow of 0.12 m^3/s at the immediate downstream of the diversion dams.

2.2.2 Water Supply

Regional water supply systems are operated in the project area to meet municipal and industrial water demand. Water supply capacities of these systems will be increased to cope with the growing water demand.

Raw water demands for water supply estimated for 2020 are taken as those of the project. It is true that demands for water supply would be increasing after the year 2020 as a result of continuous urbanization, which would take place by shifting the agricultural lands to urban areas. Therefore, it is expected that an increment of water demand for water supply after 2020 would be covered by a reduction of irrigation water demand.

Seasonal fluctuation of raw water demand for water supply is not taken into account in view of the tropical climate prevailing the project area where seasonal fluctuation of temperature is not significant. Therefore, a monthly demand is simply calculated from the annual demand divided by 12.

2.2.3. Irrigation

Diversion water demands for irrigation were calculated during the feasibility study for each month of the year based on assumed cropping patterns for each irrigation system to be developed, irrigation efficiency and expected effective rainfalls. The diversion water demand for irrigation, therefore, depends on rainfall.

Daily rainfall data were first analyzed for each irrigation system and two kinds of effective rainfalls were estimated based on rainfalls of average years and those of 1/5 (once in 5 years) drought years.

Irrigation water demands are given in Table 2.2.1 for average years and in Table 2.2.2 for 1/5 drought years.

2.2.4 Shrimp Farm

Fresh water requirement in the shrimp farms practiced in the estuaries of the Chone and the Portoviejo rivers was estimated in the feasibility study as follows.

Fresh Water Requirement for Shrimp Farm (MCM)

Month	Chone Estuary	Portoviejo Estuary
July	3.9	0.4
August	3.9	0.4
September	4.0	0.5
October	29.3	0.5
November	29.4	0.5
December	29.0	0.5
Annual Total	99.5	2.8

2.2.5 Dilution Water

When a large scale irrigation development is involved in a project, it is desirous to take into account dilution water demand to dilute irrigation return flows and to maintain river water quality at an acceptable level.

In the feasibility study, the dilution water demand was not considered because the interbasin flows were not considered, either. In the detailed engineering study, however, the dilution water demand equivalent to 20% of the diversion water demand for irrigation is taken into account as well as the interbasin flows, which are derived from the river basins downstream of La Esperanza and Poza Honda dams.

2.3 Water Transbasin Plan

2.3.1 General

Three transbasin schemes are proposed in the feasibility study as shown in Figure 2.3.1 and summarized below.

Transbasin	Capacity	Remarks
Daule Peripa to La Esperanza	18 m^3/s	Gravity flow
La Esperanza to Poza Honda	16 m^3/s	Pumping
Poza Honda to Mancha Grande	4 m^3/s	Gravity flow

The first transbasin scheme from Daule Peripa to La Esperanza is necessary to increase substantially the water resources to meet all the water demands in the project area. The second transbasin scheme from La Esperanza to Poza Honda is indispensable to meet water demand mainly for water supply and irrigation in the Portoviejo river basin, in addition to the Poza Honda dam. The third transbasin scheme from Poza Honda to Mancha Grande is also needed to meet water demand in the Chico River basin, mainly to supply El Ceibal water treatment plant and the Chico irrigation system.

It is to be understood that the project objective can be fully fulfilled only when these three transbasin schemes are implemented.

2.3.2 Transbasin from Daule Peripa to La Esperanza

In the feasibility study, the water transbasin volume from Daule Peripa to La Esperanza was evaluated under the following conditions and procedures.

(1) The Daule Peripa dam belongs to CEDEGE and is to be operated according to the reservoir operation rule of CEDEGE.

(2) According to the interinstitutional agreement between CEDEGE and CRM, CRM is entitled to divert water from Daule Peripa up to 500 MCM/year with the maximum diversion of 18 m^3/s, as far as technically possible.

(3) Reservoir water levels of Daule Peripa and La Esperanza are assumed to fluctuate in a similar pattern under the same hydrological regime. Therefore, water quantity to be technically diverted is only dependent on water level of Daule Peripa which will fluctuate between HWL of EL. 85 m and LWL of EL. 60m.

(4) An intake structure of the diversion tunnel from Daule Peripa to La Esperanza was already constructed at the Conguillo site in the tail of the Daule Peripa reservoir. The intake sill level is EL. 66.6 m. Divertable discharge will be 0 m^3/s up to reservoir water level (R.W.L) EL.66.6 m, 6.70 m^3/s at R.W.L EL. 68.5 and 18.0 m^3/s when R.W.L. exceeds EL 76.6 m

(5) Based on a long-term Daule Peripa reservoir operation study by synthetic flows, technically divertable discharges are calculated monthly, and the three consecutive year divertable water with 80% guarantee is determined to be 1,612 MCM equivalent to 537 MCM/ year.

(6) Since the agreement between CEDEGE and CRM limits the water diversion only up to 500 MCM/year, it is necessary to reduce the diversion water volume from the technically divertable 537 MCM to the agreed 500 MCM intentionally to the best interest of the project.

(7) It is proposed to reduce the diversion flow to La Esperanza in three months from January to March when rainfalls are maximum and water demands are minimum. The proposed monthly transbasin pattern is finally determined as shown in the following table.

Monthly Transbasin Pattern from Daule Peripa

Month	Technically Divertable Volume (MCM)	Adjusted Volume (MCM)	Adjusted Discharge (m^3/s)
January	41.9	29.4	11.0
February	37.9	25.5	10.5
March	39.2	26.7	10.0
April	38.9	38.9	15.0
May	48.2	48.2	18.0
June	46.6	46.6	18.0
July	48.2	48.2	18.0
August	48.2	48.2	18.0
September	46.6	46.6	18.0
October	48.2	48.2	18.0
November	46.6	46.6	18.0
December	46.9	46.9	17.5
TOTAL	**537.4**	**500.0**	

2.3.3 Integrated Reservoir Operation of La Esperanza and Poza Honda

2.3.3.1 General Concepts of Reservoir Operation

La Esperanza receives natural flows from its own basin and diverted flows from Daule-Peripa. La Esperanza together with the available interbasin flows of the Chone river system should meet water demands for shrimp farming in the Chone estuary (99 MCM/year), river maintenance (16 MCM/year), water supply to the Chone-La Estancilla water supply system (45 MCM/year), Carrizal-Chone irrigation of 15,000 ha (253 MCM/year), Los Amarillos irrigation of 1,000 ha (19 MCM/year) and Dilution Water equivalent to 20% of the irrigation water requirement.

La Esperanza should also divert water to Poza Honda. Poza Honda receives natural flows from its own basin and diverted flow from La Esperanza. Poza Honda together with the available interbasin flows of the Portoviejo river should meet water demands for water supply to the Poza Honda water supply system except the El Ceibal treatment plant (89 MCM/year), irrigation for Santa Ana system of 3,300 ha (74 MCM/year), for Pechiche-Pasaje system of 850 ha (20 MCM/year), for Mejía system of 1,250 ha (28 MCM/year), for Ceibal-Guayaba system of 4,650 ha (111 MCM/year) and for Guarango system of 1,500 ha (36 MCM/year), shrimp farming in the Portoviejo estuary (3 MCM/year), river maintenance (8 MCM/year) and Dilution Water equivalent to 20% of the irrigation water requirement.

Poza Honda should also divert water to Mancha Grande of the Chico river basin. The diverted flows together with the available natural flow of the Chico river should meet water supply to El Ceibal treatment plant (63 MCM/year), irrigation for Chico system of 1,700 ha (31 MCM/year) and Dilution Water equivalent to 20% of the irrigation water requirement.

2.3.3.2 Basic Conditions for Integrated Reservoir Operation Study

(1) Reservoir Storage Curves

Reservoir storage curves after 50 years sedimentation are used to make the study conservative.

(2) Irrigation Water Requirement

Irrigation water requirement is affected by the effective rainfall. For the study, irrigation water requirement calculated for a drought year with a return period of 5 years is used.

(3) Dilution Water

Dilution water equivalent to 20% of the irrigation water requirement is applied to the study to dilute irrigation return flows.

(4) Use of Interbasin Flows

The interbasin flows, the natural flows from the catchment area downstream of the dam, can be used to meet water demands especially during the rainy season. Use of up to 60% of the interbasin flow is assumed to be allowed.

(5) Water Demand Level

Water demands in the target year of 2020 are used for the study.

(6) Target Reservoir Water Levels

The transbasin from Daule-Peripa to La Esperanza is planned to be made by gravity. Water transbasin is recommended to be continued as far as possible. The design condition to maintain an open free flow in the diversion tunnel will, however, limit a range of the target water level of La Esperanza not more than EL. 63.5 m. Therefore, it is planned to suspend water transbasin from Daule-Peripa when La Esperanza water level is higher than EL. 63.5 m. In other words, a target water level of La Esperanza is fixed at EL. 63.5 m.

The transbasin from La Esperanza to Poza Honda is planned to be made by pumping. Lower target water level of Poza Honda is desirable to save pumping energy cost and to aim at maximum utilization of the own basin flow limiting a spillout volume from Poza Honda to the minimum. However, if the target water level is too low, more frequent water shortage will take place during operation because the reservoir storage capacity cannot be used effectively. A number of trial calculations concluded that the Poza Honda target water level should be EL.102.5 m, 4.0 m below the high water level of Poza Honda.

(7) Intake Level of Severino Pumping Station at La Esperanza

An intake water level of the Severino pumping station for water transbasin from La Esperanza to Poza Honda should be low enough to continue water pumping in low level period of La Esperanza. However, the following two design conditions require to fix the intake level at EL. 47 m, higher than the low water level of La Esperanza by 10 m.

- Anticipated reservoir sedimentation level of EL.45 m at the Severino pumping station site.

- Allowable drawdown of La Esperanza water level during construction of the Severino pumping station, fulfilling the required minimum functions of La Esperanza.

(8) Intake Level of Poza Honda-Mancha Grande Diversion Tunnel

The transbasin from Poza Honda to Mancha Grande is planned to be made by gravity. The topographic conditions at the tunnel outlet limit the lowest intake water level of Poza Honda at EL.94 m.

(9) Diversion Capacity from Daule-Peripa to La Esperanza

The diversion capacity from Daule-Peripa to La Esperanza is fixed to be 18 m^3/s by the interinstitutional agreement between CEDEGE and CRM as discussed in 2.3.2 herein.

(10) Diversion Capacity from La Esperanza to Poza Honda

A diversion capacity of 16 m^3/s was proposed in the feasibility study under the following conditions.

- Reservoir storage curves before reservoir sedimentation were used.

- Dilution water requirement to dilute irrigation return flows was not considered.

- Interbasin flows were not taken into account.

The integrated reservoir operation study is repeated based on the conditions described from (1) to (12) hereof for a diversion capacity of 12 m^3/s, 14 m^3/s and 16 m^3/s.

(11) Diversion Capacity from Poza Honda to Mancha Grande

If the natural flow of the Chico river is neglected, water requirements are 1.9 m^3/s to supply the El Ceibal water treatment plant and 2.1 m^3/s to cover peak irrigation water requirement in September for the Chico irrigation system of 1,700 ha including 20% of the dilution water, totaling 4.0 m^3/s. The diversion capacity is, therefore, fixed at 4.0 m^3/s.

(12) Long-term Hydrological Series

Long-term hydrological series were simulated at important points in the Chone-Portoviejo river basins by the Tank Model method on a monthly basis for a period of 20 years from 1971 to 1990, in the feasibility study.

In the detailed design study, the long-term hydrological series are revised by a simulation study using the CIDIAT Model for a period of 29 years from 1964 to 1992. The revised long-term hydrological series are used for the integrated reservoir operation study.

2.3.3.3 Integrated Reservoir Operation Study

Based on the conditions described in 2.3.3.2, an integrated reservoir operation and water balance study is conducted, using a computer program developed for this purpose. The results are shown in Figs. 2.3.2, 2.3.3, and 2.3.4 for a transbasin capacity of 16 m^3/s from La Esperanza to Poza Honda (Q_{Ep} = 16 m^3/s), in Figs. 2.3.5, 2.3.6 and 2.3.7 for Q_{Ep} = 14 m^3/s, and in Figs.2.3.8, 2.3.9, and 2.3.10 for Q_{Ep} = 12 m^3/s, and are summarized in the following table.

Summary of Integrated Reservoir Operation Study

Description	La Esperanza-Poza Honda Transbasin Capacity (m^3/s)		
	16	14	12
La Esperanza Reservoir			
Max.water level (EL.m)	66.0	66.0	66.0
Min. water level (EL.m)	39.8	40.4	40.0
Mean water level (50%) (EL.m)	59.9	60.2	60.3
Average water level	58.7	59.1	59.3
Average spillout (MCM/year)	118	115	118
Average evaporation (MCM/year)	21	21	21
Max.transbasin from Daule-Peripa (MCM/year)	500	500	500
Average transbasin from Daule-Peripa (MCM/year)	336	331	328
Max. transbasin to Poza Honda (MCM/year)	380	369	348
Average transbasin to Poza Honda (MCM/year)	213	212	205
Guarantee of water supply to Carrizal-Chone river basin (%)	100(100)	100 (100)	100 (100)
Guarantee of transbasin to Poza Honda (%)	95	96	96
Poza Honda Reservoir			
Max.water level (EL.m)	106.5	106.5	106.5
Min.water level (EL.m)	88.3	88.3	88.3
Mean water level (50%) (EL.m)	103.2	102.2	101.5
Average water level	102.2	101.8	101.3
Average spillout (MCM/year)	53	51	47
Average evaporation (MCM/year)	6	6	6
Max.transbasin from La Esperanza (MCM/year)	380	369	348
Average transbasin from La Esperanza (MCM/year)	213	212	205
Max.transbasin to Mancha Grande (MCM/year)	69	59	55
Average transbasin to Mancha Grande (MCM/year)	33	32	31
Guarantee of water supply to Portoviejo river basin (%)	97(83)	98 (83)	98 (86)
Guarantee of water supply to Chico river basin (%)	96(80)	94 (72)	93 (69)

(Note) Guarantee of water supply is on monthly basis. Figures in parenthesis are guarantee on annual basis which should be larger than 80% (water shortage is allowed once in 5 years). Mean water level is took as corresponding to the 50% in the duration curve.

The transbasin capacities of Q_{Ep} = 12 m^3/s and Q_{Ep} = 14 m^3/s are not recommendable because the guarantee of water supply to the Chico river basin including water supply to the El Ceibal treatment plant is lower than 80% on an annual basis.

The transbasin capacity from La Esperanza to Poza Honda has been decided to be 16 m^3/s, based on the result of the integrated reservoir operation study and also taking account of the following factors.

- Long term continuous operation of a pumping station at its full capacity will be difficult due to possible fault in power supply or some mechanical trouble. In case Q_{Ep} = 12 m^3/s, a continuous operation of sixteen months is required, while in case Q_{Ep} = 16 m^3/s it is only five months.

- A larger transbasin capacity will provide the whole transbasin schemes with more flexibility to cope with possible future changes in water demands.

The schematic water balance is shown in Fig. 2.3.11 for the proposed transbasin scheme with Q_{Ep} = 16 m^3/s.

2.3.4 Intake Level from La Esperanza

The riverbed elevation at the proposed Severino pumping station site is EL.37m, which is equal to LWL of La Esperanza. In the feasibility study, the minimum intake water level for diversion from La Esperanza to Poza Honda was proposed to be EL. 37m.

In the present detailed study, the minimum intake water level is proposed to be EL 47 m in view of the following.

(1) Reservoir sedimentation analysis has suggested that the expected sediment level at the intake of the Severino pumping station will be about EL 45 m.

(2) Allowable drawdown of La Esperanza water level during construction of the Severino pumping station will be EL. 45 m, fulfilling the required minimum function of La Esperanza as discussed in 2.3.5.

(3) As shown in the result of the integrated reservoir operation and water balance study based on the proposed minimum intake water level, the minimum and average water level of La Esperanza are EL. 39.8m and EL. 58.7m, respectively, for the target water level of EL. 63.5 m, securing a guarantee level of transbasin to Poza Honda at 95 %, which is satisfactory.

2.3.5 Requirement for Coffering

For construction of the Severino pumping station, it is necessary to keep the water level of La Esperanza at a lower level than HWL. Flood water levels are calculated by routing flood hydrographs through the reservoir with different return periods assuming various initial water levels of the reservoir. Results are shown below.

Coffering Requirement during construction of the Severino Pump Station

Return Period of Flood (years)	Initial Reservoir Level (EL. m)	Maximum Water Level (EL. m)
10	37	44.0
25	37	45.0
50	37	46.4
100	37	47.3
10	40	45.5
25	40	46.9
50	40	48.0
100	40	48.6
10	45	49.7
25	45	50.7
50	45	51.5
100	45	52.0
10	50	53.4
25	50	54.3
50	50	55.0
100	50	55.5

The Esperanza dam is scheduled to be completed in early 1996 and to start impounding from the rainy season of 1996, which means that the construction of the Severino pumping station in around 1997/1998 be made when the reservoir is created. The Carrizal-Chone irrigation system of 15,000 ha will not be placed in service until 1998 and the water demand to be met by La Esperanza will be limited until then.

If CRM allows to reduce the reservoir water level to LWL of EL. 37 m, the Severino pumping station, the intake level of which is at EL. 45 m, will not need coffering. But, in this case, La Esperanza cannot supply water to downstream during the construction of the Severino pumping station. It is recommended, therefore, to keep reservoir water level of La Esperanza at EL. 45 m to meet the limited water demand in the dry season during the construction of the Severino pumping station. Then, coffering requirement will be about 6 m including 0.3 m freeboard from the foundation of EL. 45 m, preparing for a 25 year probable flood.

Chapter 3

STUDIES
AND
INVESTIGATIONS

Chapter 3 STUDIES AND INVESTIGATIONS

3.1 General

Studies and investigations conducted for the feasibility study stage are reviewed, updated and supplemented in this detailed study stage.

In the hydrological studies, the river flow simulation study is revised and updated, the reservoir sedimentation study is supplemented, and the water quality study is reviewed with some additional water quality tests.

The detailed topographic mapping is made at the structure sites and additional topographic survey is carried out along the access roads and the route of the power transmission line.

Geological investigations as well as the construction material investigations are conducted to supplement the previous geotechnical and material investigations and to further confirm geotechnical conditions and availability of construction materials.

The environmental studies are reviewed and detailed with additional water quality tests in the study area and tidal measurements in the Chone estuary. The institutional studies are also reviewed and detailed.

3.2 Hydrological Studies

3.2.1 General

The hydrological studies during the feasibility study executed in 1991 to 1992 have been reviewed, updated and supplemented in this detailed design stage in the following procedure.

(1) Collection of recent meteo-hydrological data mainly on precipitations
(2) Checking of reliability and consistency of the meteo-hydrological data
(3) Regional rainfall analysis to generate flood hydrographs
(4) Generation of long-term monthly runoff series
(5) Sediment analysis in reservoirs

3.2.2 Basic Information for Hydrological Studies

(1) Precipitation

In this study have been used the daily rainfall data at the following eight precipitation stations located in the study area as shown in Figure 3.2.1.

Precipitation Station	Registered Period
1. Dos Bocas	1964 - 1992
2. Chone	1964 - 1992
3. Portoviejo	1964 - 1992
4. Rocafuerte	1964 - 1992
5. Calceta	1964 - 1985
6. Chamotete	1970 - 1992
7. Santa Ana	1964 - 1985
8. Boyaca	1965 - 1992

Checking of reliability and consistency of the rainfall data was made by means of a double mass curve method, and data in some part of the registered period were corrected applying the correlation with the rainfall data at neighboring stations established in the feasibility study.

The precipitation series of each precipitation station have been prepared for 29 years from 1964 to 1992 as presented in Tables 3.2.1 to 3.2.8.

(2) Evaporation

Evaporation data at Portoviejo meteorological station have been used because it is the only station that keeps good and continuous evaporation data observed by the Evaporation Pan Class A. The registered evaporation data from 1964 to 1992 are given in Table 3.2.9

(3) Streamflow

In order to fit the monthly hydrological model, it is necessary to select some representative streamflow recording stations in the study area with continuous and reliable records. The following three stations are finally selected.

Streamflow Recording Station	Registered Period
Carrizal River at Calceta	1964 - 1980
Chico River at Alajuela	1970 - 1982
Grande River at A.J. Mosquito	1971 - 1982

3.2.3 Regional Rainfall Analysis

(1) Zoning by Storm Characteristics

Frequency curves are first drawn for the selected 8 precipitation stations based on daily rainfall data to assess storm characteristics, applying the Gumbel's Extreme Distribution Type I. This first evaluation has indicated that the upper bound be represented by Chamotete station and the lower bound be represented by Rocafuete station and that Calceta station be in between the upper and the lower bounds. This clearly shows the variation of storm characteristics from the mountain to the sea.

From the above, the following zoning is made which is shown in Figure 3.2.1.

Zone 1 represented by Chamotete station
Zone 2 represented by Calceta station
Zone 3 represented by Rocafuerte station

(2) Rainfall Intensity-Duration-Frequency Curves

In the study area, only daily rainfall data are available. To draw rainfall intensity-duration-frequency curves, it is necessary to assume hourly rainfall pattern from the daily rainfall.

There are several automatic rainfall gaging stations in the Guayas river basin located immediately to the east of the study area, where hourly rainfall data are available as well as daily rainfall data. Therefore, based on the rainfall data in the Guayas river basin, an hourly rainfall distribution of the daily rainfall has been determined.

The hourly rainfall distribution is applied to the stations of Chamotete, Calceta and Rocafuerte, and the Rainfall Intensity-Duration-Frequency curves are drawn for Zone 1, 2 and 3, as shown in Figures 3.2.2 to 3.2.4.

(3) Rainfall Areal Distribution

A point rainfall should be converted to a basin average rainfall by a coefficient of areal distribution of the point rainfall. The coefficient has been defined through the analysis of many storms recorded in Manabi Province.

(4) Probable Storm Hyetograph

Based on the data stated hereinabove, probable storm hyetographs can be established using the criteria of the U.S. Corps of Engineers.

(5) Rainfall-Flood Model

A rainfall-flood model named Hydro has been used to convert probable storm hyetographs to probable flood hydrographs. The model is basically the same as the Hydrograph Evaluation of the Hydrologic Model Package of the Agricultural Research Service of the U.S. Department of Agriculture. The model is explained in Annex 1.

3.2.4 Generation of Long-Term Monthly Hydrological Series

A model for hydrological simulation developed by CIDIAT in 1986 has been used to generate long-term monthly hydrological series by monthly rainfall and other meteohydrological data. The model is explained in Annex 1.

The fitting of the model was done based on the streamflow data at three hydrological stations mentioned before. In Figures 3.2.5 to 3.2.7 are presented the fitting of the model at each station, which assures that the calibration of the model is satisfactory.

Applying the parameters fixed during the model fitting for the selected three stations, streamflows at the following 12 locations are generated from 1964 to 1992 and presented in Tables 3.2.10 to 3.2.24 in m^3/s and in Tables 3.2.25 to 3.2.39 in MCM. The locations are given in Figure 2.3.1.

Location	Drainage Area (km^2)	Type of Parameters
For Model Fitting		
A. Chico river at Alajuela	183.0	A
B. Grande river at A.J. Mosquito	187.2	B
C. Carrizal river at Calceta	523.0	C
For Simulation		
1. La Esperanza damsite	445.0	C
2. Poza Honda damsite	170.0	A
3. Santa Ana diversion damsite	481.9	A
4. La Estancilla diversion damsite	769.6	C
5. Chico river at La Cienaga	347.2	A
6. Portoviejo river at El Ceibal	1,794.4	A
7. Portoviejo river (confluent with Chico river)	1,190.0	A
8. Chico river (confluent with Portoviejo river)	585.0	A
9. Estuary of Portoviejo river	2,060.0	A
10. Carrizal river (confluent with Chone river)	1,166.0	C
11. Chone river (confluent with Carrizal river)	755.0	B
12. Estuary of Chone river	2,267.0	B

3.3 Sedimentation and Water Quality

3.3.1 Sedimentation

A reservoir created by a dam on a natural river course is subject to sediment inflow and its deposition in the reservoir. As a matter of fact, many reservoirs in the world are suffering form a sedimentation problem which could hamper a proper operation of the dam and reservoir.

In the project, three reservoirs are planned to be interconnected by the proposed transbasin schemes, which should be designed in due consideration of the reservoir sedimentation problem.

(1) Total Sediment Yield

The three reservoirs are designed to cope with the following sediment yield.

Reservoir	Project Life (Years)	Catchment Area (km^2)	Sediment Yield (MCM)	Sediment Rate ($m^3/km^2/year$)
Daule Peripa	50	4,200	260	1,238
La Esperanza	100	445	64	1,500
Poza Honda	100	170	13	743

The Poza Honda dam was constructed in 1971. A bathymetric survey was conducted in the Poza Honda reservoir from 1978 to 1985 to confirm a sediment rate. The sediment rate measured was as high as 1,750 $m^3/km^2/year$, resulting in a final sediment yield of 30 MCM after the useful life of 100 years.

It is decided to study reservoir sedimentation for the following nine cases (three cases for each reservoir) to follow the development of reservoir sedimentation.

Study Cases

Reservoir	Project Life (Years) 100	50	25	12.5
Daule Peripa		260	130	65
La Esperanza	64	32	16	
Poza Honda	30	13*	7.5	

Figures are total sediment yield in MCM.
* Original design value for Poza Honda

(2) Reservoir Sediment Deposition

Development of sediment deposition in a reservoir is quite complex because of the variations of many influence factors such as hydrological fluctuation in water and sediment inflow, texture and size of deposited sediment particles, fluctuation in reservoir water levels during operation, size and shape of the reservoir, etc.

A method proposed by the U.S. Bureau of Reclamation has been applied in this sediment study because it covers essential sedimentation characteristics to be considered in the design of dams and reservoirs and is related to the sedimentation processes in the reservoir. The method is practical, technically sound and sufficiently verified to fit the complexity of the problem based on observed sediment distribution in many reservoirs in the United States.

The area-storage curve of each reservoir is modified in consideration of sediment deposition in the reservoir and shown in Figures 3.3.1 to 3.3.3, corresponding to the design sediment yield of each reservoir.

It is generally known that so-called Delta Deposits are developed at around the average water level of a reservoir when a streamflow loses its velocity and sedimentation takes place. The formation of Delta Deposits is taken into account and sediment levels at the structure sites in the reservoirs are estimated as follows:

Structure Site	Reservoir	Original Level of Riverbed	Sediment Level after Project Life
Conguillo Intake	Daule Peripa	EL. 69 m	EL. 77 m
Severino P.S.	La Esperanza	EL. 36 m	EL. 45 m
Membrillo Outlet	La Esperanza	EL. 62 m	EL. 64 m
Cuyuyes Outlet	Poza Honda	EL. 97 m	EL. 104 m
Poza Honda Inlet	Poza Honda	EL. 77 m	EL. 82 m

Details on the reservoir sedimentation study are given in Annex 1.

3.3.2 Water Quality

Water sampling was carried out in 17 predetermined stations throughout the project area as shown in Figure 3.3.4. Water was sampled during the dry season (November 18 to December 3, 1993), (May 30 to June 13, 1994) and (August 15 to 29, 1994) and during the rainy season (January 10 to January 28, 1994).

Twenty-six (26) physical-chemical parameters were evaluated at each station, and results of BOD, COD, T-N and T-P, in addition to water quality data in the previous studies, are used as evaluation parameters for pollution load analysis.

No major industries as point source pollution are present in the project area. Details on water quality and prediction of change in water quality due to a project implementation are discussed in Section 3.6.

3.4 Topographic Survey

3.4.1 Control Points

(1) Control Point Survey

Control point survey was done by means of the Global Positioning System (GPS) with leveling survey to integrate the topographical relationships (x, y coordinates and elevations) of the proposed structures. This survey was done by Instituto Geográfico Militar (IGM).

Locations of the twenty four (24) control points from CP.23 to 46 are shown in Figure 3.4.1 and X, Y coordinates of these control points are shown in Table 3.4.1. The control points were related to the control points which were established in JICA Feasibility Study stage.

Leveling survey has been done based on the existing leveling points which were confirmed by IGM or JICA Feasibility Study Team.

The Control point survey was carried out based on the following four (4) existing points, which are shown in Figure 3.4.1.

Control Points	N (North)	E (East)	H (height)
EL TABLON	9907248.180	599319.800	358.214
MINAYA	9893895.440	580495.760	551.024
ALAJUELA	9896428.143	639158.432	116.980
TANQÜE	9909430.232	587841.529	33.872

Positioning of each control point was carried out by using three units of GPS receivers with assistance of more than four (4) satellites with continuous measurement up to two hours. Positioning hours by GPS was decided based on the information on satellites.

Based on the following geographical datum, conversion from GPS to Ecuadorian geographical system was made.

(a) Horizontal PSAD-56 (La Canoa-Venezuela)

(b) Vertical de La Libertad, Provincia del Guayas
(mean sea level)

(c) Ellipsoid Hayford-International
(a = 6,378,388 m, 1/f = 297.00)

(d) Projection Universal Transverse Mercator
(UTM, Zone 17)

(e) Scale Factor 0.9996 on the longitude West 81 degree

Table 3.4.1 shows conversion from longitude and latitude (GPS) to North to East (Ecuadorian Geographical System). Elevation of each control point is shown in the same table.

Accuracy of control points is shown in Table 3.4.2.

The following equipments were used for the control point survey by GPS.

(a) GPS Receiver : ASHTECH XII

(b) Computer : ALR 386 BGA

(c) Software : GPPS

(2) Leveling Survey

Leveling survey was carried out to connect from the first grade existing level points in Ecuador. Total length of the leveling survey was about 137 km.

Accuracy of the leveling is shown in Table 3.4.3. All the leveling results were within specified accuracy of 10 mm $\sqrt{S}$.

The following equipments were used for leveling.

(a) Level : WILD NAK-2

(b) Staff : Invar Staff

Existing bench marks for reference level points are shown in Figure 3.4.2 and shown below.

Bench Mark		Elevation	Remarks
(1)	VIII-B-7-D	45.3271	first order
(2)	VIII-B-8-A	26.8217	ditto
(3)	MQ-48	87.7191	ditto
(4)	MQ-49	152.4665	ditto
(5)	MQ-59-A-J	435.0095	ditto
(6)	XIII-B-17	112.1026	ditto
	MQ-64-A	432.6201	ditto
(7)	MQ-91	79.5066	ditto
(8)	MQ-92	78.4689	ditto
(9)	P.E15639Y	136.335	fourth order
(10)	MQ-96	64.8902	first order
(11)	MQ-97	62.5622	ditto

3.4.2 Access Roads and Transmission Line

Topographic survey composed of plane table, profile and cross section along access roads and transmission line was carried out by local contractors.

Location of the survey is shown in Figure 3.4.3 and listed below.

(1) Conguillo Access Road
(2) El Guasmo Access Road
(3) Membrillo Outlet Access Road
(4) Severino Access Road
(5) Caña Dulce Inlet Access Road
(6) Los Cuyuyes Access Road
(7) La Seca Access Road
(8) Poza Honda Inlet Access Road
(9) Daule-Peripa ~ Severino Transmission Line

Survey items and quantities are as follows:

Survey Item	Quantity	Scale
(1) Conguillo Access Road		
(a) Plane table	2.8 km2	1/2,000
(b) Profile	22.6 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	990 sections	H:1/200 V:1/200
(2) El Guasmo Access Road		
(a) Plane table	0.2 km2	1/2,000
(b) Profile	1.6 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	73 sections	H:1/200 V:1/200
(3) Membrillo Outlet Access Road		
(a) Plane table	0.05 km2	1/2,000
(b) Profile	0.35 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	15 sections	H:1/200 V:1/200
(4) Severino Access Road		
(a) Plane table	11.0 km2	1/2,000
(b) Profile	9.3 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	374 sections	H:1/200 V:1/200
(5) Caña Dulce Inlet Access Road		
(a) Plane table	3.0 km2	1/2,000
(b) Profile	2.7 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	116 sections	H:1/200 V:1/200
(6) Los Cuyuyes Access Road		
(a) Plane table	15.0 km2	1/2,000
(b) Profile	12.6 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	555 sections	H:1/200 V:1/200
(7) La Seca Access Road		
(a) Plane table	4.5 km2	1/2,000
(b) Profile	3.8 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	158 sections	H:1/200 V:1/200
(8) Poza Honda Inlet Access Road		
(a) Plane table	1.0 km2	1/2,000
(b) Profile	0.67 km	H:1/2,000 V:1/500
(c) Cross section (50 m intervals)	35 sections	H:1/200 V:1/200
(9) Daule-Peripa ~ Severino Transmission Line		
(a) Plane table	33 km2	1/2,000
(b) Profile	32.6 km	H:1/2,000 V:1/500

3.4.3 Structure Sites

Topographic survey for structure sites is carried out by local contractor. This survey consists of plane tables, profiles and cross sections.

Location of the survey for eleven (11) structure sites is shown in Figure 3.4.3 and listed below :

(1) Conguillo Inlet
(2) Membrillo Outlet
(3) Caña Dulce Inlet
(4) Los Cuyeyes Outlet
(5) Poza Honda Inlet
(6) Mancha Grande Outlet
(7) Severino Pumping Station
(8) Severino Penstock
(9) Severino Head Tank
(10) Severino Substation
(11) Severino Open Channel

Survey items and quantities are as follows :

Survey Item	Quantity	Scale
(1) Conguillo Inlet		
(a) Plane table	10,000 m2	1/200
(b) Cross section	6 sections	H:1/200
	V:1/200	
(2) Membrillo Outlet		
(a) Plane table	10,000 km2	1/200
(b) Cross section	6 sections	H:1/200
		V:1/200
(3) Caña Dulce Inlet		
(a) Plane table	16,000 m2	1/200
(b) Cross section	6 sections	H:1/200
		V:1/200
(4) Los Cuyeyes Outlet		
(a) Plane table	14,000 m2	1/200
(b) Cross section	6 sections	H:1/200
		V:1/200
(5) Poza Honda Inlet		
(a) Plane table	133,000 m2	1/200
(b) Cross section	6 sections	H:1/200
		V:1/200
(6) Mancha Grande Outlet		
(a) Plane table	58,000 m2	1/200
(b) Cross section	6 sections	H:1/200
		V:1/200

Survey Item	Quantity	Scale
(7)Severino Pumping Station		
Plane table	74,000 m^2	1/200
(8)Severino Penstock		
Plane table	20,000 m^2	1/200
(9)Severino Head Tank		
Plane table	10,000 m^2	1/200
(10) Severino substation		
Plane table	20,000 m^2	1/200
(11) Severino Open Channel		
(a) Plane table	672,000 m^2	1/200
(b) Profile	6,400 m	H:1/200 V:1/100
(c) Cross section (25 m intervals)	340 sections	H:1/200 V:1/200

3.5 Geology and Construction Materials

3.5.1 Geology

(1) General

The Project area is located in the Coast Zone in geomorphological classification of Ecuador, which covers a region of low hills developing between the Andes Range and the Pacific coast. The hills are composed of soft sedimentary stratified almost horizontal.

The following geological investigations have been performed for the detailed design of the Project:

- Core drilling on the transbasin waterways	370m/11 locations
- Water pressure tests in drill holes (Lugeon tests and open end tests)	31 sections
- Standard penetration tests in drill holes	54 times
- Test pitting on the open channel and transmission line routes	15 locations

- Sounding by S.P.T. on the open channel, the transmission line and tunnel portals on the Poza Honda reservoir — 61 locations

- Geological mapping of the transbasin waterway — 4 locations

- Laboratory rock test — 11 core samples

Details of the geological investigations are given in Annex 2.

(2) Geotechnical Considerations for Tunnel Design

The diversion tunnels to interconnect the basins of the Daule river, the Carrizal river, the Portoviejo river and the Mancha Grande river are planned to be laid at levels between EL. 60 m and EL. 110 m. In these levels, the tunnels will be located in the horizontal beds of the Onzole Formation composed of conglomerates, sandstones and mudstones.

Some of the sandstone beds with less contents of finer particles are poorly cemented and porous, while the other sandstones, the conglomerates and almost all the mudstones are moderately cemented, compact and massive. The bedrocks envisaged to be encountered by the tunnels are generally of moderately cemented and tight. The poorly cemented sandstone will not be met in the contemplated tunnel level. Mudstones in the Poza Honda-Mancha Grande diversion tunnel, however, can be weaker than the rocks in the other tunnels because of deeper developed weathering common in that area.

The geotechnical properties of the bedrocks, based on the laboratory testings and partly on the empirical judgement, are shown on Tables 3.5.1 and 3.5.2. The compressive strength of intact rocks ranges from 40 to 50 kgf/cm^2; the deformation modulus is from 7,000 to 10,000 kgf/cm^2; the cohesion from 3 to 5 kgf/cm^2 and the internal angle of friction being 40 degrees.

Seepage potential varies from zero to more than 60 in Lugeon unit in the water pressure testing in boreholes. It also showed many signs of deformation of the bedrocks under pressure of 4 to 6 kgf/cm^2, as represented by abrupt and steep increment of water injection rate suddenly rose from almost zero to 180 litres every minute at the pressure of 10 kgf/cm^2. These phenomena are deemed not always to indicate breakage or destruction of the bedrock but be at least evidences of partly irreversible opening of fissures for water passage forced by the increased pressures.

Tunnel sections near the portals are inevitably located in the weathered rock zone with less strengths and, possibly, higher seepage potential. Poor rock conditions have to be envisaged also in sections where the tunnels pass under thin rock cover under gullies. There are two locations of thin rock covers of only 16 m and 18 m in the route of the Daule Peripa~La Esperanza diversion tunnel and one with rock cover of 22 m in the La Esperanza~Poza Honda diversion tunnel. These sections will require technique to cope with possible high discharge of groundwater and very soft bedrocks weakened by water seepage.

Shotcreting of 10 to 15 cm in thickness and rock boltings, contemplated in the feasibility study, are deemed to be appropriate method for supporting the tunnel. A planned method of tunnelling by cutting machine, instead of blasting, is suitable for those soft, compact and massive bedrocks.

Steel supporting will also be needed, especially in the said sections through weathered rocks and under thin rock covers. Close installation of the steel supports, e.g. at 0.75 m intervals, may be required in those weak rock zones. Provision to drill drainage holes in advance to progress of the tunnelling work will also be required in order to control groundwater discharge, if foregoing exploratory drillings from the tunnel face indicate its necessity.

Some of the bedrocks show tendencies of slaking and swelling, probably due to clay minerals of the montmorillonite group contained. The swelling pressure index observed in the laboratory test, however, is appreciably low with values around 1.5 kgf/cm^2 or less , except for one sample. The slaking is to be suppressed by covering the rock surface with shotcrete to prevent its direct contact with the atmosphere.

It is deemed essential to apply concrete lining to the full length of the tunnel for permanent protection of the soft bedrock in the tunnel periphery which is vulnerable to erosion by water flow. It will also work to suppress unfavourable effect of rock swelling, if any.

Tunnelling of galleries under way in La Esperanza Dam provides a good example of a tunnel in the Miocene Onzole Formation. With steel supports at short intervals and shotcreting, the tunnelling through weathered rocks has been performed successfully. A few parts of noticeable groundwater discharge appeared to have caused no serious troubles. Although the tunnel at La Esperanza was being driven adequately with blasting, the mechanical cutting will be efficient and preferable for the long tunnels as those for the transbasin water flow.

(3) Geotechnical Considerations for Structure Designs

For the Severino pumping station to pump up the water of La Esperanza reservoir to the open channel leading to the La Esperanza-Poza Honda tunnel, the pumping station will be founded largely on the sandstone, some of which are poorly cemented and porous but will not be difficult for excavation and construction of the shaft because they are usually in dry condition owing to the very low groundwater table near a steep slope.

In the Severino head tank and on the route of the Severino open channel, a core drilling, ten test pits and 54 soundings have indicated that the thickness of colluvial overburden is 3 m or less in most parts. The tank and channel will be for the most part set in the mudstone bedrock, which, even if weathered, has sufficient strength to support the tank and channel structures.

A water pressure test indicated due tightness of the rock against water of such a low head as is built up in the open channel. It will be an appropriate approach, however, to design artificial coating of the channel bottom with concrete or earth blanket to secure its watertightness, considering varied seepage conditions of the rocks reflecting local variation in intensity of weathering and deterioration.

Swelling and slaking characteristics of the bedrock and the earth material originated in the same rock may cause a problem also for the open channel route. Considering that this geotechnical feature can not be completely avoided within the extensive region where the Onzole Formation develops, the unfavourable aspects of this feature have to be coped with by the design of countermeasures. Fortunately, the tendencies of swelling and slaking are neither seriously high nor prevalent in all the rock beds. From practical point of view, minor swelling on a cut slope of the canal will be not seriously damageous. Slaking, if any, can be prevented by covering the rock with shotcrete or earth material.

Alluvial deposit can be thick, e.g., up to 10 m, at the bottom of the gullies on the open channel route which are to be crossed with siphons.

For foundations of the Severino substation and towers of the transmission line, the overburden is thin and weathered bedrocks of sufficient strength will be reached in the depth of a few metres. No problem is envisaged for foundations of structures for the power supply.