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GOVERNMENT OF THE REPUBLIC OF ECUADOR

CENTRO DE REHABILITACION DE MANABI (CRM)

FEASIBILITY STUDY
ON
THE WATER RESOURCES DEVELOPMENT
FOR CHONE-PORTOVIEJO RIVER BASINS

FINAL REPORT
VOLUME I
(MAIN REPORT)

DECEMBER 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of the Republic of Ecuador, the Government of Japan decided to conduct a Feasibility Study on The Water Resources Development for Chone-Portoviejo River Basins and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Ecuador a study team headed by Mr. Osamu Takahashi, Nippon Koei Co., Ltd., four times between May 1991 and November 1992.

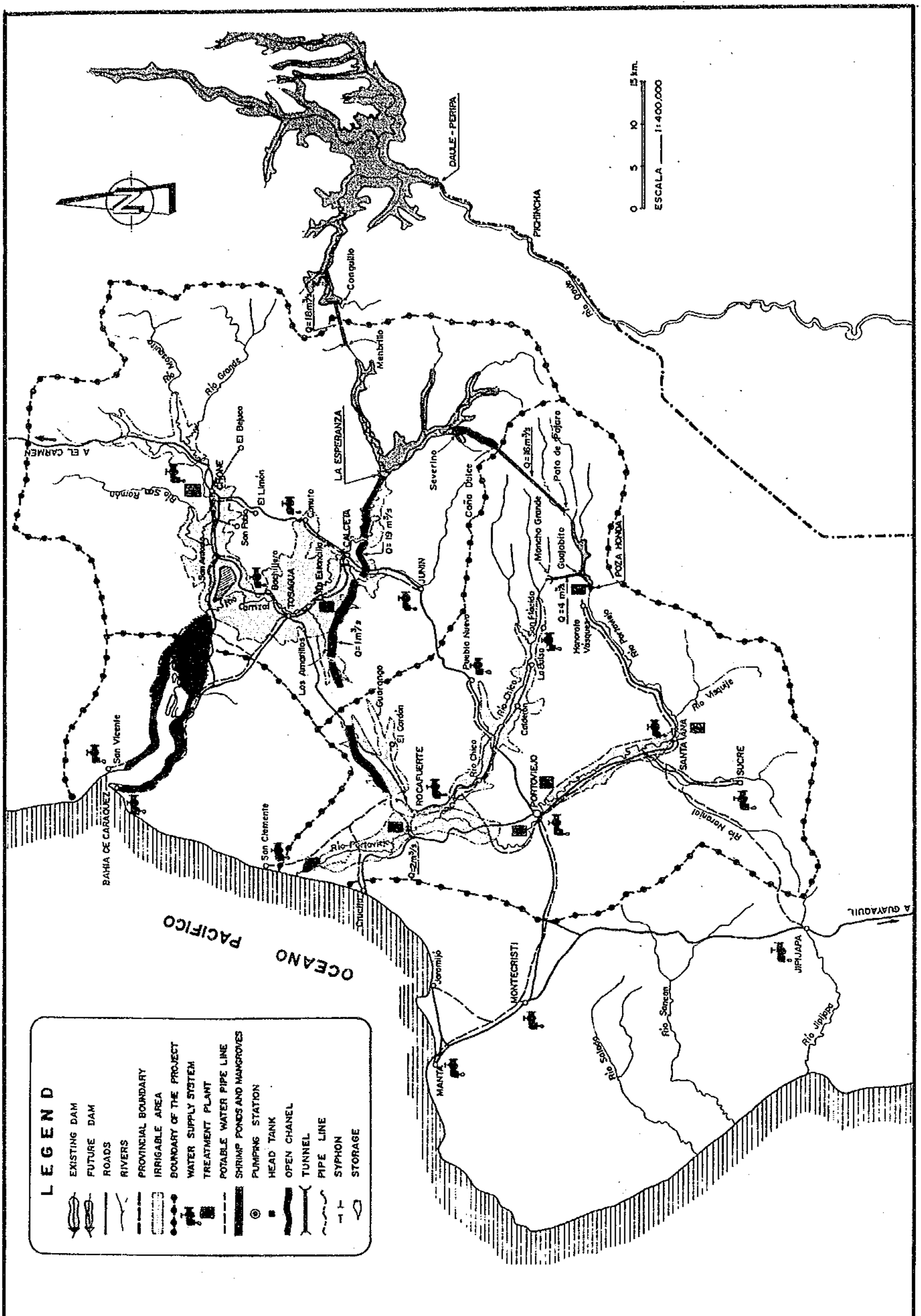
The team held discussions with the officials concerned of the Government of Ecuador, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

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

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Ecuador for their close cooperation extended to the team.

January 1993

Kensuke Yanagiya
President
Japan International Cooperation
Agency



LOCATION MAP

(Alternative -5 a)

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ABBREVIATION

Ecuadorian Institutions

CEDEGE	:	Committee for Guayas River Basin Development
CENAIM	:	National Center for Marines Research
CLIRSEN	:	Integrated Center for Remote Sensing Survey
CONADE	:	National Development Council
CPC	:	Chamber of Shrimp Producer
CRM	:	Manabi Rehabilitation Center
DITURIS	:	Tourism Directorate of Ecuadorian Government
EMAPAM	:	Municipal Enterprise of Potable Water & Sewerage of Manta City
ESPOL	:	Polytechnic Littoral College
GOE	:	Government of Ecuador
IEOS	:	Ecuadorian Institute of Sanitary Works
IGM	:	Geographic Military Institute
INAMHI	:	National Institute of Meteorology and Hydrology
INEC	:	National Institute of Statistics and Census
INERHI	:	Ecuadorian Institute of Water Resources
JRH	:	Jipijapa and Pajan Board of Water Resources
MAG	:	Ministry of Agriculture and Livestock
PHIMA	:	Integrated Water Resources Development Plan of Manabi
PMRC	:	Management Program of Coastal Resources
PRONAREG	:	National Program of Regional Survey
SRP	:	Subsecretary for Fisheries Resources

International or Foreign Institutions

ASCE	:	American Society of Civil Engineers
ASTM	:	American Society for Testing and Materials
CIDIAT	:	Interamerican Center for Integrated Development of Water and Land
FAO	:	Food and Agriculture Organization of the United Nations
IDB	:	Interamerican Development Bank
JICA	:	Japan International Cooperation Agency
OAS	:	Organization of American States
OECF	:	Overseas Economic Cooperation Fund of Japan
ORSTOM	:	Office de la Recherché Scientifique et Technique Outre-Mer
SCS	:	Soil Conservation Service
SEAFDC	:	Southeast Asian Fisheries Development Center
UNDP	:	United Nations Development Program
USDA	:	U. S. Department of Agriculture

Economic Terms and Others

B/C	:	Benefit Cost Ratio
BOD	:	Biochemical Oxygen Demand
CIF	:	Cost Insurance and Freight
COD	:	Chemical Oxygen Demand
DR	:	Discount Rate
DSS	:	Total Dissolved Solids
EC	:	Electrical Conductivity
EIRR	:	Economic Internal Rate of Return
FC	:	Foreign Currency
FOB	:	Free on Board
GDP	:	Gross Domestic Product
GRP	:	Gross Regional Product
IVA	:	Sales Tax
LC	:	Local Currency
NPV	:	Net Present Value
T-N	:	Total Nitrogen
T-P	:	Total Phosphorus
TSS	:	Total Suspended Solid

ABBREVIATION OF MEASURES

Length

mm	=	millimetre
cm	=	centimetre
m	=	metre
km	=	kilometre
masl	=	metre above sea level
EL.	=	elevation

Area

ha	=	hectare
m^2	=	square metre
km^2	=	square kilometre

Volume

l, lit	=	litre
Kl, Klit	=	kilolitre
l/s	=	litre per second
m^3	=	cubic metre
m^3/s, cms	=	cubic metre per second
m^3/min	=	cubic metre per minute
m^3/hr	=	cubic metre per hour
MCM, mcm	=	million cubic metre
m^3/d, cmd	=	cubic metre per day

Weight

mg	=	milligram
mg/l	=	milligram per litre
g	=	gram
kg	=	kilogram
t, ton	=	ton
t/y	=	ton per year
MT	=	metric ton

Time

sec	=	second
min	=	minute
hr, Hr	=	hour
d	=	day
yr	=	year

Money

S/.	=	Ecuadorian Sucres
¥	=	Japanese Yen
US$	=	U. S. dollar
US$ 1.0	=	S/. 1,550 as of end of July 1992
US$ 1.0	=	¥128 as of end of July 1992
¥1.0	=	S/. 12.11 as of end of July 1992

Energy

Kcal	=	Kilocalorie
KW, Kw	=	kilowatt
MW, Mw	=	megawatt
KWh, Kwh	=	kilowatt-hour
GWh, Gwh	=	gigawatt-hour

Others

%	=	percent
‰	=	per thousand
°	=	degree
'	=	minute
"	=	second
℃	=	degree Celsius
MD, md	=	man-day
mil.	=	million
NO, Nos	=	number
pers.	=	person
mmho	=	micromho
ppm	=	parts per million
ppb	=	parts per billion
l/h/d	=	litre per person per day
g/c/d	=	gram per capita per day
LS	=	lump sum
Head	=	cattle, Hog
OM & R	=	Operation, Maintenance and Replacement
p.a		per annum

1. GENERAL

1.1 Introduction

This Final Report is prepared and submitted to the Manabi Rehabilitation Center (CRM) under the National Development Council (CONADE) of the Government of the Republic of Ecuador (GOE) in accordance with the agreed scope of works for the Feasibility Study on the Water Resources Development for Chone-Portoviejo River Basins (the Study) between GOE and the Japan International Cooperation Agency (JICA).

The Study consists of (i) the examination of various alternative development plans and selection of the optimum plan (Phase 1), and (ii) elaboration of a feasibility study on the selected optimum plan (Phase 2).

1.2 Background of the Study

In view of the urgent necessity of solving a habitual water shortage problem of Manabi province, CRM in cooperation with the Ecuadorian Institute of Water Resources (INERHI) started a comprehensive study on the integrated water resources development of Manabi province (PHIMA) in late 1986. The Organization of American States (OAS) joined the PHIMA study in late 1987. The Government of Japan, at the request of GOE and OAS, joined the PHIMA study through JICA in early 1989.

The final report on PHIMA was prepared in January 1990 by JICA in collaboration with OAS and GOE (CONADE, INERHI and CRM), which recommended to conduct a feasibility study on the water resources development project in the Chone and Portoviejo river basins, more specifically on the water transbasin scheme from the existing Daule-Peripa reservoir to the Chone-Portoviejo river basins. The project location is shown in Fig. 1.1 and Fig. 1.2.

The PHIMA report identified six alternatives for the water transbasin scheme, combining some of the following water transbasin components, as follows.

Component No.	Description
(1)	Daule-Peripa to La Esperanza (Capacity 18 m^3/s)
(2)	Daule-Peripa to La Esperanza (Capacity 6 m^3/s)
(3)	Daule river at about 30 km downstream of the Daule-Peripa dam to Poza Honda (Capacity 12 m^3/s)
(4)	Daule river at about 30 km downstream of the Daule-Peripa dam to Poza Honda (Capacity 14 m^3/s)
(5)	La Esperanza to Poza Honda (Capacity 12 m^3/s)
(6)	La Esperanza to Poza Honda (Capacity 14 m^3/s)
(7)	La Esperanza to Chico River Basin (Capacity 14 m^3/s)
(8)	Chico River Basin to Portoviejo River Basin (Capacity 6 m^3/s)
(9)	La Esperanza to Rocafuerte via Amarillos and Guarango (Capacity 5 m^3/s)
(10)	La Esperanza to Rocafuerte via Amarillos and Guarango (Capacity 15 m^3/s)
(11)	Poza Honda to Chico River Basin (Capacity 4 m^3/s)
(12)	Construction of the Chirijos dam on the Chico river

Alternative No.	Combination of Components in Number	Reference Map
1	(1), (5), (9) and (12)	Fig. 1.3
2	(2), (3), (9) and (12)	Fig. 1.4
3	(1), (7), (8) and (9)	Fig. 1.5
4	(1), (10) and (12)	Fig. 1.6
5	(1), (6), (9) and (11)	Fig. 1.7
6	(2), (4), (9) and (11)	Fig. 1.8

The purpose of the Phase 1 of the Study is to select the optimum water transbasin scheme from the above-mentioned six alternative plans, and that of the Phase 2 of the Study is to conduct a feasibility study on the selected plan..

1.3 Composition of the Final Report

The Final Report is composed of the following:

Summary
Main Report
Supporting Report

Annex A	Socio-economy and Institutional Aspects
Annex B	Hydrology
Annex C	Water Supply Plan
Annex D	Irrigation
Annex E	Aquaculture
Annex F	Water Transbasin Plan
Annex G	Topographic Survey
Annex H	Geological Investigation
Annex I	Hydraulic and Structural Design
Annex J	Construction Plan and Cost Estimates
Annex K	Environment

Reference Data

No. 1	Topographic survey
No. 2	Seismic Refraction survey
No. 3	Geotechnical and Soil Mechanical Investigation

1.4 Project Organization

CRM in cooperation with CONADE and INERHI is the executing agency for the Study.

Executive Committee is organized as a decision making committee, which is composed by the following members:

Ab. Antonio Zavala M.	Executive Director of CRM (President of the Committee)
Dr. Pablo Lucio Paredes	General Secretary of Planning, CONADE
Ing. Juan Araujo P.	Executive Director, INERHI

Besides, a Technical Committee is organized, which is in charge of decision making of the technical aspects, and is composed of the following members:

Ing. Carlos Villacreces Viteri	Vice-Executive Director, CRM
Ing. José Cedeño Párraga	National Director of PHIMA
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The following members participated as the Ecuadorian counterparts for the Studies.

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Arq. Sixto Durán Ballén	President of the Republic
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Ing. Juan Araujo	Executive Director, INERHI
Ing. Carlos Torres	Technical Director, INERHI
Mr. Kiichi Itabashi	Ambassador of Japan in Ecuador
Mr. Tokuro Masudome	Secretary, Japan embassy

2. SOCIO-ECONOMY

2.1 National Socio-Economy

2.1.1 Location and administratives

Ecuador is located on the west coast of South America, between 1° 30' north latitude and 5° 05' south latitude and between 81° and 75° 10' west longitude. It borders Colombia in the north, Perú in the east and south, and the Pacific Ocean in the west. The Galapagos Islands, 1,000 km off the coast, are part of the Ecuadorian territory.

The Andean range crossing the country from north to south divides the territory into three regions, i.e. the Highlands (La Sierra), the Coast (La Costa) and the Amazonic region (La Amazonía/El Oriente).

The government sovereignty resides in the people and is exercised through three branches of government, i.e. the Executive, Legislative and Judicial. The Executive branch is led by the President of the Republic who is elected every four years by direct suffrage. The Vice-President chairs the National Development Council (CONADE).

2.1.2 Population

The official language is Spanish. Religion is free. The majority of the population is Catholic.

According to the National Institute of Statistics and Census (INEC), population in Ecuador is 11.4 million in 1992. Population growth was 3.6% p.a. in 1950's, 2.7% p.a. in 1970's and 2.6% p.a. in 1980's, while it is projected to be 2.3% p.a. in 1990's. The urban population is increasing more than the rural population. The share of the urban population which was 40% in 1970 increased to 54% in 1988.

2.1.3 Gross domestic product

Gross Domestic Product (GDP) of Ecuador was S/. 8,130 billion in 1990. The real growth rate of GDP was 1.66% p.a. during the period from 1981 to 1990. Among the industrial origins of GDP, the sectors of agriculture (17.4%), petroleum and mines

(12.4%), manufacturing (16.3%) and commerce (14.8%) are dominant in 1990, contributing 60.9% of the total GDP.

2.1.4 Trade and international balance of payment

Export and import of Ecuador in 1990 were US$2,714 million and US$3,719 million, respectively. Major export commodities were crude oil (46.4%), banana (17.2%), shrimp (12.5%) and coffee (3.8%) in 1990, while major import commodities were primary materials (26.4%), industrial materials (21.8%), capital goods (16.3%) and industrial goods (10.1%) in the same year.

2.1.5 Government finance

In 1990, the government total receipt was S/. 1,677 billion consisting of net current revenue of S/. 1,363 billion, capital income of S/. 226 billion and the initial balance of S/. 88 billion. The total receipt corresponds to 20.6% of GDP. The government expenditure in the same year was S/. 1,411 billion consisting of ordinary expenditure of S/. 843 billion, expenditure for development of S/. 48 billion and amortization of loan of S/. 520 billion.

2.1.6 Price and monetary system

The monetary unit is Sucre (S/.). In Ecuador, there are three currency exchange rates, i.e. (i) official rate, (ii) investment rate, and (iii) free market rate. In August 1988, the official exchange rate was set at S/. 390 per US Dollar. The Monetary Board set an exchange rate for investment in March 1990 to be S/. 629.5 per US Dollar as buying rate and two percent above the buying rate as selling rate, subject to weekly adjustment by S/. 3.5 per US Dollar. They became S/. 1,076 for buying rate and 1,098 for selling rate both per US Dollar in August 1991.

The free market rate is set by the supply and demand of foreign exchanges. The average of buying and selling rates was S/. 1,104 and S/. 1,121 per US Dollar respectively in August 1991. The average exchange rate in free market in 1990 was around S/. 821 per US Dollar.

Urban consumer prices in Ecuador rose nine times in house and household effects and 27 times in food and beverages in ten years from 1981 to 1990. Prices rose abruptly during the recent three years from 1988 to 1990. General consumer price index (1979 = 100) was 136 in 1981, 628 in 1987 and 2591 in 1990.

2.2 Regional Socio-Economy

2.2.1 Location of the study area

The Study area is located in the central part of Manabi province, one of the provinces in the Costa region facing to the Pacific Ocean as shown in Fig. 1.1. Manabi province has an area of about 19,000 km^2, while the Study area, Chone-Portoviejo river basins has an area of 4,871 km^2, consisting of the Bahia area (Lower basin of Chone river) of 544 km^2, the Chone river basin of 2,267 km^2 and the Portoviejo river basin of 2,060 km^2, as shown in Fig. 1.2.

2.2.2 Population

According to the last census executed by INEC in 1990, the population of Manabi province was 1,032,000, of which the shares of urban and rural populations were 41% and 59%, respectively. Population density of Manabi was 54.3 persons/km^2. On the other hand, total number of households was 187,120, resulting in an average household size of 5.5. The average annual growth rate of population of Manabi was 1.63% during the period from 1972 to 1990, 2.52% for urban population and 0.24% for rural population.

The population of the Study area was 484,500 in 1990, accounting for 46.9% of the total population of Manabi. The population density of the Study area was 99.5 persons/km^2, which is almost twice of that of the whole Manabi province. The population of the beneficiary area is projected to increase to 1,240,700 in 2020 by PHIMA.

2.2.3 Gross regional product

Gross Regional Product (GRP) of Manabi province was S/. 367,400 million in 1989 at current prices, or 6.9% of the total GDP of Ecuador. Among the industrial origins, the agriculture and livestock sector accounted for 42.3% of the GRP of Manabi and 14.1% of the same sector of Ecuador.

During the last 10 years about 40% or more of economically active population of the Manabi province was engaged in the agriculture and livestock sector. Major agricultural products are coffee, cocoa, maize, cotton, banana/platano and citrus. Livestock farming is also an important industry of Manabi, especially cattle and hog farming. The aquaculture of shrimp has been developed remarkably in several estuaries including lower reaches of the Chone and Portoviejo rivers.

Main export products in 1990 from Manabi province are coffee (US$40 million), shrimp (US$32 million), fishes (US$28 million), cocoa (US$10 million), etc.

2.2.4 Infrastructures

There are an international sea port in Manta, and two domestic airports in Portoviejo and Manta. Roads are divided into two categories, i.e. (i) trunk roads and (ii) secondary roads. The total length of the truck road is 1,170 km, of which 73% is asphalt-paved, while that of the secondary roads is 4,920 km, of which only 2% is asphalt-paved.

Number of customers of telephone was 17,750 in 1990, with an annual growth rate of 6.3% from 1981 to 1990. The electric energy consumption in the same year was 275 MWh with the number of customers at 86,700. An annual growth rate of energy consumption was 7.8% from 1981 to 1990.

Water supply systems served 55% of the population of Manabi in 1986. There are four regional water supply systems which served 64% of the urban population in 1986. Sewage is treated by central sewerage systems or individual septic tanks, etc. In 1988, about 350,000 people enjoyed the sewerage service, equivalent to 32% of the population. The sewerage systems consist of sewage collection network and sewage treatment generally by stabilization lagoons.

3. PROJECTS AND STUDIES RELATED TO THE STUDY

3.1 General

In the Study area, a central zone of Manabi province mainly consisting of the Chone-Portoviejo river basins, a number of 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 and studies are, among others, of vital importance for a proper conduct of the Study.

(I) Poza Honda Multipurpose Project in the Portoviejo river basin.

(2) Daule-Peripa Dam Project on the Daule river, located immediate east of the Study area.

(3) La Esperanza Dam Project on the Carrizal river, a major tributary of the Chone river.

(4) Water Transbasin Project from the Daule to the Poza Honda and La Esperanza reservoirs.

(5) Carrizal-Chone Multipurpose Project in the Chone river basin.

3.2 Poza Honda Multipurpose Project

The United Nations Development Program (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 Germany, CRM made a revision of the definite design, employing a consortium of German consultants in January 1967. A revised definite design of the dam was prepared by the consortium in August 1968. The Poza Honda Multipurpose Project was proposed to be implemented in the following three stages.

Stage 1: Construction of the Poza Honda dam

Stage 2: Construction of water treatment plant at Guarumo and water transmission lines with pumping.

Stage 3: Construction of an intake weir at Santa Ana and irrigation system commanding 3,300 ha in between Santa Ana and Portoviejo.

As the Stage I development of the project, the Poza Honda dam was constructed in 1971 in the upper reach of the Portoviejo river. Technical features of the dam are as follows.

Hydrology		
	Catchment area	175 km^2
	Annual mean basin rainfall	1,300 mm
	Annual mean inflow	95 MCM
	Runoff coefficient	42%
	Probable max. flood	1,120 m^3/s
Reservoir		
	Gross storage capacity	98 MCM
	Dead storage	13 MCM
	Emergency storage	10 MCM
	Effective storage	75 MCM
	Flood water level	EL.112.3 m
	Normal high water level	EL.108.5 m
	Emergency water level	EL. 93.5 m
	Low water level	EL. 90.3 m
	Riverbed level	EL. 75 m
	Reservoir area at HWL	4.9 km^2
Dam		
	Type	Homogeneous earthfill with asphalt facing.
	Height	40 m
	Crest elevation	EL.114.3 m
	Crest length	531 m
Spillway		
	Type, Control structure	Non-gated overflow weir
	Water conveyance	Open chute
	Energy dissipator	Stilling basin
	Length of overflow weir	70 m
	Overflow weir level	EL.108.5 m

Outflow peak discharge	875 m^3/s

Intake and Outlet

Intake level	EL. 89 m
Outlet capacity	30 m^3/s

The Stage 2 development including the construction of the Guarumo treatment plant at just downstream of the dam and a pertinent water transmission system to Portoviejo and Manta was completed in 1976. The Guarumo treatment plant has a capacity of 43,000 m^3/day, and the Poza Honda water supply system was greatly improved with an assured water source of the Poza Honda reservoir.

The Santa Ana irrigation project was constructed in 1984, consisting of Santa Ana intake weir and a irrigation canal network covering an area of 3,300 ha along the Portoviejo river between Santa Ana and Portoviejo, as the Stage 3 development of the project.

The Poza Honda Project in its Stage 1, 2 and 3 development was implemented by a technical and financial cooperation of the German government. In order to meet an increasing demand for domestic water mainly in Portoviejo and Manta, the Poza Honda water supply system was expanded in 1987 by a construction of the Caza Lagartos treatment plant with a capacity of 20,000 m^3/day at Santa Ana and a pertinent water transmission system to Manta.

The PHIMA study evaluated a water supply capacity of the Poza Honda dam at Santa Ana to be 107 MCM/year at 80% guarantee (no water shortage in four years out of 5 years). The catchment area at Santa Ana is 481 km2, including the Poza Honda catchment of 175 km^2. On the other hand, water demand is estimated also by PHIMA to be 25 MCM/year for water supply and 71 MCM for irrigation, totaling 96 MCM/year. Although it is technically possible for the Poza Honda Project to meet all the present water demand, CRM actually limits the irrigation water supply to assure domestic water supply at practically 100% guarantee even during consecutive dry years.

CRM, to meet an ever growing domestic water demand mainly in Portoviejo and Manta, decided to construct two new water treatment plants with a total capacity of 180,000 m3/day as explained below.

Cuatro Esquinas treatment plant at Portoviejo

45,000 m^3/day (Operation Stage I)

45,000 m^3/day (Operation Stage II)

El Ceibal treatment plant at Rocafuerte

45,000 m^3/day (Operation Stage I)

45,000 m^3/day (Operation Stage II)

Water transmission pipeline system

30 km from El Ceibal to Manta

5 km from El Ceibal to Rocafuerte

5 km from Cuatro Esquinas to Portoviejo

The total construction cost is estimated to be US$ 37 million, a major part of which was agreed to be financed by the French government. The construction was commenced in August 1991 with a scheduled completion in late 1993 for Cuatro Esquinas and in mid 1993 for El Ceibal. Raw water supply to these new plants in the dry season when the natural flow of the Portoviejo river is almost depleted should depends on the Poza Honda reservoir. The Poza Honda reservoir, however, cannot afford to feed the new plants with additional 66 MCM/year of water without suspending the irrigation water supply to the Poza Honda irrigation system. This is one of the major reasons for urgent necessity of water to be diverted from the Daule-Peripa to the Portoviejo river basin.

The Poza Honda reservoir will function as a water receiving pond in Alternatives 1, 2, 5 and 6 for transbasin of water from the Daule-Peripa to the Portoviejo river basin. Even in Alternatives 3 and 4, the water demand in the Portoviejo river basin will be met by a combination of water to be diverted from Daule-Peripa and the Poza Honda reservoir.

3.3 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 a master plan level, in which the construction of the Daule-Peripa dam was proposed as a master reservoir for basin development. UNDP made a preliminary study on the Daule-Peripa Dam Project in 1972. With a finance of the Interamerican Development Bank (IDB), 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 1987 with the IDB financing. The total construction cost was around US$ 140 million. The engineering consultant was TAMS-AHT-INTEGRAL and the contractor was Agroman of Spain. The main objectives of the Daule-Peripa dam are (i) flood control, (ii) domestic water supply, (iii) irrigation water supply and (iv) hydroelectric power generation. Technical features of the dam are as follows.

Hydrology	
Catchment area	4,200 km^2
Annual mean basin rainfall	2,700 mm
Annual mean inflow	5,000 MCM
Runoff coefficient	44%
Probable max. flood	14,350 m^3/s
Reservoir	
Gross storage capacity	5,300 MCM
Dead storage	1,300 MCM
Effective storage	4,000 MCM
Flood water level	EL. 88.0 m
Normal high water level	EL. 85.0 m
Low water level	EL. 60.0 m
Riverbed level	EL. 12 m
Reservoir area at FWL	290 km^2
Reservoir area at HWL	270 km^2
Allocation of Reservoir Capacity	
Flood space	700 MCM
Power generation	3,500 MCM
Irrigation	1,800 MCM
Water supply	500 MCM
Use in Manabi province	500 MCM
Main Dam	
Type	Zoned earthfill
Height from foundation	90 m
Crest elevation	EL. 90.0 m
Crest length	250 m

Dam volume	3,000,000 m^3

Sub-dam	
Type	Homogeneous earthfill
Length	18 km
Average height	10 m (max. 27 m)
Embankment volume	5,900,000 m^3
Spillway	
Type, Control structure	Gated overflow weir
Water conveyance	Open chute
Energy dissipator	Stilling basin
Width of overflow weir	59 m
Overflow weir level	EL. 77.0 m
Design peak discharge	3,480 m^3/s
Spillway gates	
No of gates	3 nos
Type	Tainter gate
Dimensions	H = 8.0 m, W= 17.0 m
Power facilities (Not yet installed as of end 1991)	
Installed capacity	65 MW x 2 units=130MW
Annual energy output	510 GWh (firm)
Design head	58.2 m
Design discharge	132.3 m^3/s per unit
Outlet facilities	
Tunnel diameter and length	9.0 m, 530 m
Outlet capacity	400 m^3/s

It is to be noted that a reservoir capacity of 500 MCM is allocated for use in the central zone of Manabi province. According to the inter-institutional agreement between CEDEGE and CRM, which was signed in December 1986 and fully endorsed by the Minister of Agriculture and Livestock, CRM is entitled to divert up to 500 MCM/year with the maximum diversion of 18 m^3/s.

3.4 La Esperanza Dam Project

A feasibility study on the 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 a Korean contractor, Daewoo. CRM was the executing agency of the project and the cost was financed by the Ecuadorian government.

During the initial stage of construction, however, the construction work was obliged to be suspended due to a geotechnical problem 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 1990 due to a financial problem.

The financial problem was solved in 1991. Out of the total construction cost of US$ 80 million, US$ 30 million is financed by the Spanish government, US$ 30 million is financed by Spanish banks and the remaining US$ 20 million is financed by the Ecuadorian government. CRM already awarded a contract for construction to a Spanish contractor, Dragados y Construcciones, who commenced the construction work from early 1992, which will be completed in mid 1996.

The technical features of the La Esperanza dam are as follows.

Hydrology	
Catchment area	445 km^2
Annual mean basin rainfall	1,520 mm
Annual mean inflow	376 MCM
Runoff coefficient	56%
Probable max. flood	3,040 m^3/s
Reservoir	
Gross storage capacity	455 MCM
Dead storage	64 MCM
Effective storage	391 MCM
Flood water level	EL. 67.7 m
Normal high water level	EL. 66.0 m
Low water level	EL. 37.0 m
Riverbed level	EL. 22 m

Reservoir area at FWL	24.0 km^2
Reservoir area at HWL	22.7 km^2
Dam	
Type	Zoned earthfill
Height from foundation	57.0 m
Crest elevation	69.0 m
Crest length	696.0 m
Dam volume	3,700,000 m^3
Spillway	
Type, Control structure	Gated overflow weir
Water conveyance	Open chute
Energy dissipator	Stilling basin
Width of overflow weir	39.0 m
Overflow weir level	62.0 m
Design peak discharge	900.0 m^3/s
Spillway gates	
No of gates	4 nos
Type	Tainter gate
Dimensions	H = 4.0 m, W = 7.5 m
Outlet facilities	
Irrigation outlet	Capacity 25 - 38 m^3/s
Low level outlet	Capacity 110 m^3/s
Outlet for river maintenance	Capacity 5 m^3/s

The objectives of the La Esperanza dam are (i) flood control in the Carrizal river, (ii) irrigation water supply to the Carrizal-Chone irrigation area of about 15,000 ha and Los Amarillos-Guarango irrigation area of about 2,500 ha, and (iii) domestic water supply. Once the La Esperanza dam is constructed in the upper reach of the Carrizal river, the habitual inundation problem in the rainy season and the severe water shortage problem in the dry season will mostly be solved in the Chone river basin. The water shortage problem of the Portoviejo river basin will still remain until the transbasin scheme is realized from Daule-Peripa to the Portoviejo river basin.

Under the water transbasin scheme, the La Esperanza reservoir will receive Daule-Peripa water in all Alternatives and will also function as an intermediate pond to divert water from Daule-Peripa to the Portoviejo river basin in Alternatives 1, 3, 4 and 5.

3.5 Water Transbasin Project from Daule-Peripa to Manabi

CRM started a study on water transbasin project from Daule-Peripa to the central part of Manabi in 1984, when the Daule-Peripa dam was under construction. A definite design for the water transbasin scheme was prepared in 1987 in the following plan.

(i) Water in the Daule-Peripa reservoir will be diverted to the La Esperanza reservoir through a 8.3 km tunnel by gravity with a transbasin capacity of 12 m^3/s.

(ii) Water in the Daule river at about 30 km downstream of the Daule-Peripa dam will be pumped up by about 150 m to be diverted into the Poza Honda reservoir through a steel pipeline of 13.3 km in length and a diversion tunnel of 11.2 km in length with an initial capacity of 8 m3/s and a final capacity of 12 m^3/s.

The construction cost was estimated at a price level of October 1986 to be US$ 26.4 million for transbasin from Daule-Peripa to La Esperanza and US$ 80.3 million for transbasin from Daule river to Poza Honda, totaling US$ 106.7 million.

The proposed transbasin scheme is taken up as Alternatives 2 and 6 of the Study being undertaken by JICA. The PHIMA study in 1989 did not recommend these two alternatives because of high pumping requirement and resultant high operation cost. CRM, in line with the PHIMA recommendation, requested to CEDEGE for construction of the tunnel entrance at the Daule-Peripa reservoir with a capacity of 18 m3/s, instead of 12 m^3/s, and CEDEGE constructed the tunnel entrance in 1990 accordingly. CRM also revised the tunnel design from Daule-Peripa to La Esperanza to have a capacity of 18 m^3/s in 1989.

According to the revised design prepared in 1989 by a Brazilian-Ecuadorian Consortium who designed the Water Transbasin Project in 1987, the diversion tunnel has a length of 8.3 km and a semi-circular section of 4.6 m in diameter, with an inlet sill elevation at EL. 66 m and an outlet sill elevation at EL. 58.5 m. The construction cost of the diversion tunnel was also revised to be US$ 37.9 million at a price level of

October 1989, which is about 70% higher than the original estimate because of capacity increase from 12 m^3/s to 18 m^3/s and the time difference of 3 years from 1986 to 1989. Although the tunnel inlet portal was already constructed in the Daule-Peripa reservoir, the JICA Study Team has reviewed the revised design for the diversion tunnel which is a common facility to Alternatives 1, 3, 4 and 5.

3.6 Carrizal-Chone Multipurpose Project

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. In view of increasing energy cost, this level of EL. 72 m has been reviewed under the present JICA study.

This idea of water transbasin from Chone to Portoviejo was adopted by the PHIMA Study and included in Alternatives 1, 2, 3, 5 and 6, because it is difficult to justify a diversion tunnel only to irrigate the Guarango area of about 1,500 ha. The diverted water will most probably be used for uncontaminated water supply to El Ceibal treatment plant at Rocafuerte.

Topographic maps in a scale of 1:10,000 with 6 m contour intervals were prepared covering all the project area, which have been utilized for a study on Alternative 4 under the present JICA Study .

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 decided by the Ecuadorian government with a financial cooperation of Spain, CRM has a strong desire to proceed with the project and is actually seeking for financing for a definite design and construction.

4. HYDROLOGY

4.1 Data Collection and Review

The meteo-hydrological data were collected from CRM and the National Institute of Meteorology and Hydrology (INAMHI). Availability of meteorological data including rainfall data is shown in Table 4.1 for major meteorological stations in the Study area. The isohyetal map in Manabi province is shown in Fig. 4.1 and the meteorological characteristics at Portoviejo are illustrated in Fig. 4.2.

Availability of river runoff data as well as the rainfall data is shown in Table 4.2. Location of these hydrological stations are shown in Fig. 4.3.

4.2 Rainfall

Continuous long-term (1970 - 1990) rainfall data are prepared at each rainfall station based on the observed data and the produced ones from neighboring rainfall station data by a correlation method.

Continuous long-term (19770 - 1990) basin rainfall data are prepared at each point of interest based on the continuous long-term rainfall data at several rainfall stations by means of the Thiessen method.

4.3 Runoff Analysis

Runoff analysis is made for the following points of interest, by means of the Tank Model simulation method based on the continuous long-term basin rainfall data.

- La Esperanza damsite
- Poza Honda damsite
- Chirijos damsite
- Daule-Peripa damsite
- Santa Ana diversion Damsite
- Chico river at the confluence with Portoviejo river
- Portoviejo river at the confluence with Chico river
- Estuary of Portoviejo river
- Carrizal river at the confluence with Chone river
- Chone river at the confluence with Carrizal river

- Estuary of Chone river

The Tank Model structure for the respective point is elaborated giving due attention to the following conditions.

- Annual runoff coefficient
- Hydrograph pattern
- Base flow
- Total annual runoff volume

Results of the runoff analysis are given in Tables 4.3 through 4.13.

4.4 Flood Study

The flood study made in the Master Plan stage (PHIMA Study) is reviewed at the existing two dams (Daule-Peripa dam and Poza Honda dam) and at the proposed two dams (La Esperanza dam and Chirijos dam). The results are summarized as follows.

Return Period	Peak Flood Discharge (m^3/s)			
(years)	La Esperanza	Chirijos	Poza Honda	Daule-Peripa
2.3	52.5	31.9	39.2	243.9
10	271.3	136.1	185.1	952.8
50	479.6	231.0	320.5	1,567.9
100	577.9	275.0	383.8	1,851.6
500	759.4	356.2	499.0	2,366.7

4.5 Sediment Load Analysis

The Sediment load analysis made in the Master Plan stage (PHIMA study) is reviewed and found to be satisfactory. Therefore, the result of the PHIMA study will be followed in this stage as far as the sediment load analysis is concerned. The sediment loads at each damsite estimated in the PHIMA study are shown in Table 4.14.

5. WATER DEMANDS

5.1 Demand for Water Supply

The service area to be covered by the project for potable water supply is defined as the service area which is currently supplied and is to be expanded for coverage in future by the three regional water supply systems, i.e. (i) Poza Honda system, (ii) La Estancilla system, and (iii) Chone system.

It is anticipated that water supply in the Study area will depend on the regional water supply systems for safe and stable water supply since the area is generally dry with little rainfall and no sufficient or reliable water sources are available. At present, some people depend inevitably on unsafe water sources such as rivers, streams, unprotected shallow wells, etc., or on tank lorries which is insufficient in quantity and expensive in cost.

The ultimate target of water supply in the Study area is to supply all the people with public piped water through the regional water supply systems, which will have to be expanded both in capacity and service population.

Water demand includes that for industrial use and for tourism, in addition to that for domestic use. Future water demand is projected by the following procedure.

i) Projection of population with the coverage rate
ii) Projection of tourism population in the service area
iii) Projection of unit water demand in the service area
iv) Water demand forecast in the service area

The population in the service area as well as the coverage rates is projected as follows.

	Service Area Population (1,000 persons)							
Year	Poza Honda		Estancilla		Chone		Total	
1990	503	(80)	123	(70)	71	(70)	697	(77.2)
2000	622	(85)	150	(80)	82	(80)	854	(83.6)
2010	763	(90)	182	(90)	95	(90)	1,040	(90.0)
2020	927	(95)	223	(95)	108	(95)	1,258	(95.0)

Figures in parenthesis are coverage rate in percent.

Tourism population in several resort areas is estimated as follows.

Year	Tourism Population (Persons/day) Crucita	Charapoto	Manta	Bahia	Total
1990	500	1,430	2,670	8,830	13,430
2000	1,190	3,510	6,890	46,010	57,600
2010	1,900	5,690	9,250	57,440	74,280
2020	2,820	8,450	9,250	58,360	78,880

Unit domestic water demand recommended by IEOS in 1991 and the unit industrial water demand which is estimated to be 20% of the unit domestic demand for cities with the population more than 100,000 and to be 10% for cities with the population from 5,000 to 100,000 is given in Table 5.1. These figures are taken as a target to estimate future unit water demand in the service area. The actual level of unit water supply is about 50%-60% of the recommended unit demands of IEOS. This level is estimated to increase in future in the following pace.

Year	1990	2000	2010	2020
Level (%)	55	70	85	100

Projected unit water demands in the service area are given in Table 5.1. Unit water demand for tourism population is estimated based on the domestic unit water demand for cities larger than 100,000 in population.

By means of the above-mentioned procedures, the water demands in the service area are projected as follows, in terms of daily average water demands.

Regional Water Supply System / Year	Water Demand (m^3/day) 1990	2000	2010	2020
Poza Honda System	89,950	155,470	252,730	395,800
Chone System	8,780	17,260	27,510	39,570
La Estancilla System	12,500	30,760	52,180	76,940
Total	111,230	203,480	332,420	512,290
(in m^3/s)	(1.29)	(2.36)	(3.85)	(5.93)
Unit demand* (l/p/d)	161	238	320	407

* Including unaccounted-for water which is around 45% at present.

5.2 Irrigation Water Demand

5.2.1 Existing irrigation systems

There are three irrigation systems in the Study area, i.e. (i) Poza Honda irrigation system, (ii) Chico irrigation system, and (iii) La Estancilla irrigation system.

The Poza Honda irrigation system extends along the Portoviejo river, consisting of 7 sub-systems. The service areas and actually irrigated areas in 1988 of each sub-system are as follows.

Name of Sub-system	Commanding area (ha)	Irrigated area in 1988 (ha)
Santa Ana	2,750	1,170
Lote 5A	200	190
Mejia	830	580
Ceibal	2,700	1,790
La Jagua	1,570	660
El Cerrito	400	350
La Guayaba	300	110
Total	8,750	4,850

The Santa Ana, Lote 5A, Mejia and a part of the Ceibal sub-systems are supplied by the Poza Honda dam throughout the year, but the other part of the Poza Honda system depends on the natural flow of the Portoviejo river. Because of water shortage in 1988, only an area of 4,850 ha was actually irrigated out of the total commanding area of 8,750 ha.

The Chico irrigation system includes 3 sub-systems i.e. La Cienaga, Pechiche and Pasaje, as shown below.

Name of Sub-system	Commanding area (ha)	Irrigated area in 1988 (ha)
Cienaga	300	290
Pechiche	650	610
Pasaje	500	480
Total	1,450	1,380

The Chico system fully depends on the natural flow of the Chico river, which is the major tributary of the Portoviejo river. Irrigation in the dry season is only possible in its early stage (May and June) because the Chico river is almost depleted in the later part of the dry season.

The La Estancilla irrigation system covers 2,150 ha, of which 1,520 ha was actually irrigated in 1988 due to shortage of the natural flow of the Carrizal river, which is the major tributary of the Chone river.

In summary, the Study area is provided with irrigation facilities covering an area of 12,350 ha but the actual irrigated area is limited to about 7,500 ha due to shortage of water resources.

5.2.2 Irrigation development

The present land use of the Study area is summarized as follows.

(Unit : km^2)

	Land Category	Chone	Portoviejo	Total
1)	Agricultural lands			
	- Crop and horticulture	561.9	604.0	1,165.9
	Annual crops	107.3	204.2	311.5
	Perennial crops	454.6	399.8	854.4
	- Pasture	902.6	450.7	1,353.3
	- Complex of crops and pasture	778.5	481.4	1,259.9
	Sub-total	2,243.0	1,536.1	3,779.1
2)	Non-agricultural lands	568.0	523.9	1,091.9
	Total	2,811.0	2,060.0	4,871.0

From the viewpoint of land classification, the land suitable for agriculture amounts 130,000 ha consisting of Category A and B, which are presently fully utilized for cultivation. There is no room for further expansion of the agricultural lands. The agriculture development should, therefore, be directed to intensified farming introducing the irrigated farming. Irrigation development area is delineated in the following manner.

a) Delineation is made on topographic maps of 1:50,000 in scale.

b) Irrigation development area is located downstream of existing and proposed dams.

c) The area is irrigated by a gravity system from dams or diversion dams.

d) The existing irrigation areas are included.

e) The gross area is converted into a net area with a conversion factor of 80% for the category "A", 70% for "B" and 30% for "C" in the land classification.

The irrigation development areas are thus delineated into the following 8 schemes with the total net area of 29,250 ha.

Scheme	River basin	Area (ha)
Carrizal-Chone	Carrizal and Chone	15,000
Amarillos	Carrizal	1,000
Guarango	Portoviejo	1,500
Rio Chico	Chico	1,700
Pechiche-Pasaje	Chico and Portoviejo	850
Santa Ana	Portoviejo	3,300
Mejia	Portoviejo	1,250
Ceibal-Guayaba	Portoviejo	4,650
Total		29,250

5.2.3 Irrigation water requirement

The irrigation water requirement in mm/month is calculated in the following formula.

$$ET\,crop = ET_p * Kc$$
$$IR = ET\,crop + PD - ER$$
$$DWR = IR / E_f$$

where, ET crop : Crop evapotranspiration (mm/month) (Crop consumptive use)

ET_p : Potential evapotranspiration (mm/month)

Kc : Crop coefficient

IR : Net irrigation requirement (mm/month)

PD	:	Water requirement for land preparation of paddy field (mm/month)
ER	:	Effective rainfall (mm/month)
DWR	:	Diversion water requirement (mm/month)
E_f	:	Irrigation efficiency

ET_p is estimated by the modified Penman method based on the meteorological data at Portoviejo, Rocafuerte, Santa Ana, La Estancilla and Calceta. Kc values of annual crops are calculated by Grassi-Christiansen formula and those of citrus, platano and rice are quoted from the feasibility report on the Carrizal-Chone Multiple Project. Water requirement of 120 mm is added for paddy field as PD. ER is related to actual rainfall and ET crop. The SCS method established by USDA is applied to estimate ER, taking rainfall data corresponding to 5-year return period of drought. E_f is taken at 0.53 for paddy and 0.46 for upland crops.

Irrigation water requirements are calculated on monthly basis in accordance with the proposed cropping pattern as shown in Fig. 5.1

The water requirement to irrigate the total development area of 29,250 ha is calculated to be 571 MCM/year with 80% guarantee and peak requirement occurs in September. The water requirement with 50% guarantee (ER calculated by average rainfall instead of 5-year probable drought) is also calculated to be 428 MCM/year. Details are shown in Tables 5.2 and 5.3.

5.3 Water Requirement for Shrimp Farming

The shrimp farming in Manabi province was practiced in 12,074 ha in 1990, accounting for about 8% of the country's total. The shrimp farms are concentrated in the estuary of the Chone river where 4,967 ha is currently operated. In 1989, Manabi produced 7,458 tons of shrimps, corresponding to about 9% of the country's total. The current shrimp production in the Study area is 4,061 tons accounting for 54% of the total shrimp production in Manabi province.

Salinities are influenced by the seasonality of rainfall and runoff. Surface waters in the upstream side of the shrimp ponds have salinities as low as 0 parts per thousand (ppt.) in the rainy season due to heavy rainfall and abundant runoff of the river. In the dry season, on the other hand, surface salinities rise more than 40 ppt. equal to or larger than that of seawater.

Shrimp farming is practiced throughout the year because of the perennial supply or availability of postlarvae from the wild and hatcheries. The average growing period is about three to four months, and it is not difficult to harvest two crops a year. The present productivity ranges from 425 to 900 kg/ha/crop, with the average at 660 kg/ha/crop. Assuming the number of crops a year at 2.5, the average productivity a year is 1,650 kg/ha.

The optimum range of salinity for good growth of shrimps is from 15 to 25 ppt. If proper fresh water supply controls the salinity of water in the shrimp ponds within the optimum range, shrimps will grow faster and the number of crops a year may increase from the present 2.5 to 3.0, in addition to the increase in productivity from the present 660 kg/ha/crop to 830 kg/ha/crop. The annual shrimp production is thus estimated to be 2,905 kg. Fresh water is required only during the dry season when the salinity increases more than 25 ppt.

The shrimp ponds extended in the estuaries of the Chone river and the Portoviejo river are as follows as well as their future probable area expansions.

(ha)

	1984	1987	1990	1995	2000
Chone Estuary					
Zone A (Sea side)			990	990	990
Zone B (River side)	4,120	4,827	3,977	4,157	4,427
Portoviejo Estuary	103	130	130	130	130
Total	4,223	4,957	5,097	5,277	5,547

Based on the current salinity data at the estuaries, annual fresh water requirement in 2000 onward is estimated as follows.

	Gross area (ha)	Net area (ha) (60% of Gross)	Unit water requirement (m^3/ha)	Total water requirement (MCM/year)
Chone river				
Zone A (Sea side)	990	594	39,600	23.5
Zone B (River side)	4,427	2,656	28,600	76.0
Portoviejo river				
Las Gilces	130	78	35,900	2.8
Total	5,547	3,328	30,700	102.3

Seasonal fluctuation of the fresh water requirement is estimated as follows.

(MCM)

Month	Chone Zone A	Chone Zone B	Portoviejo	Total
July	3.9	–	0.4	4.3
August	3.9	–	0.4	4.3
September	4.0	–	0.5	4.5
October	3.9	25.4	0.5	29.8
November	3.9	25.5	0.5	29.9
December	3.9	25.1	0.5	29.5
Annual Total	23.5	76.0	2.8	102.3

5.4 Other Water Demands

Dams in Ecuador are obliged to release a certain volume of water as a river maintenance flow.

In the Study area, the Poza Honda dam must release a constant flow of 0.25 m^3/s throughout the year in addition to the various water requirements. The La Esperanza dam under construction and the Chirijos dam under planning are also needed to release a constant flow of 0.50 m^3/s and 0.25 m^3/s, respectively. This river maintenance flow will amount 23.7 MCM per year without the Chirijos dam and 31.6 MCM per year with the Chirijos dam.

6. ALTERNATIVE TRANSBASIN PLANS

6.1 Topographic Survey and Mapping

All the Study area is covered by topographic maps of 1:50,000 in scale prepared by IGM. CRM prepared detailed topographic maps in relation with its development projects. Detailed maps made available to the Study are as follows:

	Scale and Contour Interval	Coverage	Related project
(1)	1:10,000 6m	Route of Alternative-4	Carrizal-Chone Multipurpose Project
(2)	Various	Route of Alternative-2 (Daule river-La Esperanza) (Daule river-Poza Honda)	Water Transbasin Project from Daule-Peripa to Manabi
(3)	1:10,000 6m	Route of Alternative-4 (Guarango-Rocafuerte-Portoviejo)	Poza Honda Multipurpose Project
(4)	1:250 1m	Inlet site of Daule-Peripa to La Esperanza tunnel (Conguillo site)	Water Transbasin Project from Daule-Peripa to Manabi
(5)	1:100 1m	Outlet site of Daule-Peripa to La Esperanza tunnel (Membrillo site)	Water Transbasin Project from Daule Peripa to Manabi

The following topographic maps are newly prepared for the Study.

	Scale and Contour Interval	Coverage
(1)	1:5,000 5 m	Route of Alternative-1 and 5 (La Esperanza-Poza Honda, Poza Honda-Chico river)
(2)	1:5,000 5 m	Route of Alternative-3 (La Esperanza-Chico river-Portoviejo river)
(3)	1:5,000 5 m	Chirijos dam and reservoir site
(4)	1:1,000 1 m	Severino Pumping Station site for Alternative-1 and 5
(5)	1:1,000 1 m	Altamira Pumping Station site for Alternative-3
(6)	1:1,000 1 m	La Maravilla Pumping Station site for Alternative-4
(7)	1:1,000 1 m	Chirijos damsite

The topographic maps as above mentioned are used for the Study in general and for the preliminary design for 6 alternatives for water transbasin in particular.

6.2 Preliminary Geological Investigations

6.2.1 General geology

Ecuador is divided geologically into 3 major regions, i.e. the Oriente, the Andes range and the Costa. The Oriente is the eastern part of Ecuador, lying in the region of upstream reach of the Amazon and composed of old geological layer of metamorphic and sedimentary rock in Palaeozoic to Mesozoic age.

The Andes range corresponds to the Andes Mountains and huge and high volcanic mountains of Cretaceous, 3,000 m to 6,000 m in elevation, stretch widely. Lithology in this range is Andestic, basaltic and pyroclastic rock. The Costa occupies the costal region of Ecuador where younger geological layer of sedimentary rock of Tertiary (Miocene to Pliocene) makes gentle mountains.

The Study area is situated in the Costa region. Geological basement of this area is Piñón formation, Cretaceous in geological age and basalt in rock type. This layer outcrops at Picoaza town in the western vicinity of Portoviejo city. Major geological layers related to the project is Borbon, Onzole and Tosagua formations in Tertiary.

The Borbon formation consisting of sandstone and mudstone is distributed around the Daule-Peripa dam. The Onzole formation is profoundly related to engineering works of the project, extending over almost all the project area except for a local area of Guarango. The Tosagua formation spreads over the area Guarango to Rocafuerte. This formation is composed of homogeneous calcareous mudstone. Gypsum, anhydrite or other swelling minerals are involved in this formation.

From the view point of geotectonics, gentle anticline structure is supposed. The anticline axis NE to SW in direction is assumed to extend from Portoviejo city toward Daule-Peripa dam. However, since the gradient of anticline is very gentle the dip of bedding actually appears horizontal in outcrops. Small scale faults, 1 km to 2 km in length, are supposed to exist in some places. Regarding the fault system, two directions, NE and SE, are dominant.

As a geomorphological feature, appearance of cliffs are noted in places higher than 200 m in elevation. These cliffs consist of mudstone and these were presumably formed by the difference of erosion between the mudstone and the underlied coarser sandstone.

6.2.2 Seismic refraction survey

During the Phase 1 of the Study, seismic refraction survey was carried out in 49 lines and 40 km long along the routes of Alternatives-1, 3, 4 and 5, and at the Chirijos damsite. The survey results are summarized as follows.

Site	P wave velocity (km/sec)	Depth (m)	Geological Type
Tunnel Alternative 1, 3 & 5	0.3 - 0.5	0 - 3	Top soil
	0.5 - 1.0	3 - 10	Decomposed soil and colluvial.
	1.0 - 1.5	10 - 15	Weathered rock
	2.1 - 2.3	15 -	Fresh rock
Tunnel Guarango	0.3 - 0.5	0 - 3	Top soil
	0.6 - 0.9	3 - 15	Decomposed soil
	0.9 - 1.5	15 - 25	Weathered rock
	2.1 - 2.3	25 -	Fresh rock
Chirijos dam	0.3 - 0.5	0 - 5	Top soil
	0.6 - 1.1	5 - 20	Decomposed soil alluvial, colluvial
	1.1 - 1.5	20 - 30	Weathered rock
	2.1 - 2.3	30 -	Fresh rock

6.2.3 Engineering geology

(1) Diversion Tunnel from Severino to Poza Honda (Alternatives-1 and 5)

The tunnel route is located in the mountainous area of 200 m to 400 m in elevation. Referring to the seismic survey results, rock type in tunnel formation level will be composed of sandy mudstone except for portal portions where rock type is colluvial deposits.

Rock classification and main engineering properties are evaluated as follows.

		Portal position	Inside part of tunnel
Rock type		Colluvial	Sandy mudstone
Rock class		D (soil)	CL (soft rock)
P wave velocity	Vp (km/sec)	1.5	2.1 - 2.3
Unit weight	γ (g/cm^3)	1.7	2.1
Unconfined compressive strength	qu (kgf/cm^2)	10 - 20	60 - 100
Static elastic modulus	Es (kgf/cm^2)	2,000	10,000 - 12,000
Permeability coefficient	K (cm/sec)	$1x10^{-3}$ - $1x10^{-4}$	1×10^{-5}

Sandy mudstone is soft in solidity but massive and rarely cracked. Large scale fractured zone is not found through the tunnel route. Seepage water quantity will not be much during tunnel excavation. Since the rock is soft, steel support is required. Closer arrangement of support will be needed in the portal portion where the rock is colluvial.

(2) Diversion Tunnel from Altamira to Portoviejo River (Alternative-3)

The tunnel route is selected in the mountainous area of 200 m to 400 m in elevation. Geological composition or rock type along the tunnel formation level is divided into two groups; one is colluvial or weathered sandy mudstone in tunnel portal portions and the other is sandy mudstone inside part of the tunnel.

Rock classification and engineering properties are evaluated as follows.

		Portal position	Inside part of tunnel
Rock type		Colluvial Weathered rock	Sandy mudstone
Rock class		D	CL
P wave velocity	Vp (km/sec)	1.5	2.1 - 2.3
Unit weight	γ (g/cm^3)	1.7	2.1
Unconfined compressive strength	qu (kgf/cm^2)	10 - 20	60 - 100
Static elastic modulus	Es (kgf/cm^2)	2,000	10,000 - 12,000
Permeability coefficient	K (cm/sec)	1×10^{-4}	1×10^{-5}

Similar to the geology along the tunnel from Severino to Poza Honda, sandy mudstone shows crackless feature and no large scale fractured zone is expected. Steel support will be required in the sandy mudstone layer. Closer arrangement of support will be needed in the portal portion where the rock is colluvial or weathered sandy mudstone.

(3) Diversion Tunnel from Amarillos to Guarango (Alternative-4)

The tunnel passes a gentle hill of 100 m to 150 m in elevation. In this area, weathering is so heavy and deep that no outcrops of rock are found. Rock type is calcareous mudstone according to the boring result carried out for the study on the Carrizal-Chone multipurpose project. This rock belongs to the Tosagua formation. Clay minerals of gypsum, anhydrite and montmorillonite, which are subject to swelling when stress is released, are included in the rock. Laboratory rock tests carried out this time indicate that the rate of content of these swelling minerals is about 1% in the weathered zone while it is negligible in the fresh mudstone zone.

Referring to the seismic survey, rock type along the tunnel formation level are divided into three groups; (i) weathered mudstone with considerable swelling minerals assumed in portal positions, (ii) slightly weathered mudstone with few swelling minerals expected in Amarillos side of the tunnel, and (iii) fresh mudstone extending inner part of the tunnel.

Rock classification and engineering properties are evaluated as follows.

Rock type	(1) Weathered mudstone with swell minerals	(2) Mudstone slightly weathered with few swell minerals	(3) Fresh mudstone
Rock class	E (soil)	D (very soft)	CL (soft)
Vp (km/sec)	0.9 - 1.5	1.5	2.1 - 2.5
γ (g/cm^3)	1.6	1.7	2.1
qu (kgf/cm^2)	10	30	60
Es (kgf/cm^2)	1,000 - 2,000	5,000	10,000 - 12,000
K (cm/sec)	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-5}$

Tunnel construction through the weathered mudstone with swelling minerals will be difficult and costly, and a careful supporting system will be needed. Geological problems will also take place even in the fresh mudstone zone if swell minerals are found by further rock tests.

(4) Diversion Tunnel from Poza Honda to Mancha Grande (Alternative-5 and 6)

Geological condition of this tunnel route is nearly the same as the tunnel from Altamira to Portoviejo river. Rock classification and engineering properties are evaluated as follows.

Rock type	Sandy mudstone	Colluvial
Rock class	CL	D
Vp (km/sec)	2.1 - 2.3	1.5
γ (g/cm^3)	2.1	1.7
qu (kgf/cm^2)	60 - 100	10-20
Es (kgf/cm^2)	10,000 - 12,000	2,000
K (cm/sec)	$1 x 10^{-5}$	$1 x 10^{-4}$

The tunnel can be excavated with ordinary steel support in the inside part (sandy mudstone layer), but in the portal positions (colluvial layer) closer arrangement of support will be required. Judging from deep groundwater table and low permeability of rock, seepage water quantity during tunnel excavation will be small.

(5) Diversion Tunnel from Daule-Peripa to La Esperanza (For all Alternatives)

Geological investigation along this tunnel route were carried out for the study on the Water Transbasin project from Daule-Peripa to Manabi. Rock types along the tunnel formation level is fine sandstone and mudstone. The rock is classified into medium to good rock from the viewpoint of R.Q.D and grade IV-III on the basis of Beniawski's rock classification and into the rock of CL to CM in Japanese criteria for rock classification. Engineering properties are estimated as follows:

Unit weight	γ = 2.1 g/cm^3
Unconfined compressive strength	qu = 60 - 100 kg/cm^2
Static elastic modulus	Es = 10,000 - 12,000 kg/cm^2
Permeability coefficient	K = 1 x 10^{-4} - 1x10^{-5} cm/sec

Existing boring cores and rock outcrops in the field suggest that the rock is massive and crackless without serious fractured zones.

Judging from the solidity of rock, steel support will be required for tunnel construction. The tunnel is expected to pass mostly the fresh rock layer, but in the portal position of the tunnel, rock is weathered and loosened (D class in classification) where closer arrangement of support will be needed.

(6) Diversion Tunnel from Daule River to Poza Honda (Alternative-2 and 6)

Geological investigations along this tunnel route were also executed for the study on the Water Transbasin project from Daule-Peripa to Manabi.

The tunnel passes the very fine sandstone and sandy mudstone of the Onzole formation. This rock is classified into CL to CM in solidity and its engineering properties are nearly the same as those in the tunnel route from Daule-Peripa to La Esperanza.

Large scale fractured zones are not expected. Seepage water quantity during tunnel construction will be small. Steel support will, however, be required because the rock is soft in solidity.

(7) Chirijos Damsite

Riverbed portion is wide at the damsite. Slopes of both banks are about 30 degrees. Base rock is mudstone which is thickly covered with decomposed soil in both abutments (about 20 m thick) and alluvial soil in the riverbed (15 to 20 m thick). The surface of the mudstone is weathered with the thickness of 10 to 20 m. Therefore, fresh rock lies 30 to 40 m deep from the ground surface. Rock classification and engineering properties of each layer are evaluated as follows.

Engineering properties		Alluvial and decomposed soil	Weathered mudstone	Fresh mudstone
Rock class		-	D	CL
Unit weight	γ (g/cm^3)	1.6	1.7	2.1
Cohesion	C (kgf/cm^2)	0.1	1.0	5.0
Internal frictional angle	ϕ (degree)	15	30	30
Unconfined compressive strength	qu (kgf/cm^2)	1.0	10	60 - 100
Static elastic modulus	Es (kgf/cm^2)	200	2,000	12,000
Permeability coefficient	K (cm/sec)	1×10^{-3}	1×10^{-4}	1×10^{-5}

Judging from the strength of fresh mudstone, only fill-type dam is technically feasible. The bearing capacity of the weathered mudstone is sufficient as the dam foundation, but water tightness is not enough. Since ordinary grouting is not effective in the weathered mudstone, cut-off wall with core material, cement-bentonite slurry or concrete reaching the fresh mudstone or blanket method to the upstream side of the core will have to be considered.

The rock especially in the left abutment is not resistive enough against slope sliding. Excavated slops for spillway construction should be properly protected.

As for the dam construction materials, mudstone near the damsite is suitable for impervious core material as well as for random material. Rock and sand material is not available near the damsite. Rock material will have to be supplied from Picoaza quarry about 40 km far from the damsite. Filter material as well as concrete aggregates should be produced by crushing the Picoaza rock.

(8) Pumping Station Sites

There are four pumping station sites investigated under the Study, (i) Severino pumping station for Alternatives-1 and 5, (ii) Altamira pumping station for Alternative-3, (iii) Las Maravillas pumping station for Alternative-4, and (iv) Daule pumping station for Alternatives-2 and 6.

Geological compositions in the Severino site consist of (i) decomposed soil layer of about 5 m deep from the ground surface, (ii) weathered sandy mudstone of 5 to 15 m deep under the decomposed soil layer, and (iii) fresh sandy mudstone under the weathered sandy mudstone. The weathered sandy mudstone is considered to be firm enough for the foundation of the pumping station.

At the Altamira site, weathering is wide and deep. Geological compositions are similar to those of the Severino site and evaluated as follows as well as the engineering properties.

Geological compositon	Depth	P wave velocity	Rock class
Decomposed soil (Slightly clay)	0 - 15 m	0.3 - 0.8 km/sec	-
Weathered rock (Mudstone)	15 - 30 m	1.1 - 1.5 km/sec	D
Fresh rock (Mudstone)	30 m below	2.1 - 2.3 km/sec	CL

Engineering properties		Decomposed soil	Weathered mudstone	Fresh mudstone
Unit weight	γ (g/cm³)	1.6	1.7	2.1
Cohesion	C (kgf/cm²)	0.1	1.0	5.0
Internal frictional angle	ϕ (degree)	15	25	30
Unconfined compressive strength	qu (kgf/cm²)	1.0	10.0	60
Static elastic modulus	Es (kgf/cm²)	200	2,000	12,000

The Altamira pumping station will be founded on the decomposed soil layer. Some foundation treatments may be needed subject to further investigation on the bearing capacity of the layer.

Geological conditions at the Las Maravillas site are nearly equal to those of the Altamira site, and those at the Daule site are almost the same as those of the Severino.

(9) Open Channel (For all Alternatives)

Some technical remarks from engineering geologies related to open channel construction are summarized below according to the geomorphological conditions; alluvial area and mountain side colluvial area.

In the alluvial area, open channels are constructed on the alluvial soil layer, which is assumed to consist of silty clay. Since the surface is loose, settlement may take place in some places, and compaction of the foundation or replacement with good soils may be required after channel excavation.

In the mountain side colluvial area, on the other hand, open channels are constructed on the colluvial soil, decomposed soil or weathered rock layer. Slope stability will be a major problem when the open channel is constructed in colluvial soil or decomposed soil. At places where the channel crosses small rivers, protection work against debris flows should be considered.

6.3 Reservoir Operation Study

6.3.1 Diversion from Daule to Manabi

The Daule-Peripa reservoir is planned to be operated to meet the demands for power (minimum water level for power generation, EL. 65 m), domestic water, irrigation including dilution water of irrigation return flow, transbasin to La Esperanza (minimum level for transbasin, EL. 66.6 m) and transbasin to the Santa Elena Peninsula. The design water levels of the Daule-Peripa reservoir are summarized as follows.

Normal High Water Level	EL. 85 m
Low Water Level	EL. 60 m
Flood Water Level	EL. 88 m

At the request of the JICA Study Team, CEDEGE conducted a reservoir operation study, generating synthetic flows as inflows to the reservoir, for 30 series of 30 years each.

According to the proposed tunnel design from the Daule-Peripa reservoir to the La Esperanza reservoir with a tunnel diameter of 4.6 m, a divertable discharge is dependent on the Daule-Peripa reservoir water level. The transbasin discharge is 0 m^3/s for a reservoir level lower than EL. 66.6 m and more than 18 m^3/s for a reservoir level high than EL. 74.5 m. The interinstitutional agreement between CEDEGE and CRM limits the water transbasin up to 18 m^3/s and 500 MCM/year.

The reservoir operation study by CEDEGE indicated that the transbasin to La Esperanza in a volume of 500 MCM/year is secured at about 90% guarantee as shown below.

Level of guarantee (%)	Divertable water volume (MCM/year) $Q_{max} = 18\ m^3/s$
Maximum volume	568
50	568
80	537
89	495
Minimum volume	136

It is understood that water of 537 MCM/year can be diverted to La Esperanza at 80% guarantee (4 years assured out of 5 years). Technically divertable water (Qmax = 18 m^3/s) and adjusted diversion to limit an annual volume to 500 MCM for each month are as follows.

Water Diversion from Daule-Peripa to La Esperanza.

Month	Volume to be diverted technically (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/Average	537.4	500.0	15.8

The adjustment is made by reducing the diversion water volume to La Esperanza in three months from January to March when rainfalls are maximum and water demands are minimum. The adjusted volumes for each month are applied to the reservoir operation study of La Esperanza as the maximum divertable water from Daule-Peripa to La Esperanza.

6.3.2 Integrated reservoir operation of La Esperanza and Poza Honda for Alternative-1

La Esperanza receives natural flows from its own basin and diverted flows from Daule-Peripa. Aiming at the maximum use of the natural flow, water diversion is suspended when the La Esperanza water level is higher than EL. 62 m, and the maximum water diversion is made when it is lower than EL. 62 m. La Esperanza should meet water demands for shrimp farming (99 MCM/year) in the Chone estuary, river maintenance (16 MCM/year), water supply (45 MCM/year for Chone-La Estancilla water supply system and 61 MCM/year for El Ceibal treatment plant) and irrigation (171 MCM for Carrizal-Chone system, 44 MCM for Los Amarillos and Guarango systems, 19 MCM for a part of Ceibal-Guayaba system).

La Esperanza should also divert water to Poza Honda. Poza Honda receives natural flows from its own basin and diverted flow from La Esperanza. Aiming at the maximum use of the natural flow, water diversion from La Esperanza to Poza Honda is suspended when the Poza Honda water level is higher than EL. 102.5 m, and the full capacity water diversion is made when it is lower than EL. 102.5 m. Poza Honda should meet water demands for water supply (91 MCM/year of Poza Honda water supply except the El Ceibal treatment plant), irrigation (60 MCM/year for Santa Ana system, 14 MCM/year for Pachiche-Pasaje system, 23 MCM/year for Mejia system, and 74 MCM/year for remaining part of Ceibal-Guayaba system), shrimp farm (3 MCM/year in the Portoviejo estuary), and river maintenance (8 MCM/year).

The results of the reservoir operation study are shown in Fig. 6.1 and summarized as follows.

La Esperanza	
Max. water level	EL. 66.0 m
Min. water level	EL. 37.0 m
Average water level	EL. 57.2 m
Average spillout	29 MCM/year
Poza Honda	
Max. water level	EL108.5 m
Min. water level	EL. 93.0 m
Average water level	EL104.4 m
Average spillout	5 MCM/year

Diversion Tunnels	Daule-Peripa to La Esperanza	La Esperanza to Poza Honda	Amarillos to Guarango
Capacity (m^3/s)	18	9	5
Diversion volume (MCM/year)			
Average year	353	175	110
Dry year	485	208	110

6.3.3 Reservoir operation of La Esperanza and Poza Honda for Alternative-2

Poza Honda in case of Alternative-2 receives diverted water from the Daule river instead of La Esperanza. Water demands to be met by Poza Honda are the same as those for Alternative-1. The reservoir operation is exactly the same as for Alternative-1. Therefore, the diversion capacity is 9 m^3/s as in case of Alternative-1.

La Esperanza receives diverted water from Daule-Peripa with the diversion capacity of 9 m^3/s (max diversion allowed from Daule: 18 m^3/s - diversion capacity from Daule to Poza Honda: 9 m^3/s = 9 m^3/s). Water demands to be met by La Esperanza are also the same as those for Alternative-1. The reservoir operation of La Esperanza will be almost the same as that for Alternative-1 because the fluctuation pattern of both La Esperanza and Poza Honda is similar.

The results of water balance study for Alternative-2 are shown in Fig. 6.2 and summarized as follows.

Reservoir operation of La Esperanza and Poza Honda
Same as for Alternative-1

Diversion Tunnels	Daule-Peripa to La Esperanza	Daule river to Poza Honda	Amarillos to Guarango
Capacity (m^3/s)	9	9	5
Diversion volume (MCM/year)			
Average year	178	175	110
Dry year	277	208	110

6.3.4 Integrated reservoir operation of La Esperanza and Poza Honda for Alternative-3

La Esperanza receives diverted flow from Daule-Peripa in its full allowable flow (Q_{max} = 18 m^3/s) when the water level of La Esperanza is lower than EL. 64 m, higher water level than that for Alternative-1 by 2 m to divert more water from Daule-Peripa in order to cover additional irrigation water demand for Chico system (23 MCM/year).

Poza Honda does not receive diverted flow. When the Poza Honda water level is higher than EL. 105.0 m, priority is given to the use of Poza Honda water, and when it is lower than EL. 105.0 m, priority is given to the use of diverted flow from La Esperanza.

The results of water balance study for Alternative-3 are shown in Fig. 6.3 and summarized as follows.

La Esperanza	
Max. water level	EL. 66.0 m
min. water level	EL. 37.0 m
Average water level	EL. 55.1 m
Average spillout	39 MCM/year
Poza Honda	
Max. water level	EL. 108.5 m
Min. water level	EL. 90.25 m
Average water level	EL. 105.0 m
Average spillout	21 MCM/year

Diversion Tunnels	Daule-Peripa to La Esperanza	La Esperanza to Chico River	Chico River to Portoviejo
Capacity (m^3/s)	18	12	6
Diversion volume (MCM/year)			
Average year	402	214	77
Dry year	500	231	94

Characteristic of the Amarillos-Guarango diversion tunnel is common to Alternative-1.

6.3.5 Reservoir operation of La Esperanza and Poza Honda for Alternative-4

La Esperanza should meet water demands for water supply (62 MCM/year), irrigation (111 MCM/year) and shrimp farm (3 MCM/year) in addition to the water demands to be covered by La Esperanza for Alternative-1. Poza Honda as well as the Portoviejo river in its upstream reach does not receive any diverted flow. Poza Honda with its own basin flow cannot meet the water demands for water supply (29 MCM for Guarumo and Caza Lagartos treatment plants), irrigation (60 MCM for Santa Ana system) and river maintenance (8 MCM/year) at an acceptable level of guarantee (80%).

The results of water balance study for Alternative-4 are shown in Fig. 6.4 and summarized as follows.

Diversion Tunnels	Daule-Peripa to La Esperanza	Amarillos to Guarango
Capacity (m^3/s)	18	15
Diversion volume (MCM/year)		
Average year	354	286
Dry year	453	286

6.3.6 Integrated reservoir operation of La Esperanza and Poza Honda for *Alternative-5*

Alternative-5 is one of the variations of Alternative-1, to divert irrigation water to Chico system from Poza Honda instead of Chirijos dam construction. Therefore, more water should be diverted from La Esperanza to Poza Honda than in case of Alternative-1. Water diversion from Daule-Peripa is made when the La Esperanza water level is lower than EL. 64 m as in case of Alternative-3.

The results of water balance study for Alternative-5 are shown in Fig. 6.5 and summarized as follows.

La Esperanza	
Max. water level	EL. 66.0 m
min. water level	EL. 37.0 m
Average water level	EL. 54.7 m
Average spillout	45 MCM/year
Poza Honda	
Max. water level	EL. 108.5 m
Min. water level	EL. 90.25 m
Average water level	EL. 106.7 m
Average spillout	6 MCM/year

Diversion Tunnels	Daule-Peripa to La Esperanza	La Esperanza to Poza Honda	Poza Honda to Chico River
Capacity (m^3/s)	18	10	4
Diversion volume (MCM/year)			
Average year	393	199	23
Dry year	500	231	23

The diversion from Amarillos to Guarango is common to Alterntive-1.

6.3.7 Reservoir operation of La Esperanza and Poza Honda for Alternative-6

Alternative-6 is one of the variations of Alternative-2, to divert irrigation water to Chico system from Poza Honda instead of Chirijos dam construction. Reservoir operation of La Esperanza is exactly the same as for Alternative-2. That of Poza Honda is also exactly the same as for Alternative-5. The results of water balance study for Alternative-6 are shown in Fig 6.6.

6.4 Preliminary Designs for Transbasin Facilities

6.4.1 Daule-Peripa to La Esperanza transbasin scheme

(1) Capacity: 18 m^3/s

Access roads	
Mountainous area	11 km
Hilly area	14 km
Diversion tunnel	
Length	8.3 km
Diameter	3.7 m

(2) Capacity: 9 m^3/s

Access roads	
Mountainous area	11 km
Hilly area	14 km
Diversion tunnel	
Length	8.3 km
Diameter	2.7 m

6.4.2 Daule river to Poza Honda transbasin scheme

(1) Capacity: 9 m^3/s

Access roads	
Mountainous area	12 km
Hilly area	5 km
Diversion tunnel	
Length	11.2 km
Diversion	2.7 m
Pipeline	
Length	13.3 km
Diameter	1,500 mm
Number of Lane	2

(2) Capacity: 10 m^3/s

Access roads	
Mountainous area	12 km
Hilly area	5 km
Diversion tunnel	
Length	11.2 km
Diameter	2.9 m
Pipeline	
Length	13.3 km
Diameter	1,600 mm
Number of Lane	2

6.4.3 La Esperanza to Poza Honda transbasin scheme

(1) Capacity: 9 m^3/s

Access roads	
Mountainous area	4 km
Hilly area	3 km
Open channel	
Length	6.9 km
Diversion tunnel	
Length	10.7 km
Diameter	2.7 m

(2) Capacity: 10 m^3/s

Access roads	
Mountainous area	4 km
Hilly area	3 km
Open channel	
Length	6.9 km
Diversion tunnel	
Length	10.7 km
Diameter	2.9 m

6.4.4 La Esperanza to Portoviejo river transbasin scheme

(1) La Esperanza to Chico river, Capacity: 12 m^3/s

Access roads	
Hilly area	3 km
Open channel	
Length	6.5 km

Syphon	
Length	1.4 km
Diameter	2.9 m
Diversion tunnel	
Length	13.0 km
Diameter	3.1 m

(2) Chico river to Portoviejo river, Capacity: 6 m^3/s

Open channel	
Length	2.4 km
Syphon	
Length	0.7 km
Diameter	2.4 m
Diversion tunnel	
Length	8.0 km
Diameter	2.5 m

6.4.5 Poza Honda to Chico river transbasin scheme

Capacity: 4 m^3/s

Diversion tunnel	
Length	4.1 km
Diameter	2.5 m

6.4.6 La Esperanza to Guarango transbasin scheme

(1) Transbasin capacity: 5 m^3/s

Open channel	
Capacity	23 m^3/s - 5 m^3/s
Length	40.3 km
Diversion tunnel	
Length	6.6 km
Diameter	2.5 m
Syphon	
Capacity	13 m^3/s - 5.5 m^3/s
Length	4.5 km

(2) Transbasin capacity: 15m^3/s

Open channel	
Capacity	33 m^3/s - 3.3 m^3/s
Length	62.7 km
Diversion tunnel	
Length	6.6 km
Diameter	3.4 m

Syphon	
Capacity	23 m^3/s - 3.3 m^3/s
Length	10.5 km

6.4.7 Chirijos dam

Hydrology	
Catchment area	80 km^2
Annual Mean rainfall	1,220 mm
Annual Mean inflow	41 MCM (520 mm)
Runoff coefficient	0.43
Probable flood (1/10,000)	560 m^3/s
Reservoir	
Gross storage capacity	46 MCM
Dead storage	10 MCM
Effective storage	36 MCM
Flood water level	EL. 101.0 m
Normal high water level	EL. 98.0 m
Low water level	EL. 78.0 m
Riverbed elevation	EL. 68.0 m
Reservoir area at HWL	3.8 km^2
Dam	
Type	Zoned earthfill
Height from foundation	60 m
Crest elevation	EL. 103.0 m
Crest length	517 m
Spillway	
Type, Control structure	Non-gated overflow weir
Water conveyance	Open chuteway
Energy dissipator	Stilling basin
Length of overflow weir	35 m
Overflow weir level	EL. 98.0 m
Outflow peak discharge	360 m^3/s (1.2 times of 200-Yr flood)
Intake and Outlet m	
Intake level	EL. 78.0 m
Outlet capacity	2 m^3/s

6.5 Construction Cost Estimates of Transbasin Facilities

6.5.1 Daule-Peripa to La Esperanza transbasin scheme

Work Item	Quantity	Unit price (US$)	Amount (1,000 US$)
(1) Capacity: 18 m^3/s			
Preparatory works			3,730
Access roads			10,800
Mountainous area	11 km	600,000	6,600
Hilly area	14 km	300,000	4,200
Tunnel(D=3.7 m, L=8.3 km)			26,500
Excavation, tunnel	132,000 m^3	100	13,200
Concrete	43,000 m^3	230	9,890
Inlet and outlet works		LS	1,000
Others (10%)			2,410
Total			41,030
(2) Capacity: 9 m^3/s			
Preparatory works			2,510
Access roads			10,800
Mountainous area	11 km	600,000	6,600
Hilly area	14 km	300,000	4,200
Tunnel(D=2.7 m, L=8.3 km)			14,310
Excavation, tunnel	71,000 m^3	100	7,100
Concrete	23,500 m^3	230	5,410
Inlet and outlet works		LS	500
Others (10%)			1,300
Total			27,620

6.5.2 Daule river to Poza Honda transbasin scheme

Work Item	Quantity	Unit price (US$)	Amount (1,000 US$)
(1) Capacity: 9 m^3/s			
Preparatory works			7,350
Access roads			8,700
Mountainous area	12 km	600,000	7,200
Hilly area	5 km	300,000	1,500
Pipeline (D=1,500 mm)			27,800
2 lanes	13.3 km	1,900,000	25,270
Others (10%)			2,530
Tunnel(D=2.7 m, L=11.2 km)			19,110
Excavation, tunnel	95,800 m^3	100	9,580
Concrete	31,700 m^3	230	7,290
Inlet and outlet works			500
Others (10%)			1,740
Surge tank (2 sites)			1,940
Pumping station and substation			13,200
Power transmission line			2,700
Total			80,800
(2) Capacity: 10m^3/s			
Preparatory works			8,130
Access roads			8,700
Pipeline			32,190
2 lanes, D=1,600 mm	13.3 km	2,200,000	29,260
Others (10%)			2,930
Tunnel(D=2.9m, L=11.2 km)			21,190
Excavation, tunnel	107,800 m^3	100	10,780
Concrete	33,820 m^3	230	7,780
Inlet and outlet works		LS	700
Others (10%)			1,930
Surge tank (2 sites)		LS	1,940
Pumping station and substation		LS	14,600
Power transmission line		LS	2,700
Total			89,450

6.5.3 La Esperanza to Poza Honda transbasin scheme

Work Item	Quantity	Unit price (US$)	Amount (1,000 US$)
(1) Capacity: 9 m^3/s			
Preparatory works			4,060
Access roads			3,300
Mountainous area	4 km	600,000	2,400
Hilly area	3 km	300,000	900
Steel pipe			770
2 lanes, D= 1,800 mm	250 m	2,800	700
Others (10%)			70
Open channel (L=6.9 km)			1,660
Excavation	120,000 m^3	2.0	240
Embankment	120,000 m^3	4.0	480
Concrete lining	6,000 m^3	110.0	660
Others (20%)			280
Syphon			1,200
Concrete pipe (D=2,600 mm)	640 m	1,700	1,090
Others (10%)			110
Tunnel(D=2.7 m, L=10.7 km)			20,280
Excavation, tunnel	91,500 m^3	100	9,150
Concrete	30,300 m^3	230	6,970
Inlet and outlet works		LS	500
Steel support	1,820 t	1,000	1,820
Others (10%)			1,840
Pumping station and substation		LS	10,200
Power transmission line		LS	3,200
Total			44,690

(2) Capacity: $10m^3/s$

Preparatory works			4,410
Access roads			3,300
Steel pipe			830
2 lanes, D=1,900 mm	250 m	3,000	750
Others (10%)			80
Open channel (L=6.9 km)			1,760
Excavation	126,000 m^3	2.0	250
Embankment	126,000 m^3	4.0	700
Concrete lining	6,500 m^3	110.0	720
Others (20%)			290
Syphon			1,270
Concrete pipe (D=2,700 mm)	640 m	1,800	1,150
Others (10%)			120
Tunnel(D=2.9m, L=10.7 km)			22,420
Excavation, tunnel	103,000 m^3	100	10,300
Concrete	32,310 m^3	230	7,430
Steel support	1,950 t	1,000	1,950
Inlet and outlet water			700
Others (10%)			2,040
Pumping station and substation			11,300
Power transmission line			3,200
Total			48,490

6.5.4 La Esperanza to Portoviejo river transbasin scheme

Work Item	Quantity	Unit price (US$)	Amount (1,000 US$)
Preparatory works			6,590
Access roads, Hilly area	3 km	300,000	900
Steel pipe			850
2 lanes, D=2,000 mm	220 m	3,500	770
Others (10%)			80
Open channel (L=6.52 km, Q=12m^3/s; L=2.37 km, Q=6 m^3/s)			2,600
Excavation	168,000 m^3	2.0	340
Embankment	232,000 m^3	4.0	930
Concrete lining	8,200 m^3	110.0	900
Others (20%)			430
Concrete pipe for syphon			4,100
D=2,900 mm	1,360 m	2,000	2,720
D=2,100 mm)	670 m	1,500	1,010
Others (10%)			370
Tunnel (D=3.1m, L=13.0 km)			27,980
Excavation, tunnel	140,000 m^3	100	14,000
Concrete	41,900 m^3	230	9,640
Steel support	2,530 t	1,000	2,530
Inlet and outlet works			900
Others (10%)			2,710
Tunnel (D=2.5m, L=8.0 km)			13,920
Excavation, tunnel	60,400 m^3	100	6,040
Concrete	21,100 m^3	230	4,850
Steel support	1,260 t	1,000	1,260
Inlet and outlet works			500
Others (10%)			1,270
Pumping station and substation			10,000
Power transmission line			3,700
Total			72,400

6.5.5 Poza Honda to Chico river transbasin scheme

Work Item	Quantity	Unit price (US$)	Amount (1,000 US$)
Capacity: 4 m^3/s			
Preparatory works			730
Tunnel (D=2.5 m, L=4.05 km)			7,330
Excavation	30,600 m^3	100	3,060
Concrete	10,700 m^3	230	2,460
Steel support	640 t	1,000	640
Inlet and outlet works			500
Others (10%)			670
Total			8,060

6.5.6 La Esperanza to Guarango transbasin scheme

Work Item	Quantity	Unit price (US$)	Amount (1,000 US$)
(1) Capacity: 5 m^3/s			
Preparatory works			4,950
Open channel			
Capacity 23 m^3/s- 5 m^3/s	40.4 km	300	12,120
Regulating pond		LS	20
Diversion tunnel (D=2.5 m, L=6.6 km)			19,510
Excavation, tunnel	63,500 m^3	130	8,260
Concrete	31,100 m^3	230	7,150
Steel support	1,330 t	1,000	1,330
Inlet and outlet works		LS	1,000
Others (10%)			1,770
Pipeline			
D=1,400 mm, 2 lanes	300 m	2,800	840
Syphon			
Capacity (13.0 m^3/s - 5.5 m^3/s)	4,520 m		4,140
Pumping station and substation			4,700
Power transmission line			8,200
Total			54,480

(2) Capacity: 15 m^3/s

Preparatory works			8,210
Open channel Capacity: ($33\ m^3/s$- $3.3\ m^3/s$)	62.5 km	330	20,620
Regulation pond		LS	20
Diversion tunnel (D=3.4 m, L=6.6 km)			28,170
Excavation, tunnel	100,400 m^3	130	13,050
Concrete	40,500 m^3	230	9,320
Steel support	1,740 t	1,000	1,740
Inlet and outlet works		LS	1,500
Others (10%)			2,560
Pipeline D=2,100 mm, 2 lanes	300 m	4,000	1,200
Syphon Capacity: ($23\ m^3/s$- $3.3\ m^3/s$)	10.47 km		11,440
Culvert Capacity 3.3 m^3/s	200 m	540	110
Open channel and syphon to Rocafuerte treatment plant			2,060
Pumping station and substation		LS	7,500
Power transmission line		LS	11,000
Total			90,330

6.5.7 Chirijos dam

Work Item	Quantity	Unit Price (US$)	Amount (1,000 US$)
Preparatory Works			4,097,700
Diversion Tunnel			5,291,200
Excavation, open	34,000 m^3	2.0	68,000
Excavation, tunnel	24,900 m^3	100.0	2,490,000
Concrete, structure	2,900 m^3	150.0	435,000
Concrete, tunnel	8,700 m^3	180.0	1,566,000
Steel support	250 ton	1,000.0	251,200
Others (10%)			481,000
Cofferdam			4,448,400
Excavation, common	770,000 m^3	2.0	1,540,000
Embankment, core	76,000 m^3	4.0	304,000
Embankment, random	108,000 m^3	4.0	432,000
Embankment, riprap	136,000 m^3	13.0	1,768,000
Others (10%)			404,400
Main Dam			27,209,600
Excavation	1,060,000 m^3	2.0	2,120,000
Embankment, core	1,219,000 m^3	4.0	4,876,000
Embankment, filter	54,000 m^3	15.0	810,000
Embankment, random	1,600,000 m^3	4.0	6,400,000
Embankment, riprap	810,000 m^3	13.0	10,530,000
Others (10%)			2,473,600
Spillway			4,027,700
Excavation, common	253,000 m^3	2.0	506,000
Excavation, weathered rock	163,000 m^3	3.5	570,500
Excavation, hard rock	19,000 m^3	5.0	95,000
Concrete	16,600 m^3	150.0	2,490,000
Others (10%)			366,200
Total			45,074,600

6.6 Operation and Maintenance Cost

6.6.1 Pumping energy cost

(1) Severino Pumping Station

Q = 9 m^3/s, Hmax = 73.5 m, Have = 55 m
Pave = 16 Q Have = 7,920 kW
Operation factor = 175/(31.55 x 9) = 0.62 (Alt.-1)
Eave = Pave x 365 x 24 x 0.62 = 43.0 GWh
Power cost = 43.0 x US$0.06/kWh = US$2.58 million

Q = 10 m^3/s, Hmax = 73.5 m, Have = 58 m
Pave = 16 Q Have = 9,280 kW
Operation factor = 198/(31.55 x 10) = 0.63 (Alt.-5)
Eave = Pave x 365 x 24 x 0.63 = 51.2 GWh
Power cost = 51.2 x US$0.06/kWh = US$3.07 million

(2) Altamira Pumping Station

Q = 12 m^3/s, Hmax = 56 m, Have = 40 m
Pave = 16 Q Have = 7,680 kW
Operation factor = 214/(31.55 x 12) = 0.57 (Alt.-3)
Eave = Pave x 365 x 24 x 0.57 = 38.3 GWh
Power cost = 38.3 x US$0.06/kWh = US$2.30 million

(3) Daule Pumping Station

Q = 9 m^3/s, Hmax = 107.5 m, Have = 107.5 m
Pave = 16 Q Have = 15,480 kW
Operation factor = 175/(31.55 x 9) = 0.62 (Alt.-2)
Eave = Pave x 365 x 24 x 0.62 = 84.1 GWh
Power cost = 84.1 x US$0.06/kWh = US$5.05 million

$Q = 10\ m^3/s$, Hmax = 107.5 m, Have = 107.5 m

Pave = 16 Q Have = 17,200 kW

Operation factor = 198/(31.55 x 10) = 0.63 (Alt.-6)

Eave = Pave x 365 x 24 x 0.70 = 94.9 GWh

Power cost = 94.9 x US$0.06/kWh = US$5.69 million

(4) La Maravilla Pumping Station

$Q = 5\ m^3/s$, Hmax = 42 m, Have = 42 m

Pave = 16 Q Have = 3,360 kW

Operation factor = 110/(31.55 x 5) = 0.70 (Alt.-1, 2, 3, 5, 6)

Eave = Pave x 365 x 24 x 0.70 = 20.6 GWh

Power cost = 20.6 x US$0.60/kWh = US$1.24 million

$Q = 15\ m^3/s$, Hmax = 42 m, Have = 42 m

Pave = 16 Q Have = 10,080 kW

Operation factor = 286/(31.55 x 15) = 0.60 (Alt.-4)

Eave = Pave x 365 x 24 x 0.60 = 53.0 GWh

Power cost = 53.0 x US$0.06/kWh = US$3.18 million

6.6.2 Operation and maintenance cost

Open channel	1% of direct construction cost
Pumping station	2% of direct construction cost
Tunnel	0.1% of direct construction cost
Access road	0.5% of direct construction cost
Pipeline & syphon	0.2% of direct construction cost
Other facilities	0.5% of direct construction cost

Transbasin scheme		Annual O&M Cost (1,000 US$)
Daule-Peripa to La Esperanza		
$Q = 18\ m^3/s$	(Alt.-1, 3, 4, 5)	81
$Q = 9\ m^3/s$	(Alt.-2, 6)	68
Daule River to Poza Honda		
$Q = 9\ m^3/s$	(Alt.-2)	405
$Q = 10\ m^3/s$	(Alt.-6)	444
La Esperanza to Poza Honda		
$Q = 9\ m^3/s$	(Alt.-1)	277
$Q = 10\ m^3/s$	(Alt.-5)	302
La Esperanza to Portoviejo River		
$Q = 12\ m^3/s$ $Q = 6\ m^3/s$	(Alt.-3)	301
Poza Honda to Chico River		
$Q = 4\ m^3/s$	(Alt.-5, 6)	7
La Esperanza to Guarango		
$Q = 5\ m^3/s$	(Alt.-1, 2, 3, 5, 6)	271
$Q = 15\ m^3/s$	(Alt.-4)	456

6.7 Summary of Cost for Each Alternative

Cost summary is shown in Table 6.1.

7. ENVIRONMENTAL CONSIDERATION

7.1 Methodology

Initial Environmental Examination (IEE) is considered to be an appropriate method to check each alternatives for water transbasin from the environmental point of view. The result of IEE will be one of the useful tools for selection of the most recommendable alternative from the environmental viewpoint. Besides, the IEE is the first approach of Environmental Impact Assessment (EIA) by scoping, which needs to be carried out only when the necessity of a detailed EIA is proved by the IEE.

A check list method is applied as a basic tool of IEE because it is the useful initial method for identification of impacts and evaluation of significance of them. The check list is prepared by using major items of environmental effects as rows and the alternative transbasin plans as columns. The expected effects are evaluated from 1 to 3 for each alternative with classifying positive or negative.

The expected environmental effects and their significance is identified by the IEE. After the scoping of the expected impacts, more detailed environmental study, EIA, will be conducted to the impacts which may have significant effects on the environment.

7.2 Effects on Water Environment

(1) Reservoirs

Water quality of La Esperanza reservoir will be much improved because a considerable amount of water is diverted from Daule-Peripa to La Esperanza for all Alternatives. On the other hand, water quality of Poza Honda reservoir will be much improved for Alternatives-1, 2, 5 and 6. In case of Alternatives-3 and 4, no improvement in reservoir water quality is expected.

Water quality of the proposed Chirijos reservoir will possibly be eutrophicated because the reservoir has a function of annual flow regulation as well as seasonal flow regulation.

(2) Rivers

Water quality of the Carrizal river and the lower reach of the Chone river will be improved by water released from La Esperanza for all Alternatives, especially in the dry season.

Water quality of the Portoviejo river in its middle and upstream reaches will greatly be improved in all Alternatives except Alternative-4, where no improvement is expected in the water quality of the Portoviejo river.

Water quality of the Chico river will be improved only in Alternative-3, remained the same in Alternative-5 and 6, and worsened in Alternatives-1, 2 and 4 due to Chirijos dam construction in the upper reach of the Chico river.

7.3 Social Impact Related to Chirijos Dam

For the construction of the proposed Chirijos dam, land compensation of and resettlement from the dam and reservoir site will be associated with a potential social problem.

The reservoir area below EL. 130 m is about 861 ha and includes 311 houses with about 1,870 people. The land to be submerged is mainly used for cultivation of perennial crops such as coffee, cacao, fruits, etc. occupying about 65% of the total area. More than half of the total people engage in agriculture.

The total land compensation cost is estimated based on the present price level to be S/. 1,500 million (US$1.3 million).

7.4 Result of Preliminary Environmental Study

Result of the preliminary environmental study is summarized below. The Alternatives-3, 5 and 6 are the most recommendable and the Alternative-4 is the least recommendable from the environmental point of view.

	Alt.-1	Alt.-2	Alt.-3	Alt.-4	Alt.-5	Alt.-6
1. Items related to project location						
a) Resettlement	-3	-3	0	-3	0	0
b) Inundation of primary agricultural land	-1	-1	0	-1	0	0
2. *Items during project operation*						
a) Improvement of river water quality						
- Carrizal-Chone	3	3	3	3	3	3
- Portoviejo upstream	3	3	3	0	3	3
- Portoviejo downstream	1	1	1	1	1	1
- Chico	-2	-2	2	-2	0	0
b) Improvement of reservoir water quality						
- La Esperanza	3	2	3	3	3	2
- Poza Honda	2	2	0	0	3	3
- Chirijos	-2	-2	0	-2	0	0
Total points	4	3	12	-1	13	12

8. SELECTION OF THE BEST ALTERNATIVE

All the proposed alternative plans for water transbasin, Alternatives-1 to 6, are compared one another from the following viewpoints:

(1) Total project cost including capitalized O & M cost with energy cost.
(2) Initial investment cost for project construction
(3) Initial investment cost for Phase I development of the project if phasing is possible
(4) Environmental impact including social impact
(5) Cost of operation and maintenance
(6) Level of guarantee in meeting water demands
(7) Easiness or difficulty involved in project operation

Item (1) is the most important and is given 55 points for comparison. Rather important items are (2), (4) and (6) and are given 10 points each. The remaining items of (3), (5) and (7) are of minor importance and are given 5 points each. Then the full mark will be 100. The comparison is summarized as follows.

Item	Alt.-1	Alt.-2	Alt.-3	Alt.-4	Alt.-5	Alt.-6
(1)	40	30	50	45	55	35
(2)	2	0	8	4	10	6
(3)	5	2	3	0	4	1
(4)	4	3	9	0	10	9
(5)	3	1	4	5	2	0
(6)	10	10	8	0	8	8
(7)	5	3	1	0	4	2
Point	69	49	83	54	93	61

As clearly indicated above, the Alternative-5 is definitely the most recommendable as a result of the overall comparison of the proposed six alternatives.

9. PLAN OPTIMIZATION

Through a comprehensive comparison study of six alternatives, the Alternative-5 has been finally selected as the best alternative, as discussed in Chapter 8. Here, the Alternative-5 is optimized in terms of capability of water supply in dry years and of distribution of capacities for the Esperanza - Poza Honda transbasin scheme and the Esperanza - Guarango transbasin scheme, both of which are transbasin from the Chone river basin to the Portoviejo river basin.

In the comparison study of six alternatives, irrigation water requirement for average years is applied. Total irrigation water requirement in the Portoviejo river basin is 243 MCM/year for average years, while it is 299 MCM/year for dry years (dry year of return period of 5 years). To ensure water supply even in dry years, the transbasin capacity of the Esperanza - Poza Honda scheme is reviewed because a larger capacity tunnel construction in the Esperanza - Guarango scheme is not recommendable due to geological conditions.

The study has resulted that the capacity of the Esperanza - Poza Honda transbasin scheme should be increased to 13 m^3/s from the originally calculated 10 m3/s. This scheme is called as the Alternative-5b, which ensures water supply even in dry years, when the irrigation water requirement is higher than that of average years.

On the other hand, in view of technically difficult and costly construction of the Amarillos - Guarango tunnel in the Esperanza - Guarango transbasin scheme which is planned through soft rock with swelling minerals, another alternative is considered to dispense with this tunnel construction as the Alternative-5a. In this alternative all the water should be diverted from the Chone river basin to the Portoviejo river basin by the Esperanza - Poza Honda transbasin scheme.

A reservoir operation study has indicated that all the water requirements will be met if the capacity of the Esperanza - Poza Honda transbasin scheme is further increased to 16 m^3/s without constructing the Amarillos - Guarango tunnel.

Required capacities for the above mentioned three alternatives are summarized below, and schematic water balance for alternatives 5a and 5b is given in Fig. 9.1 and Fig. 9.2.

Transbasin Scheme	Alternatives		
	5	5b	5a
Esperanza - Poza Honda	10 m^3/s	13 m^3/s	16 m^3/s
Esperanza - Guarango	5 m^3/s	5 m^3/s	-

Cost comparison is made for the two alternatives, 5b and 5a, based on preliminary designs, and the result is shown in Table 9.1 and summarized as follows.

(Cost in US$ million)

	Alt. 5a	Alt. 5b
Construction Cost	154.8	193.4
Direct cost	112.2	140.2
Indirect cost	42.6	53.2
Annual O & M Cost	5.24	5.02
Energy cost	4.76	4.31
O & M cost	0.48	0.71

The Alternative 5a will cost only 80% of the cost of the Alternative 5b mainly because of cancelling of the Amarillos - Guarango tunnel, though the annual O & M cost will be slightly higher for the Alternative 5a due to slightly higher pumping head.

The function of the Amarillos - Guarango tunnel was to supply good quality raw water to the El Ceibal water treatment plant in addition to irrigation water supply to the Guarango area. In case of the Alternative 5a, if water is delivered to the El Ceibal treatment plant through the Portoviejo river, water quality problem may take place. This problem will be solved by supplying the El Ceibal treatment plant through the Chico river which is expected to be subject to much less water pollution in the future. The Poza Honda - Rio Chico tunnel has enough capacity to supply additional 2 m^3/s of water without increasing the original capacity of 4 m^3/s, which is provided by the minimum diameter tunnel construction.

The Alternative 5a has thus been decided to be the optimum plan and further study has been concentrated to the Alternative 5a.

10. ADDITIONAL GEOTECHNICAL INVESTIGATIONS

10.1 Geological Investigation

Boring work was carried out with 6 holes and 210 m in total depth along the Esperanza - Poza Honda tunnel route and the Poza Honda - Chico River tunnel route as well as major structure sites. Results are summarized as follows.

(1) Foundation rock for pumping station, head tank and tunnel are composed of mudstone, sandstone and these alternation. These rocks are classified into soft rock, CL class in the Japanese rock classification.

(2) Thickness of soil layer (alluvium and colluvium) is 2 m at the pumping station, 5m at the head tank site, and 9 m at the syphon sites.

(3) Thickness of soil layer (colluvial) is about 10 m around the portal place of tunnel from Esperanza to Poza Honda. On the other hand, in the portal place of tunnel from Poza Honda to Chico river, weathered rock zone is as deep as 20 m.

(4) There is a tendency that mudstone in the tunnel route from Poza Honda to Mancha Grande of the Chico river basin is loosened by weathering action, in other words, this mudstone becomes gradually loose after excavation if it is left in the natural condition.

(5) The value of R.Q.D. is 80 on an average, that is to say there are few cracks in the rock layer.

(6) Groundwater tables are as follows:

Hole No.	Site	Groundwater table below ground surface
B-1	Pumping station and head tank	Dry
B-2	Syphon	3 m
B-3	Esperanza - Poza Honda tunnel inlet	15 m
B-4	Esperanza - Poza Honda tunnel outlet	14 m
B-5	Poza Honda - Mancha Grande tunnel inlet	8 m
B-6	Poza Honda - Mancha Grande tunnel outlet	10 m

Permeability test in-situ was carried out using the boring holes. At the boring holes B1 and B2 the test was done by a free flow method, while Lugeon Test was applied in other boring holes. Test results are as follows.

Hole No.	Geological Type	Permeability Coefficient k (cm/sec)
B-1	Colluvium	6.3×10^{-4}
B-2	Alluvium	9.6×10^{-3} - 2.0×10^{-2}
B-3	Mudstone	2.4×10^{-4} - 5.5×10^{-5}
B-4	Mudstone	1.8×10^{-5} - 7.5×10^{-6}
B-5	Mudstone	1.0×10^{-6}
B-6	Mudstone	3.5×10^{-4}

At B-1 and B-2, the geological type is colluvial and alluvial which naturally resulted in higher permeability. The permeability of the mudstone for B-3 to B-6 is generally low, although in the partial cracky zones coefficients of permeability in the order of 10^{-4} were measured.

In relation to the tunnel construction, laboratory rock test was carried out. Boring core samples were used for testing. Test items are bulk density, water absorption and unconfined compressive strength. In addition to these test items, for rock samples taken from the previous boring work made for the Amarillos - Guarango tunnel, clay minerals are analyzed by X-ray in order to confirm existence of swelling minerals such as gypsum, anhydrite and/or montmorillonite. Test results are summarized below.

(1) Bulk density ranges 1.9 g/cm^3 to 2.1 g/cm^3, which is the standard value for soft rocks.

(2) The average value of the unconfined compressive strength is 60 kg/cm^2, which indicates that the rock is not so strong as it appears.

(3) Relatively high rate of water absorption of 20 to 30% was measured, though the rate of volume change due to swelling is as low as less than 1%.

(4) In the rock sample of the Amarillos - Guarango tunnel, expansive or swelling minerals, montmorillonite, has been detected.

10.2 Soil Mechanical Test

Along the open channel route from the Severino pumping station to the inlet of the Esperanza - Poza Honda tunnel, laboratory soil mechanical test was carried out. Samples were collected by a shelby sampler (thin wall tube sampler) and by block sampling from test pits. Test items are densities in natural water content and saturated, specific gravity, natural water content, Atterberg test, shrinkage test, potential volume change, swelling, permeability, unconfined compressive strength, triaxial test, compaction test, double hydrometer and pin hole test for dispersive material content, etc

In the soil mechanical test, examination regarding the expansive and dispersive clay is especially conducted because the soil in this area has a serious tendency of failure by swelling in the rainy season. Test results clearly shows a possibility of expansiveness in some places and a careful earthwork design is needed for the open channel.

11. FEASIBILITY DESIGNS OF PROJECT FACILITIES

11.1 General Features of Project Facilities

As discussed in Chapter 9, the Alternative-5a has finally been selected. The general features of the project facilities are proposed as follows.

(1) Daule Peripa - Esperanza Transbasin Scheme

Tunnel

Capacity	18 m^3/s
Length	8.3 km
Diameter	3.7 m, standard horse-shoe section, free flow type

(2) Esperanza - Poza Honda Transbasin Scheme (Fig. 11.1)

Pumping station

Pumping capacity	16 m^3/s
Max. head	76.0 m
Nos. of pump unit	5 units
Stand-by unit	1 unit
Discharge of one unit	192 m^3/min. (3.2 m^3/s)
Type	Double suction volute type

Pipeline

Length	250 m
No. of lanes	2 lanes
Diameter	2,100 mm

Head Tank

Width	12 m
Length	18 m

Open Channel

Capacity	16.0 m^3/s
Length	5.4 km
Gradient (I)	1/3,000
Section	Trapezoidal B = h = 2.2 m

Syphon

Capacity 16.0 m^3/s

Syphon No.	Length	Max. head	Remarks
1	62 m	13 m	Concrete box culvert
2	225 m	38 m	Concrete pipe
3	325 m	47 m	- do -
4	55 m	7 m	Concrete box culvert
5	50 m	10 m	- do -
6	189 m	20 m	- do -

Tunnel

Capacity	16.0 m^3/s
Length	10.7 km
Gradient	1/1,500
Diameter	3.5 m, standard horse-shoe section, free flow type

(3) Poza Honda - Mancha Grande Transbasin Scheme

Tunnel

Capacity :	4.0 m^3/s
Length :	3.9 km
Diameter :	2.5 m, standard horse-shoe section, free flow type

Based on the results of additional geotechnical investigations, locations of the Severino pumping station and head tank, and routes of open channel, syphons and tunnels have been revised from the preliminary designs described in Chapter 6.

11.2 Feasibility Designs of Esperanza - Poza Honda Transbasin Scheme

(1) Severino Pumping Station

Geological condition around the pumping station is favorable. Outcrops of relatively hard sandstone is observed in the backside of the pumping station. Although some boulder layers overlie near the river side, the structure can easily be founded on the fresh rock layer. Unconfined compressive strength and permeability of the foundation rocks are 130 kg/cm^2 and 1×10^{-5} cm/sec, respectively.

The proposed design of the Severino pumping station, intake and power supply single line diagram are shown in Fig. 11.2, Fig. 11.3 and Fig. 11.4, respectively. Outdoor equipment is planed to locate in the hilly area near the pumping station as shown in Fig. 11.5. Electric power is supplied to the pumping station from the Daule Peripa power station, which will have a capacity of 130 MW in the near future. Route map of the 138 kV transmission line is given in Fig. 11.6.

(2) Open Channel and Syphons (Fig. 11.7, 11.8 and 11.9)

Geological type in the open channel formation is colluvial decomposed soil (heavily weathered mudstone) and weathered rock layer. This soil layer extend approximately 4 m to 5 m in thickness and is gradually transferred into the weathered rock layer. Open channel are designed from the following considerations derived from the geotechnical characteristics.

- The soils are judged to be more or less expansive from the soil mechanical tests, and countermeasures such as replacing of swelling soil with non swelling soil will be needed.

- Weathered rock layer under the soil layer is considered firm enough for the foundation of an open channel.

- The silt and clay in the soil layer are not suitable for embankment because severe shrinkage is expected. Weathered rock as well as tunnel excavated material can be used for embankment.

- The in-situ material shows low permeability and no seepage will take place from the open channel.

- As for the syphon sites, the N value by the standard penetration test ranges 7 to 25 in the alluvial layer of about 9 m in thickness. Permeability is relatively high with the coefficient $K = 3.7 \times 10^{-3}$ cm/sec.

Bearing the above factors in mind, concrete lining with a fabric mesh is designed for the open channel, and the following three types of foundation treatment are proposed depending on the geotechnical condition on which the channel is to be constructed.

Lining thickness	10 cm
Side slope	1 : 1.5
Bottom width (B)	2.2 m (B = h, water depth)
Height (H)	2.5 m (freeboard 0.3 m)

Type I: Replacement with a selected filter material (15 cm in thickness), if weathered rock line is above the open channel formation.

Type II: Replacement with a selected filter material (15 cm in thickness) and excavated rock fragments (35 cm in thickness), if weathered rock line is slightly below the open channel formation, together with geotextile mat on the base.

Type III: Replacement with a selected filter material (30 cm in thickness) and excavated rock fragments (90 cm in thickness), if weathered rock line is below the open channel formation, together with geotextile mat on the base.

As for the design of syphons a box culvert type is applied for head of less than 20 m and a concrete pipe type is designed for head of more than 20 m.

(3) Tunnel

The tunnel route is located in the mountainous area from 200 m to 400 m in elevation. Rock type is mainly composed of mudstone throughout the tunnel formation. In the portal portions, however, colluvial and decomposed mudstone (soil layer) exist with a thickness of 10 to 20 m.

The mudstone is soft with the measured unconfined compressive strength of 60 kg/cm^2 on an average and 30 kg/cm^2 in minimum, but massive and rarely cracked. Since the samples for rock tests were taken at the tunnel portal portion, the compressive strength of the rock in the inner part of the tunnel is expected to be around 150 kg/cm^2. In view of low permeability of the rock, leakage water during tunnel excavation will not be much.

For tunnel construction, New Austrian Tunnelling Method (NATM) is considered most suitable for this site. Load header is applied for tunnel excavation. Immediately after excavation, shotcrete with a wire mesh will be provided on the excavated rock surface. Several rock bolts are to be driven depending on the actual rock condition. Then, finally, the tunnel construction will be completed by concrete lining with a 30 cm thickness for the whole stretches. Steel support is to be used for tunnelling in the colluvial and weathered rock zone near tunnel portals. Drain holes are also considered to relieve water pressure from around the tunnel.

The following four types of the tunnel sections are designed depending mainly on the expected rock conditions as shown in Fig. 11.1.

	Type I	Type II	Type III	Type IV
Place	Inner part	Inner part	Inner part	Portals & Fractured Zone
Rock Condition	Fresh and relatively hard	Fresh but relatively soft	Slightly weathered	Colluvial or weathered
Distance (m)	4,500	4,500	1,300	350
Shotcrete thickness (cm)	10	10	15	15
Rock bolts	ø22x4Nos.x2m (1.2 m pitch)	ø22x8Nos.x2m (1.2 m pitch)	ø22x8Nos.x2m (1.2 m pitch)	ø22x8Nos.x2m (1.2 m pitch)
Concrete lining (cm)	30 (w/o R. bar)	30 (w/o R. bar)	30 (w/single R. bar)	30 (w/double R. bar)
H-steel support	-	-	H125, 1.2m pitch	H125, 1.2m pitch

Work adits are planned to facilitate tunnel construction work and to save construction time. The work adits will have a circular section with a diameter of 4.0 m in the upper portion and a rectangular section in the lower portion. One adit is located in the outlet portion and has a length of 500 m, and the other is located at about 7.3 km point from the outlet and has a length of 630 m. Type II or Type III will be applied for these tunnel work adits.

(4) Tunnel Inlet and Outlet (Fig. 11.10)

There is no special structure at the tunnel inlet. The structure is gradually changed from the open channel to the tunnel in the transition part of 20 m in length.

In the tunnel outlet, a control gate will be provided to protect back flow from the Poza Honda reservoir. The gate is planned to be fully closed when the reservoir water level is higher than El. 102.5 m.

11.3 Feasibility Designs of Poza Honda - Mancha Grande River Transbasin Scheme

(1) Tunnel (Fig. 11.11)

The tunnel route is located in the mountainous area from 200 m to 400 m in elevation. Around the tunnel outlet portion, however, the topographic condition shows a gentle slope where the colluvial deposit and heavily weathered rock layer cover the ground surface.

The mudstone in the inner part of the tunnel has a crackless feature and a large scale fractured zone is not expected, although minor shearing zone may exist locally. Since permeability is low, leakage water during tunnel construction will not be a problem. Basically, the geological condition through the tunnel formation is the same as that for the Esperanza - Poza Honda tunnel.

Tunnel designs are classified into the same four types as for the Esperanza - Poza Honda tunnel. The tunnel lengths for the four types are tentatively decided as follows.

	Type I	Type II	Type III	Type IV
Distance (m)	1,300	1,300	850	450

One tunnel work adit is planned at the tunnel inlet portion with a length of 350 m. The section of the tunnel adit is the same as that for the Esperanza - Poza Honda tunnel.

(2) Tunnel Inlet and Outlet

At the tunnel inlet, a discharge control structure with energy dissipator is designed to control a discharge through the tunnel and to ensure a free open flow in the tunnel. At the tunnel outlet, the tunnel section is gradually changed to the open channel section and connected with the Mancha Grande river. The design of tunnel inlet and outlet is shown in Fig. 11.12.