FEDERATIVE REPUBLIC OF BRAZIL

THE STUDY
ON
THE DISASTER PREVENTION AND RESTORATION PROJECT
IN
SERRA DO MAR, CUBATÃO REGION, STATE OF SÃO PAULO

FINAL REPORT
MAIN

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JAPAN INTERNATIONAL COOPERATION AGENCY

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JANUARY 1991

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

In response to a request from the Government of the Federative Republic of Brazil, the Japanese Government decided to conduct a study on the Disaster Prevention and Restoration Project in Serra Do Mar, Cubatao Region, State of Sao Paulo and entrusted the study to the Japan International Cooperation Agency(JICA).

JICA sent to Brazil a study team headed by Dr. Michio Ooishi, the Nippon Koei Co.,LTD ,and composed of members from the Nippon Koei Co., LTD. and Nikken Consultants, Inc. twice between November 1989 and September 1990.

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

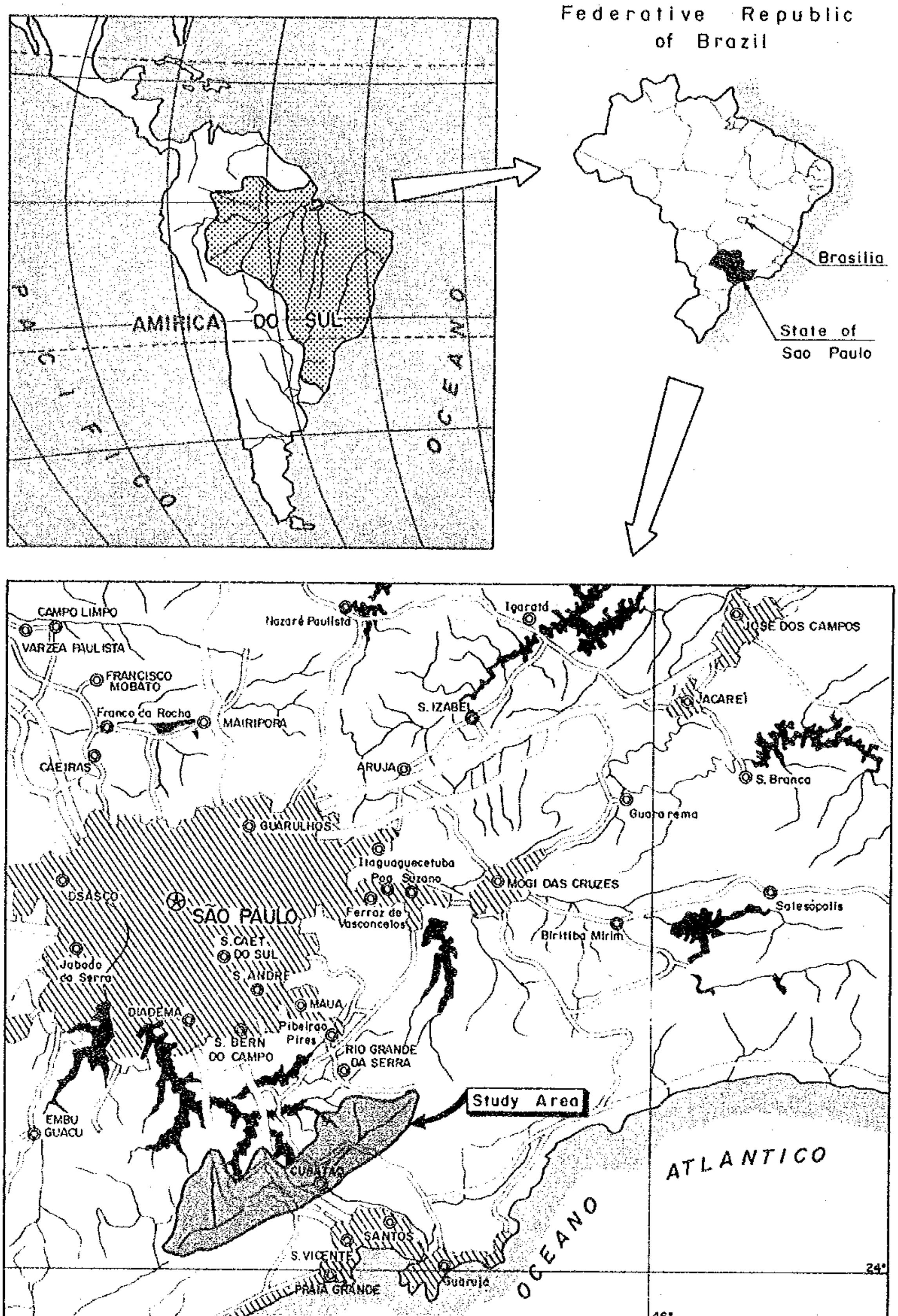
I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Federative Republic of Brazil and the State of Sao Paulo for their close cooperation extended to the team.

January 1991

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency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Brasilia
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AMIRICA DO SUL
OCEANO
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VARZEA PAULISTA
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SÃO PAULO
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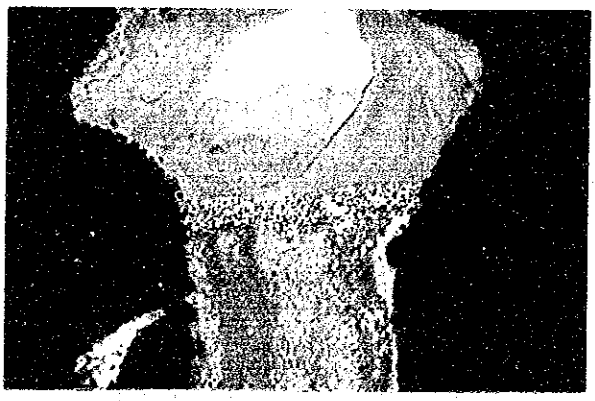
Jabodo da Serra
S.CAET. DO SUL
S. ANDRÉ
MAUA
DIADEMA
S. BERN DO CAMPO
Pibeirao Pires
RIO GRANDE DA SERRA
Study Area
EMBU GUACU
CUBATAO
ATLANTICO
OCEANO
SANTOS
S. VICENTE
PRAIA GRANDE
Guarujá
24°
46°
44°
43°

GENERAL MAP

A general view of CUBATAO industrial complex and CUBATAO City.

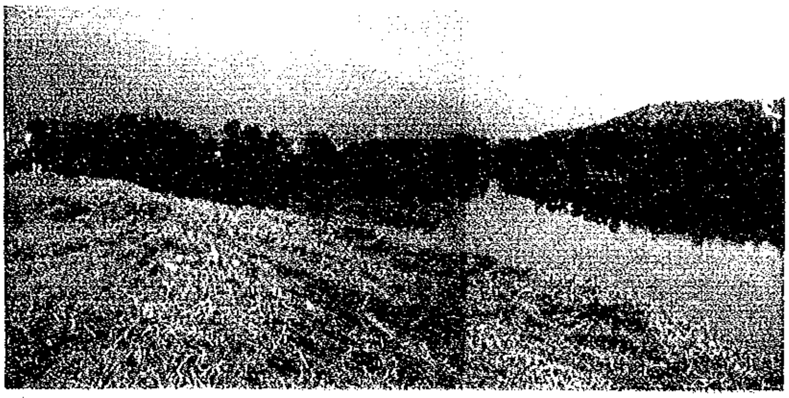
Air pollutant gases lanched from industrial establishment; Winds bring gases to the mountain side in daytime. Refinaria(left), Ultrafeltil and Copebras(right).

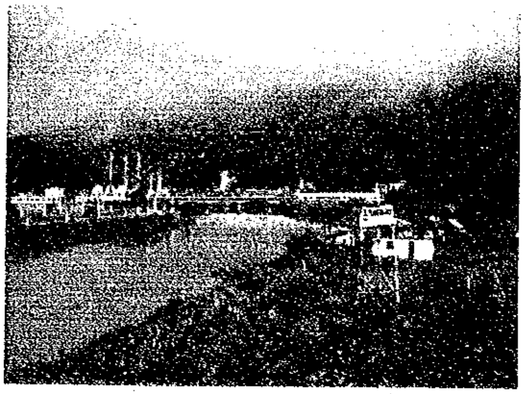
A large number of slope failures occured on the steep slopes upstream of the Moji River on Jan 22-25, 1985. Almost high trees standing on the slopes had already been dead by 1985's disaster(right).



An aerial view of the riprap cross dam with sediment deposit mid-stream of the Moji River.

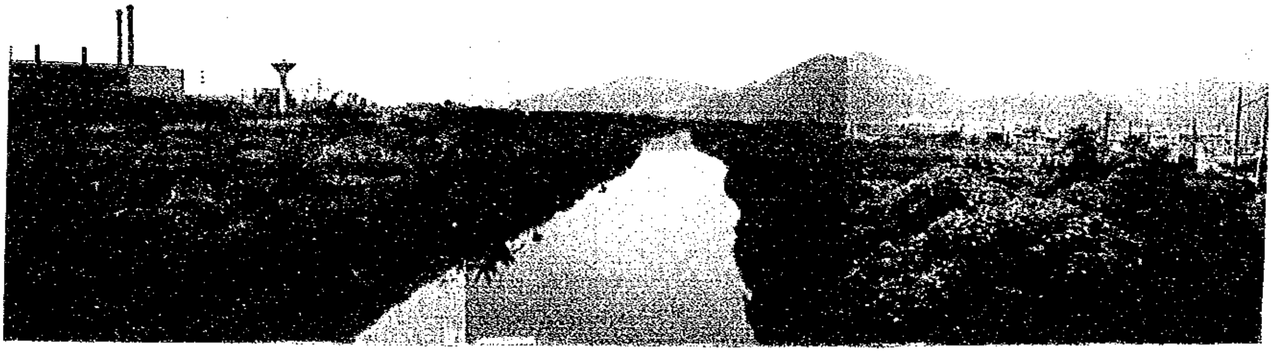
A series of three gabion dams constructed upstream of Ultrafertil.



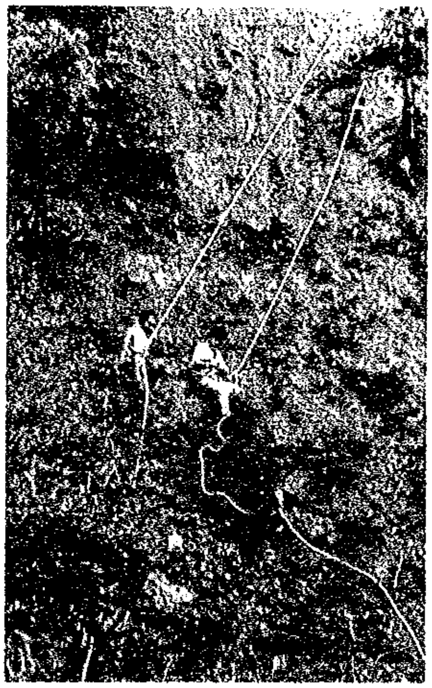


Confluence of the Cubatão and the Pereque River; Flood dyke was constructed on right bank after the destructive disaster in 1971.

Lower reaches of the Cubatão River; Industrial and residential areas are developed along the both sides.



Lower reaches of the Moji River; where river channel improvement works are proposed in the priority project.



Monitoring on the control area after 3 months of seeding.

Young plant of Miconia sp, 50 cm tall, after 10 months of the aerial seeding.

SUMMARY

1. BACKGROUND

The study area, situated in a coastal mountain and plain area 60 km south of São Paulo, is characterized by development of heavy chemical industry and its tropical forest. However, since the mid-1970s, a number of slope failures have occurred which cause sediment run-off disasters to the industrial establishments, infrastructures and residences. These are frequently on the steep slopes of Sera do Mar, in rainy seasons, and mainly due to the degradation of vegetation by air pollution.

The lower reaches of the Moji and Cubatão rivers also suffer flood disasters, especially in the downstream reaches of the Moji river.

These recurring disasters necessitated this study on disaster prevention and environmental restoration in Serra do Mar, Cubatão region which carried out by the JICA study team in close cooperation with the State of São Paulo.

2. OBJECTIVES

The objectives of the study are: 1) to formulate a master plan to prevent disasters to the year 2000 and to select a priority project, 2) to conduct a feasibility study on the priority project by the mid-1990s, and 3) technical transfer to the Brazilian counterpart personnel.

3. MASTER PLAN

3.1 Sediment Run-off Disaster Prevention Plan

(1) Basic considerations

The master plan for the sediment run-off disaster prevention was formulated on the assumption that the present vegetation conditions will not be improved in near future because of the difficulty in restoring completely degraded forest to original conditions by the year 2000. Accordingly,

- a protection area having 12 Sabo subbasins was chosen on grounds of probable slope failure, past major sediment run-off records and the properties at risk to be protected.

- a design scale of 100 years was adopted for the following reasons; the importance of the area to be protected, the uncertainty of natural disaster phenomena and Japanese standards.

(2) Disaster prevention plan

Thirty-two(32) Sabo dams and eleven(11) channel improvement works with a total length of 5,740 m were proposed for the master plan. The main dimensions of the proposed structures are shown below.

Sabo Subbasin No.	Structural Measures		
	Sabo Dams No.	Sabo Dams Effective Height	Channel Works (m)
1	1	10 m	860
2	3	7 m,10 m,10 m	560
3	2	10 m each	530
4	2	8 m,10 m	600
5	2	10 m, 5 m	450
6	3	10 m each	700
7	6	10 m each	350
8	2	7 m,10 m	420
9	3	10 m each	150
10	2	8 m,10 m	-
11	3	10 m each	560
12	3	9 m,10 m,10 m	560
Total	32		5,740

3.2 Flood Disaster Prevention Plan

(1) Basic considerations

The master plan for flood disaster prevention was formulated on the basis of the following basic considerations.

- the urban area and industrial establishments in the fluvial plain were determined to be the protected areas as follows:

  Cubatão river (RFFSA bridge - Sabesp weir)

  Perequê river (Road bridge at river mouth - Ultrafèrtil weir)

  Piaçaguera river (Confluence with the Moji river - spillway of Copebras estate)

  Indio river (Confluence with the Moji river - RFFSA bridge)

- the design scale of a 50-year return period was adopted for the mainstreams of the Cubatão and Moji rivers, and a 25-year return period for their tributaries by the reason of importance of protected area and the criteria applied in the State of São Paulo.

(2) Disaster prevention plan

Of the conceivable alternative schemes, schemes of C-2(2) in the Cubatão river basin and M-2 in the Moji river basin were selected as the optimum plan on the basis of least cost.

Scheme C-2(2) consists of 2 tunnels of 600 m each and river channel improvement of 6.7 km, and Scheme M-2 consists of 9.5 km of river channel improvement.

Work items	Quantities
Cubatão River System	
Construction of diversion tunnel	600 m
Channel improvement	6.7 km
Moji River System	
Channel improvement	
Moji	4.5 km
Piaçaguera	3.7 km
Indio	1.3 km

3.3 Forest Restoration Plan

(1) Basic considerations

The present forest restoration plan of the State of São Paulo includes two stages, namely first stage; planting and aeroseeding of the pioneer species, and second stage; replantation of the climax species in Capoeira area.

According to the monitoring survey conducted by CETESB in February 1990, the first stage was judged to have finished with success results. Therefore, the second stage of the present forest restoration plan can be adopted as the master plan project with the target year 2000.

Twenty(20) areas were selected as the strategic replantation areas with each catchment area of 0.4 ha.

(2) Forest restoration plan

Replantation of one thousand trees in each area was proposed for the master plan. The work items and quantities are as shown below.

Item	Quantities
Selection of climax species	-
Seedling production	24,000 units
Service roads restoration	35 km
Topographic works	80,000 m^2
Planting works	20,000 units
Maintenance works	20,000 units
Support works	-

3.4 Non-Structural Measures

Non-structural measures, in combination with structural measures, are effective and of vital importance in minimizing damage from natural disasters. From experiences Japan, the following points can be suggested.

- Preparation and publication of hazard map
- Simplification of existing judgment and information transmitting systems
- Prompt and accurate management of existing observation stations

3.5 Implementation Program

(1) Implementation schedule

The implementation schedule of the master plan was prepared by taking into account the construction sequence and conditions. The total project period was assumed to be 10 years, in which the project period was divided into two(2) stages: the first five(5) years (1991-1995) and the second five(5) years (1996-2000).

(2) Construction cost

The construction cost of the master plan on a financial basis was estimated for the sediment run-off and flood disaster prevention works, and the forest restoration works as given below. The price level was set at the end of June 1990 and official exchange rates were fixed as US$1.00 = Cr$60.

(Unit: US$ million)

Item		Financial	Direct	Indirect
Sediment Run-off Prevention Plan		75.0	45.9	29.1
Flood Prevention Plan	- Cubatão	43.2	25.5	17.7
	- Moji	22.7	13.9	8.8
Forest Restoration Plan		2.0	1.7	0.3
Total		142.9	87.0	55.9

3.6 Project Justification

(1) Economic cost

The economic cost was estimated as follows:

(Unit: US$ million)

Item	Sediment Run-off Prevention	Flood Disaster Prevention	
		Cubatão	Moji
Direct Construction Cost	41.1	23.3	12.7
Compensation Cost	0.06	0.06	0.08
Administration Cost	2.1	1.2	0.6
Engineering Services	4.1	2.3	1.3
Physical Contingency	7.1	4.0	2.2
Total	54.4	30.9	16.9

(2) Economic evaluation

Economic evaluation was carried out to assess economic viability by comparing economic costs and benefits. The Economic Internal Rate of Return (EIRR) was used as the criterion as shown in the following table.

Item	Sediment Run-off Prevention Plan	Flood Prevention Plan	
		Cubatão	Moji
EIRR (%)	11.2	5.4	8.3

(3) Project justification

The master plan for the sediment run-off prevention works could be justified solely by the EIRR of 11.2% quoted above. When the unmeasurable social impacts and intangible damages which would be induced from sediment run-off disasters are taken into account, this master plan was judged to be highly viable for implementation.

With regard to the master plan for the flood protection works, major industrial establishments are at high risk of recurrent inundation from the Moji river and its tributaries. In considering the future land use plan envisaged for the Moji river basin, the probable flood damage in future is likely to increase significantly as compared the present projection. If this is combined and with the economic evaluation, the flood protection works for the Moji river basin is also highly viable.

The master plan for the forest restoration would be justified from effective erosion control aiming at preventing sediment run-off and flood disaster in the middle and long term.

4. SELECTION OF PRIORITY PROJECT

The priority project targeted on the mid-1990s was selected from the master plan as follows.

4.1 Sediment Run-off Disaster Prevention

Priority project was determined as shown below in accordance with the two selection priorities; the probability of serious disaster and EIRR. As a result, nine(9) Sabo dams, and six(6) channel works in seven(7) subbasins were selected as shown below. These structural measures were designed for the probable sediment run-off discharge of about a 25-year return period.

Item	Subbasin											
	1	2	3	4	5	6	7	8	9	10	11	12
1st criteria		+	+				+	+				
2nd criteria EIRR (%)	(-)	12.7	14.7	2.4	1.8	2.1	17.0	9.1	3.9	11.8	11.9	12.9
Priority Project		*	*				*	*		*	*	*

Note: + means first priority subbasins having possibility of flowing out toxic gases and liquid in sediment run-off disasters
* means selected priority project

4.2 Flood Disaster Prevention

About 4.5 km of channel improvement and flood dike construction on the Moji river, including the lower reaches of some tributaries were selected for the priority project because of their higher economic viability and the circumstances of recurrent inundation. These structural measures will be designed for a 10-year return period.

4.3 Forest Restoration Plan

Forest restoration works to be done by 1995 were selected as the priority project in accordance with the implementation program of the master plan.

5. FEASIBILITY STUDY ON PRIORITY PROJECT

5.1 Preliminary Design and Work Quantities

(1) Sediment run-off disaster prevention works

The preliminary design for the sediment run-off disaster prevention works was carried out based on the design criteria in Japan. The work quantities of the sabo dams, channel works and groundsills are summarized below.

Dam No.	Dam		Channel Works	Groundsill	
	H (m)	V (m^3)	L (m)	Nos	V (m^3)
2-1	13	22,000	530	4	1,200
3-1	14	9,800	490	1	200
7-1	12	3,600	250	5	1,000
7-3	14	3,800	-	-	-
7-4	12	2,000	-	-	-
8-1	11	3,700	440	4	400
10-1	9	1,100	-	-	-
11-1	14	7,300	410	11	1,100
12-1	13	4,900	750	9	900
Total		58,200	2,870	34	4,800

Note: H; Dam height V; Volume of structure L; Total length

(2) Flood disaster prevention works

The preliminary design for the flood disaster prevention works was conducted in accordance with the criteria in Japan. The work quantities of the river improvement works are summarized below.

Component	Type of Structure	Quantity
Dike		265,000 m^3
Excavation		334,000 m^3
Dredging		141,000 m^3
Revetment	Wet masonry	9,800 m^2
Culvert		1.5m x 1.5m (6 sites) 2.0m x 2.5m (1 site)
Intake Weir	Concrete	
Parapet Wall	Concrete	
Road Bridge		40.8 m
Railway Bridge		130.5 m

5.2 Construction Plan

The contract system considering the participation of foreign contractors associated with Brazilian contractors are proposed to execute the project works.

The projects will be proposed to be executed with four (4) packages taking into account the project scale, amount of construction costs and secure implementation.

5.3 Cost Estimate

The construction cost for the priority project was estimated based on the preliminary design and construction plan. The basic assumptions and conditions adopted for the cost estimate are basically the same as that of master plan stage as follows:

The construction costs for the priority projects in the financial basis were estimated as follows:

(Unit: US$ million)

Item	Sediment Disaster Prevention			Flood Disaster Prevention Works Moji River		
	F/C	L/C	TOTAL	F/C	L/C	TOTAL
I Preparatory Work (5-15% of II)	1.0	1.2	2.2	0.2	0.1	0.3
II Construction Cost	7.0	7.8	14.8	4.0	3.1	7.1
III Compensation Cost		0.1	0.1		0.2	0.2
IV Administration Cost (5% of I + II)		0.9	0.9		0.4	0.4
V Engineering Service (10% of I + II)	1.4	0.3	1.7	0.6	0.1	0.7
VI Physical Contingency (15% of I+II+III+IV+V)	1.4	1.5	2.9	0.7	0.6	1.3
VII Price Contingency (F/C 3%, L/C 3%)	1.4	1.6	3.0	0.8	0.6	1.4
Total	12.3	13.4	25.7	6.3	5.1	11.4

(Unit : million US$)

Works	Construction Cost		
	Direct	Indirect	Total
(1) Sediment run-off disaster prevention works	17.0	8.7	25.7
Basin 2	6.0	3.0	9.0
Basin 3	2.7	1.3	4.0
Basin 7	2.7	1.4	4.1
Basin 8	1.1	0.8	1.9
Basin 10	0.3	0.1	0.4
Basin 11	2.2	1.1	3.3
Basin 12	2.0	1.0	3.0
(2) Flood disaster prevention works	7.4	4.0	11.4
(3) Forest restoration works	1.1	0.2	1.3
Total	25.5	12.9	38.4

5.4 Project Justification

(1) Economic cost

The constitution and concept of the economic cost for the priority project was assumed to be the same as applied in the master plan. The economic cost for the priority project was estimated as follows:

(Unit : million US$)

Works	Economic Cost		
	Direct	Indirect	Total
(1) Sediment run-off disaster prevention works	15.1	4.9	20.0
Basin 2	5.4	1.7	7.1
Basin 3	2.3	0.8	3.1
Basin 7	2.4	0.8	3.2
Basin 8	1.1	0.3	1.4
Basin 10	0.2	0.1	0.3
Basin 11	1.9	0.6	2.5
Basin 12	1.8	0.6	2.4
(2) Flood disaster prevention works	6.8	2.2	9.0
Total	21.9	7.1	29.0

(2) Economic evaluation

An economic evaluation was carried out to ascertain the economic viability of the proposed projects by comparing the economic costs and benefits. The Economic Internal Rate of Return (EIRR) was applied as a criterion for economic evaluation.

Works/Sabo Sub-basin	EIRR (%)
Sabo Works	
2	13.3
3	17.8
7	23.5
8	16.8
10	30.1
11	21.2
12	22.3
Total	18.2
River Improvement Works	11.1

5.4 Environmental Impact Assessment

The environmental effects of the priority projects will be generally limited to the construction stage. However, the magnitude are expected to be small, because the impacts are tentative and effective countermeasures will be taken during construction of the projects.

5.5 Project justification

Overall economic evaluation of the Sabo works, consisting of 7 Sabo sub-basins, shown an EIRR of 18.2%. Of the above, sub-basin No.7, 10, 11 and 12 were analyzed to exhibit quite high economic return of more than 20%. On the other hand, the Moji river improvement works shown an EIRR OF 11.1%.

For the above-mentioned reasons, both the sediment run-off and the flood prevention works could be justified. Moreover, taking into account unmeasurable social impacts and intangible damage, these projects were judged to be highly viable for implementation.

6. RECOMMENDATION

Main points to be strongly recommended are summarized as follows:

1. The proposed priority project for the sediment run-off disaster prevention works is strongly recommended to be implemented because of social request, technical feasibility and high economic return. The civil defense plan and forest restoration program also be continued.

2. The priority project for the flood disaster prevention are highly recommended to be implemented due to high economic viability and repeated inundation.

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ABBREVIATIONS OF ORGANIZATIONS

JICA	Japan International Cooperation Agency
SMA	Secretaria do Meio Ambiente
IBC	Instituto Brasileiro de Cafê
SES	Secretaria de Energia e Saneamento
SCTDE	Secretaria da Ciência, Tecnologia e Desenvolvimento Econômico
SEP	Secretaria de Economia e Planejamento
PMC	Prefeitura Municipal de Cubatão
CETESB	Companhia de Tecnologia de Saneamento Ambiental
DAEE	Departamento de Aguas e Energia Elêtrica
IPT	Instituto de Pesquisas Tecnolôgicas do Estado de São Paulo S.A.
IBt	Instituto de Botânica
CTH	Centro Tecnolôgico de Hidrâulica
CONDEMA	Conselho Municipal de Defesa do Meio Ambiente de Cubatão
CONDEMA SANTOS	Conselho Municipal do Meio Ambiente de Santos
IF	Instituto Florestal
USP	Universidade de São Paulo
IGGSP	Instituto Geogrâfico e Geolôgico de São Paulo
IG	Instituto Geolôgico
IGC	Instituto Geogrâfico e Cartogrâfico
IBGE	Instituto Brasileiro de Geografia e Estatistica
EMPLASA	Empresa Metropolitana de Planejamento da Grande São Paulo S.A.
ELETROPAULO	Eletricidade de São Paulo
CESP	Cia. Energêtica do Estado de São Paulo
CPFL	Cia. Paulista de Força e Luz
SABESP	Saneamento Bâsico do Estado de São Paulo
DERSA	Desenvolvimento Rodoviârio S.A.
INPE	Instituto de Pesquisas Espaciais
RFFSA	Rede Ferroviâria Federal S.A.
SAA	Secretaria de Agricultura e Abastecimento
FDTE	Fundação para o Desenvolvimento Tecnolôgico
EME	Distrito de Metereologia
SC	Secretaria da Cultura
DTRI	Setor de Pesquisa Tecnolôgica de Sistemas de Tratamento de Residuos Industriais (CETESB)
SIC	Secretaria da Indûstria e Comêrcio
CODEC	Coordenadoria Estadual de Defesa Civil
COMDEC	Cubatão Municipal Civil Defense Comission
COSIPA	Cia. Siderûrgica Paulista
COPEBRAS	Cia. Petroqûimica Brasileira
S. MARCOS	Ultrafêrtil S.A. Ind. e Com. de Fertilizantes

ABBREVIATIONS OF MEASUREMENT

Length

mm = millimeter
cm = centimeter
m = meter
km = kilometer
ft = foot
yd = yard

Area

cm^2 = square centimeter
m^2 = square meter
ha = hectare
Km^2 = square kilometer

Volume

cm^3 = cubic centimeter
l = lit = liter
kl = kiloliter
m^3 = cubic meter
gal. = gallon

Weight

mg = milligram
g = gram
kg = kilogram
ton = metric ton
lb = pound

Time

s = second
min = minute
h = hour
d = day
yr = year

Electrical Measures

V = Volt
A = Ampere
Hz = Hertz (cycle)
W = Watt
KW = Kilowatt
MW = Megawatt
GW = Gigawatt

Other Measures

% = percent
PS = horsepower
^{o} = degree
' = minute
" = second
^oC = degree in centigrade
10^3 = thousand
10^6 = million
10^9 = billion (milliard)

Derived Measures

m^3/s = cubic meter per second
cusec = cubic feet per second
mgd = million gallon per day
KWh = Kilowatt hour
MWh = Megawatt hour
GWh = Gigawatt hour
KWh/y = Kilowatt hour per year
KVA = Kilovolt ampere
BTU = British thermal unit
psi = pound per square inch

Currency

US$ = US dollar
¥ = Japanese Yen
NCZ$ = Brazilian New Cruzado

I. INTRODUCTION

1.1 Background

The study area, situated in a coastal mountain and plain area 60 km south of São Paulo, is characterized by the largest development of heavy chemical industry in South America, and an environment of tropical forests. However, since the mid-1970s, slope failures have been occurring every five(5) to 10 years on the steep slopes of Serra do Mar in rainy seasons mainly due to the degradation of vegetation by air pollution.

A disastrous slope failure January 1985, which was the largest in recent years, caused serious damage to the industrial establishments located at the foot of Serra do Mar because of the tremendous sediment run-off.

Immediately after this, in June 1985, the Government of the State of São Paulo instituted "the Special Commission for Restoring the Serra do Mar in the Cubatão Region".

With the aim of restoring the damaged slopes of Serra do Mar, the Special Commission has been steadily undertaking various disaster prevention plans consisting of structural and non-structural measures including a vegetation restoration plan, with the support of the several agencies concerned.

The lower reaches of the Moji and the Cubatão rivers also suffer from frequent flood damage. The flood of 1971, the largest since 1936, inundated the entire Cubatão municipality to a maximum depth of approximately 3.5 m and caused serious damage to the residential area. Inundation occurs even more frequently in the Moji river basin.

To cope with these disasters, the Government of the Federative Republic of Brazil, in October 1988, requested technical assistance in a study on sediment run-off and flood disaster prevention in this region. In response to this request, the Government of Japan dispatched a Scope of Work Mission in June 1989. In accordance with the Scope of Works agreed between the Brazilian and Japanese Governments, the Japan International Cooperation Agency (JICA) sent to Brazil a study team twice between November 1989 and September 1990 to conduct a master plan study and a feasibility study on selected priority project.

The study team carried out the study in collaboration with the agencies concerned of the Government of Brazil, especially the Secretaria do Meio Ambiente(SMA), Companhia de Tecnologia de Saneamento Ambiental (CETESB), Departamento de Aguas e Energia Elètrica (DAEE), Instituto de Pesquisas Tecnológicas do Estado de São Paulo S.A.(IPT) and the Instituto de Botânica (IBt).

1.2 Objectives of the Study

The objectives of the study are:

(1) To formulate a master plan to prevent disasters to the year 2000, and to select a priority project from the formulated master plan (Phase-1 Study).

(2) To conduct a feasibility study of the priority project to be implemented by the mid-1990s (Phase-2 Study).

(3) To promote technical transfer to the Brazilian counterpart personnel.

1.3 Organization for the Study

The study team headed by Dr. Michio Ooishi comprises ten(10) experts and has been working in close cooperation with counterpart agencies of the State of São Paulo since November 1989, in accordance with the study schedule. An Advisory Committee headed by Mr. Hiroaki Kobayashi, Ministry of Construction in Japan, was organized by JICA in order to review and advise the study.

Lists of members of the coordinating bodies and the counterpart agencies of the State of São Paulo, the Advisory Committee and JICA coordinator, and the study team are shown in Tables 1 to 3.

1.4 Outline of Report

This report is in four(4) parts, a executiye summary report, a main report, a supporting report and a data book. The executive summary report is the summary of the study. The main report describes the master plan, the selected priority project and the feasibility study on the priority project. The supporting report consists of the following 13 annexes, which explain the detailed study results in each field. The data book mainly contains basic data on hydrology and topographic survey.

ANNEX A : Socio-Economy
ANNEX B : Sediment Run-off and Flood Disaster Damage Survey
ANNEX C : Existing Disaster Prevention Measures
ANNEX D : Topographic Survey
ANNEX E : Geological Investigations
ANNEX F : Hydrology
ANNEX G : Sediment Study
ANNEX H : Sediment Run-off Disaster Prevention Study
ANNEX I : Flood Disaster Prevention Study
ANNEX J : Vegetation and Soils
ANNEX K : Environment
ANNEX L : Preliminary Design
ANNEX M : Construction Plan and Cost Estimate

II. STUDY AREA

2.1 Location

The study area is situated between 23°45' and 24°00' of south latitude and 46°20' and 46°40' of west longitude with a total area of around 252 km^2, 64 km^2 being the Moji river basin and 188 km^2 being the Cubatão river basin.

2.2 Socio-Economy

2.2.1 Population and labor force

Brazil's population in 1980 was 119.0 million with a population density of 14.0 persons/km^2, as shown in Table 4. This population is expected to reach 150.4 million in 1990 with a population density of 17.6 persons/km^2, and increasing with the average annual growth rate of 2.37% over the last decade. The country's labor force, which was 43.2 million in 1980, was estimated to have increased to 59.5 million by 1987, with an average annual growth rate of 4.68%. Of this increase, 2.9 million (17.8%) has been in the industrial sector and 10.8 million (66.3%) in the services sector. Overall the agricultural sector employed 23.7% of the total labor force in 1987, the industrial sector 23.0% and the services sector 49.7%.

The population of the State of São Paulo in 1980 was 25.0 million, with a population density of 100.9 persons/km^2. This population was estimated at 31.1 million in 1987 with a population density of 125.4 persons/km^2 and increasing by an average annual growth rate of 3.16%. The labor force of São Paulo was 10.4 million in 1980, which was expected to have reached 14.2 million in 1987 with an average annual growth rate of 4.58%. Of this increase of 3.8 million, the industrial sector absorbed 0.9 million (22.1%) and the services sector 2.5 million (64.5%). The percentage distribution by industrial group in 1987 was as follows: 8.5% in the agricultural sector, 34.1% in the industrial sector, and 52.1% in the services sector.

The population in Cubatão municipality in 1980 was recorded as 79,162, with a population density of 345.6 persons/km^2. This population is estimated to be 105,547 in 1990, with a population density of 713.1

person/km^2. The labor force in Cubatão was 31,576 in 1980 and is estimated to be approximately 42,100 in 1990.

2.2.2 Economic performance

(1) Gross domestic product

Gross Domestic Product (GDP) in 1988 was Cr$ 91,952 million (US$ 279.5 billion) at current prices. GDP at current prices has increased astronomically in the last two decades. In real terms, however, it has been Cr$ 12,402 million in 1980, Cr$ 13,111 million in 1985 and Cr$ 14,613 million in 1988 at 1980 constant prices, with an average annual growth of 2.07% for the period of 1980-88.

By industrial origin, the agricultural sector stood at 2.6% in 1988; the industrial sector at 37.9%, being slightly down from 40.6% in 1980, whereas the services sector increased from 49.2% to 52.3%. The percentage share of the agricultural sector dropped drastically from 10.2% in 1980, to 9.0% in 1985 and to 2.6% in 1988.

Per capita GDP in 1988 was Cr$ 636.7 (US$ 1,935) at current prices. In real terms, however, it was Cr$ 0.101 at 1980 constant prices, compared with Cr$ 0.102 in 1980, indicating no real increase in per capita GDP.

Table 5 shows the GDP and per capita GDP since 1970.

(2) Gross regional domestic product

Gross Regional Domestic Product (GRDP) in the State of São Paulo was Cr$ 64 thousand in 1970, Cr$ 341 thousand in 1975 and Cr$ 4,605 thousand in 1980 at current prices, respectively. GRDP accounted for approximately one-third of GDP; 36.6% in 1970, 37.1% in 1975 and 1980. In real terms, GRDP was Cr$ 2,012 thousand in 1970, Cr$ 3,251 thousand in 1975 and Cr$ 4,605 thousand at 1980 constant prices, with an average annual growth rate of 8.63% for the period of 1970-80.

By industrial origin, the agricultural sector represented 3.8% of GRDP in 1980, the industrial sector 48.0% and the services sector 48.0%. The share of the industrial sector compared with 43.9% in 1970 and that of the services sector 50.4%.

Per capita GRDP in 1980 was Cr$ 0.184, which was 1.76 times larger than that of GDP. This ratio has gradually decreased from 1.96 in 1970, and 1.85 in 1975.

(3) Economic performance in study area

The economic activities in the study area are dominated by the industrial sector, represented by the major industrial establishments in Cubatão municipality. This is one of the nation's largest industrial complexes and has been in operation since the 1950s. Its main products are petroleum, petro-chemical products, iron and steel, chemicals, and mixed fertilizers.

In 1980, 126 manufacturing establishments in Cubatão produced Cr$ 298 thousand, accounting for 5.9% of the total value of production in the state of São Paulo. In particular, the chemical industry with 44 registered establishments produced Cr$ 191 thousand, accounting for 64% of the total municipal amount and 21.1% of the total value in the whole state chemical industry. The metallurgy industry, which produced Cr$ 91 thousand (30.5% of the total municipal amount), accounted for 13.4% of this sectoral total value in São Paulo.

Table 6 shows the value of production by industrial sub-sector in the state and in Cubatão. Fig.1 shows the locations of the major industrial establishments in Cubatão.

2.2.3 Present land use

The land in the study area is classified into four main categories: 1) built-up area of urban activities, 2) industrial area, 3) grassland, and 4) forest and bush.

The total land in the study area amounting to 252 km^2 is currently used as follows: 1) 5.0 km^2 or 2.0% of the total land is built-up area, 2) 22.9 km^2 or 9.1% is industrial area, 3) 18.3 km^2 or 7.2% is grassland, and 4) 205.8 km^2 or 81.7% is forest and bush.

The total area of 99.7 km^2 in Cubatão municipality is used as follows: 1) 5.0 km^2 (5.0%) is built-up area, 2) 22.9 km^2 (23.0%) is industrial area, 3) 11.8 km^2 (11.8%) is grassland, and 4) 60.0 km^2 (60.2%) is forest and bush. There are no industrial areas in the three other municipalities comprising São Vicente, São Bernardo do Campo and Santo Andre.

Fig.2 schematically illustrates the present land use in the study area.

2.2.4 Infrastructure

In the study area, there are four(4) arterial highways maintained by the state government, SP-150 or Anchieta runs through the west of the center in Cubatão, interconnecting São Paulo city to the north via São Bernardo do Campo and Santos to the south. SP-160 or Imigrantes, which is located in the west in almost paralell with Anchieta, also runs north and south, connecting São Paulo city and São Vicente to the south. SP-55 or Piaçaguera runs east and west, connecting to the Anchieta at an interchange in the north of the municipal center. SP-148 or Caminho do Mar runs north and south connecting São Paulo city to Cubatão.

The total traffic volume via Anchieta was approximately 9.0 million, or 24,600 daily in 1988, classified into 80% by passenger cars and 20% by trucks.

All the residences in Cubatão municipality were supplied with municipal water in 1988, whereas the sewerage system covers only 1% of all the residences. Approximately 75% of the whole residences were covered by the electricity supply in 1988.

Other social infrastructures include 78 educational institutes, 14 medical facilities, 82 churches, and 64 public facilities.

2.3 Sediment Run-off and Flood Damage

2.3.1 Sediment run-off damage

A large number of small scale landslides on the steep slopes of Serra do Mar have occurred in rainy seasons during the past 30 years. Six(6) major sediment run-offs have occurred since 1960: in 1962, Feb.

1971, Jan. 1976, Feb. 1980, Jan. 1985 and Dec. 1988. Fig.3 shows the location of the past major sediment run-off disasters.

Past Major Sediment Run-off

Date of occurrence			Slope failures in the study area	
Year	Month	Day	Number	Total area (10^3 m^2)
1962	---	---	40	7.6
1971	Feb	24-27	218	70.6
1976	Jan	27-30	303	94.4
1980	Feb	18-19	187	58.6
1985	Jan	22-25	905	194.3
1988	Dec	20-22	215	103.4

Of the above, sediment run-off disaster in Jan. 1985 was the largest in scale. Sediment run-off coupled with torrential mud flow lasted around three(3) days in succession between Jan. 22 and 25, transporting a massive amount of sediment to the industrial complex. The damage included destruction of machines, equipment and installations, damage to inventory stocks, and even temporary suspension of production lines. The total direct damages and losses due to this disaster was reported to amount to approximately Cr$ 17.2 million.

The railway bridge on the left bank of the Moji river was destroyed by sediment run-off on Feb. 1971.

Sediment run-off induced by slope failures occurred upstream of the Canal Norte and the Cachoeira Rivers in the rain of Jan. 27-30, 1976. The sediment run-off discharge of about 100 thousand m^3 intruded into industrial establishments.

Flooding with sand, gravel, timber, and debris occurred between Jan. 20-22, 1988 about 1 km upstream of the confluence of the Rio das Pedras and the Cubatão river. Nine(9) inhabitants were killed, three(3) bridges and several houses were destroyed.

2.3.2 Flood damage

(1) Flood characteristics and mechanism

Major floods appear during the three(3) months of the rainy season from December to February. As soon as heavy rain falls in the mountain area, river water levels rise rapidly in the middle and lower reaches within 2 to 6 hours and the rivers occasionally overtop their banks. The floods are considered to be flashy or torrential. Their duration is usually less than 1 day, but dispersion of flood water in estuaries is frequently delayed by high tides.

The flooding on the fluvial plain of Cubatão thus may be caused by the following factors: 1) overbank flow from the main river, 2) insufficient capacity of the drainage system, 3) aggravation by high tides, and 4) their combined effects.

(2) Past major floods and damage

Past large scale floods occurred in 1968, Feb. 1971, Jan. 1973, Jan. 1976, Nov. 1979, Jan. 1983, Jan. 1985 and Dec. 1988. Of these, the 1971 flood was most serious.

In Feb. 1971, the urban area of Cubatão was inundated by river water which overflowed from the Cubatão and Pereque rivers. In addition, sea water which intruded in the low lying areas near the marsh enhanced the effect of inundation coupled with local rain water, and aggravated the flood. Flooding continued for 3 to 4 hours in most of the urban area and for around 4 days in low lying areas. The maximum inundation depth was approximately 3.5 m in the municipal center. The inundation area extended over about 340 ha, corresponding to this maximum inundation depth. The flood damage was estimated to have been Cr$ 18.5 million at 1973 prices, comprising Cr$ 13.2 million in Cubatão river basin and Cr$ 5.3 million in Moji river basin, respectively.

The right bank of the lower Moji river has been frequently inundated due to overflowing river water and local rain water. It is reported that 12 persons or more died in Vila Parisi area due to the Feb.1971 flood and Vila Parisi area was inundated for 4 to 5 days to a maximum depth of 2 to 3 m in 1972 and 1976.

The flood prone area including flow direction is presented in Fig.4.

2.4 Existing Disaster Prevention Measures

2.4.1 Existing disaster prevention structures

Disaster prevention structures consist of structures for sediment run-off, and flood control. Existing structures and their locations are presented in Fig.5.

Major structures for sediment run-off control are riprap cross dams and gabion dams in the valley areas to protect specific industrial establishments. While, those for flood control are flood dikes to protect the urban area from flooding.

(1) Sediment run-off

The main facilities in the various sectors which were designated by the Special Commission are summarized below.

Main Existing Facilities for Control of Sediment

Sector	Area	Facility	
1	Moji	Riprap cross dam	: 4 Nos.
2	Ultrafertil	Gabion dam	: 3 Nos.
3	Copebras	Rock and earth dam	: 2 Nos.
		Concrete block dam	: 1 No.
		Riprap cross dam	: 1 No.
4	Perequê	Riprap cross dam	: 4 Nos.
		Earth wall	: 700 m
5	Refinaria	Gabion dam	: 9 Nos.
		Concrete wall	: 200 m

(2) Flood control

Some measures for flood control have been provided. The main flood control works are presented below.

a) Cubatão river

The middle and lower reaches of the Cubatão river were improved after the destructive floods of 1971, as summarized below.

- Improved channel of the middle and lower Cubatão (2.5 km long)
- Flood dike with slope protection on right bank of Cubatão river (2.0 km long)
- Cut-off channel of middle and lower Cubatão river (200 m long)
- Improvement of confluence of Cubatão river and Perequê river (500 m long)

b) Moji river

The main works in the Moji river system have been channelization of the Indio river and drainage culverts.

The followings are major related facilities in the Cubatão and Moji rivers.

- Petrobras weir (Cubatão middle reach)
- Pump station (Cubatão middle reach)
- Outlets from Henry Borden Power station (Cubatão upper reach)
- Sabesp intake weir and treatment plant (Cubatão upper reach)
- Union Carbide weir (Perequê middle reach)
- Ultrafertil weir (Moji upper reach)

2.4.2 Non-structural measures

Major non-structural measures in the Cubatão river basin have been relocation of residents in danger areas, a civil defense plan, air pollution control, experimental planting and so on. Of the above measures, the civil defense plan is outlined below.

The objectives of the civil defense plan are 1) to protect residents from disasters (evacuation plan) and 2) to eliminate situations where accidents in the industrial establishments induced by disasters could cause dangerous harm to the residents (management plan).

In this plan, the stepwise warning system consists of four(4) stages: observatory, alert, critical and emergency. The stepwise warning is announced based on information on rainfalls and necessary action is taken up in accordance with guidelines as shown in Fig.6.

2.4.3 Authorities concerned with disaster prevention

The Special Commission consisting of various governmental agencies prepares and implements programs for restoring Serra do Mar in the Cubatão region.

The activities of the Special Commission are actually executed by the six(6) authorities of SMA(environment), CETESB(air pollution control, vegetation), IBt(vegetation), DAEE(sediment run-off and flood control), IPT(geology) and COMDEC(civil defense in Cubatão region).

2.5 Topography and Geology

2.5.1 Topography

The study area is topographically divided into three(3); a plateau area, a mountain slope area and a plain area.

The plateau area which has an undulating surface is forms the eastern edge of the Brazilian plateau with an altitude of 700-800m.

The mountain slope area is covered with natural forest except for the scars of slope failures and is characterized by steep slopes of 30-40^{o} on average and a gentle slope along the Anchieta highway.

The plain area, where dissected fans and fluvial deposits predominate, extend from the confluence of the Cubatão and Moji river to the estuary.

2.5.2 Geology

The study area is mainly dominated by migmatites, schists and sporadically intrusive granite of Pre-Cambrian age as shown in Fig.7 and Fig.8.

The migmatites including gneiss and quartzite are massive, sound and well jointed. They feature steep slopes with gradients of more than 30^{o}, continuous outcrops and large scale waterfalls. The schists are characterized by gentle slopes because of their schistosity and foliation.

Generally, the rocks strike NE-SW and dip at 60-80 NW and are faulted in the same direction as the strike. Colluvial and residual soils are distributed with a thickness of 0.5-2.0m on the steep slopes and more than 2.0m on the gentle slopes.

Dissected fans consisting mainly of sediment run-off deposits of Pleistocene age are found at the foot of mountains. The lower portions are covered by alluvial deposits.

Riverbed deposits vary in size from silt to medium sand in the middle reaches, and pebbles to boulders with thin layers of sand and silt in the upper reaches. From the confluence of the Cubatão and Moji rivers to the estuary, fine sand and clayey soils with organic matter of

Holocene age are found at swamps in the plain area.

2.6 Present River Conditions

2.6.1 River basins and systems

Mainstreams in the study area are the Cubatão river (A= 183 km^2) and Moji river (A= 64 km^2). Main tributaries are the Perequê and Pilões of the Cubatão river, and Piaçaguera, Indio and Onça of the Moji river. The river basins and systems are presented in Fig.9.

The Cubatão river with a total length of 39 km originates near the Billings reservoir on the north west plateau of Serra do Cubatão at an altitude of 700 m. While, the Moji river having a total length of 18 km originates on the north east mountain slope of Serra do Cubatão at an altitude of 800 m.

The average riverbed slopes of the Cubatão river basin are 1/270 on the plateau, 1/10 in the mountain and valley areas and 1/90 to 1/2000 on the plain. Meanwhile, the average riverbed slopes of the Moji river basin are 1/7 in the mountain and valley areas, 1/50 in the upper and middle reaches and 1/2000 on the plain. The longitudinal profiles of both river basins are illustrated in Fig.10.

2.6.2 Carrying capacities of channels

Carrying capacities of the existing channels were estimated by the non-uniform flow method by using the mean high water of spring tide of 0.49 m IGGSP, and Manning's coefficient of roughness of 0.03 in the low water channel and 0.07 in the high water channel.

The estimated carrying capacities are presented in Fig.11. The average carrying capacity in the lower and middle reaches of the Cubatão is from 800 to 1000 m^3/s (w=1/5 or more) except upstream of the Anchieta bridge, which is less than 500 m^3/s. Average capacity in the Perequê is less than 200 m^3/s (w=1/2) downstream of RFFSA bridge and 500 m^3/s (w=1/25) in the upstream reaches. While, that of the Moji was estimated to be below 300 m^3/s (less than w=1/2).

2.7 Meteorology and Hydrology

2.7.1 Climatic conditions

The study area is located in a subtropical climatic zone with mild and moist features. The climate of the study area is broadly classified into summer(wet) from October to March and winter(dry) from April to September.

An average annual rainfall is around 3,400mm on the mountain slopes (EL.500m) and 2,700mm in the plain area. About 75% of the annual rainfall is concentrated in the summer. The monthly rainfall is presented in Fig.12.

The mean temperature in Cubatão city is around 25°C in the summer and 20°C in the winter, and the mean relative humidity is around 74%.

The following are the tidal parameters observed at Santos estuary.

MHHL (Mean high water of spring tide) : 0.491m IGGSP
MSL (Mean sea level) : -0.016m IGGSP
MLLL (Mean low water of spring tide) : -0.908m IGGSP

2.7.2 Rainfall analysis

There are ten rainfall observation stations in and around the study area as shown in Fig.13. The observed rainfall data are of two(2) kinds, daily rainfall data recorded from AM 7:00 to AM 7:00, and hourly rainfall data. The rainfall has been observed since 1936.

Heavy rainfall is generally caused by a cold front and when a front is accumulated by Serra do Mar, and it brings about heavy rainfall with a long duration.

The average monthly rainfall fluctuates from 400 to 460 mm on the mountain slopes and from 320 to 340 mm on the plain area. Rainfall is mostly concentrated at night. The average duration of rainfall is around 50 hours ranging from 34 to 63 hours and about 90% of the total rainfall depth has been concentrated in 2 days in the eight(8) main floods of recent times.

The probable basin mean rainfall and point rainfall were estimated by the Gumbel method as follows:

Basin Mean Rainfall and Point Rainfall

(Unit:mm)

Return Period (yr)	Basin Mean Rainfall(2-day)		Point Rainfall (2-day)	
	Cubatão Basin	Moji Basin	E3-153R (Cubatão)	E3-038R (Moji)
2	205.7	182.3	233.1	191.5
5	281.2	249.9	311.4	262.7
10	331.2	294.6	363.3	309.9
25	394.2	351.1	428.9	369.4
50	441.3	393.0	477.5	413.6
100	487.8	434.7	525.7	457.5

2.7.3 Run-off and discharge analysis

In order to estimate flood run-off, the storage function method was applied through calibration of coefficients from the available flood data. The basin was divided into subbasins as shown in Fig.14.

Probable flood run-off was estimated by using this model and design hyetographs of the Feb.1971 type in the Cubatão river basin and the Feb.1985 type in the Moji river basin. Estimated peak discharges at main points are presented in Table 7.

2.7.4 Flooding analysis

Flooding analysis was conducted by constructing a simple hydraulic model in order to estimate inundation depths in the land areas.

According to this analysis, it is observed that the inundation occurs with a five(5) year return period or more in the Cubatão river and a flood which possibly occurs every year in the Moji river.

2.8 Sedimentation

Sediment and soil materials were examined by taking samples from the riverbed, mountain slope and plateau. Physical tests were conducted for all the samples based on ABNT as summarized below.

Sediment Material Properties

Site	Grain size (D=50, mm)	Uniformity	Specific Gravity (g/cm3)
Cubatão	0.25	1.57	2.74
Perequê	0.19	1.68	2.74
Moji	0.46	2.87	2.74
Upstream of cross dam in Pedras	1.15	4.82	2.78
Mountain slope	0.018	1.97	2.77
Plateau	0.02	6.71	2.77

Channel sediment transport capacities were estimated for the Cubatão, Perequê and Moji rivers by three(3) kinds of sediment formulae. Of these formulae, the estimated capacities by Brown formula which is most applicable to this study are shown in Fig.15.

From this figure, it can be seen that there is wide variety in sediment capacity and therefore some reaches are relatively subject to sudden removal of accumulated sediment.

2.9 Sediment Run-off

2.9.1 Characteristics of sediment run-off

Sediment run-off is the combinated effect of slope failure and unstable torrent bed deposit. Slope failures in this study are small scale landslides on the steep mountain slopes.

(1) Slope failures

Distribution and dimensions

The distribution maps of total slope failures in the last 30 years (1962-1989), and those of six(6) major slope failures are in Figs.16 and 17, respectively. The number and area of slope failures in each sector were also summarized in Table 8. Almost all the slope failures were concentrated on the mountain slopes of each basin of the Moji, Perequê and the lower Cubatão rivers.

The sectors can be classified into five(5) groups on the basis of the number of the past slope failures in 1962-1982 as shown in Fig.18 and indicated below. Of these, groups A, B and C were judged to be the most susceptible areas to slope failures. Groups A and B have had a greater tendency to increasing numbers of slope failures since 1971 as compared with groups C, D and E.

Classification and Number of Past Major Slope Failures

Group	Division No.	Number of Slope Failures per km^2 (1962-1989)	Establishment
A	MR-2,MR-3	50-70	Ultrafertil, Copebras
B	MR-1,CL-6,CL-7	30-50	Union Carbide, Petrobras
C	MR-5,ML-1,CL-5	10-30	Eletropaulo
D	CL-3,CL-4,CL-8	5-10	
E	CR-3,CL-1,CL-2	less than 5	

The average area, depth to slip surface and volume of typical slope failures are considered to be 2,420 m^2, 0.7 m and 1,700 m^3, respectively.

Cause and trigger

Slope gradient, slope configuration and vegetation conditions can be identified as the main cause, and intensive rainfall as the trigger of slope failures.

It is found that the slopes with gradients of less than 20^o are free from slope failures, but those of greater than or equal to 30^o are susceptible to the slope failures. The ratio of slope failures on a rectilinear slope is highest followed by a convex slope. Few slope failures can be recognized on talus slopes. Vegetation degradation by air pollution has been recognized as one of the main causes of slope failures since the mid-1970s. In particular, the vegetation of around 80 percent of the area had been degraded by pollution by 1977 and more than 95 percent by 1985.

With regard to the trigger of slope failures, the Special Commission has clarified the relationship between slope failures and rainfall such as rainfall intensity and accumulated rainfall as shown in Fig.19. As a result of the analysis, 6-hour rainfall was considered to be the best index to estimate total area of slope failures because of high correlation coefficient of more than 0.94 as shown in Fig.20. The following relationships were obtained.

Relationship between Slope Failures and Rainfall

Group	Equation	Correlation Coefficient
A	Y = 0.46(X-63.3)	0.940
B	Y = 0.30(X-80.6)	0.944
C	Y = 0.21(X-80.3)	0.971
D	-	-
E	-	-

Note: Y means total area (10^3 m^2) of slope failures per km^2
X means 6-hour rainfall (mm)

Mechanism

From the viewpoint of the soil mechanism, the reduction of apparent cohesion at the slip surface by the vertical infiltration and the saturated zone enlargement with time are considered to be main cause of the slope failures as shown in Fig.21. Where the vegetation has been degraded by pollution, surface water can easily infiltrate into the colluvial soil and so induce slope failures due to the root decay.

(2) Torrent bed deposit

Sand and gravel with a thin layer of silt/clay are typical torrent bed deposits and one of the main sources of sediment run-off. However, the particle size of the deposits depends on the river conditions such as gradients of river courses, river width, meanders and geology. On the other hand, boulders with a diameter of more than 50 cm are scattered in the river course and in upper reaches of each tributary. The average thickness of torrent bed deposits is 0.5m ranging from 0.3m to 1.0m.

2.9.2 Evaluation of important existing structures

Important existing structures were evaluated as follows:

a) Sector 1 (Moji)

Four(4) riprap cross dams in the upper reaches of the Moji river, about 60 m long and 1.5 m high, are sufficient for sediment control and riverbed stabilization. However, they were judged to be temporary structures because of the random arrangement of riprap materials.

b) Sector 2 (Ultrafêrtil)

Three(3) gabion dams with storage capacities of 24,800 m^3, 138,200 m^3 and 44,200 m^3 above the factory site were expected to be sufficient. However, they were judged to be rather fragiler when under direct attack from sediment run-off in view of many destructive experiences in Japan. A made of industrial wastes with a height of around 10m was expected to large embankment provide important protection against sediment run-off .

c) Sector 3 (Copebrâs)

There are two(2) rock and earth dams, and two(2) riprap cross dams constructed at the foot of the mountain slope at the confluence of the Cachoeiro and the Canal North rivers. The rock and earth dam in the lower reach, about 4-5 m high and 250 m long, was considered to be sufficient, with its maximum sediment run-off storage capacities of 82,000 m^3 for the Cachoeira and 70,000 m^3 for the Canal North river. However, the dam will be destroyed by rushing sediment run-off when sediment run-off exceeds the maximum storage capacity. The capacity of these riprap cross dams evaluated to be insufficient to protect the works.

d) Sector 4 (Refinaria)

A series of nine(9) gabion dams are located on the Pedras river from 10 to 500 m upstream of the oil tanks. They were considered to be insufficient to protect the refinery due to their small storage capacities.

2.10 Vegetation and Soil

2.10.1 Conditions of vegetation and soil

(1) Existing conditions

Since the study area has abundant rainfall and rather warm temperature, the forest of the study area is a tropical rain forest which is characterized by abundant species. The forest structure consists of three(3) strata: upper, middle and lower. The study area is widely covered with coppices (Capoeira) including some subhigh trees of Tibouchina sp.

Soil types in the study area are Red Yellow Latosol, Red Yellow Podzolic Soil, Cambisol and Red Yellow Latosol Intergrade Red Yellow Podzolic Soil. These four(4) soil types are widely and irregularly distributed over the study area. The pH of the soil was checked at five(5) sites which were including in the vegetation survey. The measurement of pH was made in cooperation with CETESB, and was found to range from 3 to 4.

(2) Changes in the damaged vegetation

Based on a set of vegetation maps prepared by CETESB, changes in the vegetation have been studied as shown in Fig.22. From this it will be seen that vegetation conditions have been remarkably degraded since the last half of the 1970s mainly due to air pollution.

(3) Vegetation and air pollution

The causes of this forest damage are well-established. According to the published reports, the damage to the forest is perceived to be as follows:

- the prevailing wind blows from south or west to north or northeast.

- diffusion of emission gases is limited mainly due to the topographic conditions.

- accumulation effects of emission gases can be observed especially on fine or fair days with gentle wind.

- the valley of the Moji river basin functions as a corridor for highly concentrated emission gases.

- a mist often appears and causes wash-out effects of aerosol with very low pH.

(4) Vegetation and slope failures

A number of slope failures have been recorded in the Moji river basin since the early 1960s. Slope failures have occurred both in the forest and shrub areas after torrential rainfall.

Based on existing information, the following processes of slope failures can be pointed out from the view point of vegetation.

- interception of rainfall by leaves on the trees is reduced by die-back,
- roots of damaged trees rot away gradually after the trees die-back,
- soils tied firmly around roots are loosened by the rotting of roots,
- water infiltrates into the soil and the saturated soil conditions cause slope failures.

2.10.2 Present forest restoration plan

IBt (from 1985 to 1986) and CETESB (since 1988) have been conducting the forest restoration activities according to the basic plan as shown in Fig.23.

(1) Experimental planting

Aiming at recuperation of vegetation using the native flora, IBt firstly quickly recover the naked soil so as to avoid erosion and then reintroduced large trees to provide greater soil stability. Herbs taken from adjoining areas and including Araceae, Com postae, Musaceae, shrubs as Piper sp, parts or seeds of trees, mainly of Ficus enormis, Miconia theaezans, Tibouchina granulosa and various species of Leguminosae were used for that experimental planting. The results have showed that the development of native plants used has been similar to, or better than, that of exotics and after 3 years the trees, specially the Melastomataceae are 3m high. However it is necessary to increase research into tropical forest and to control more the air pollution for the vegetation to have a chance of regrowth in the Cubatão region.

(2) Aeroplantation

Aeroplantation activities of seeds have been conducted by CETESB to restore forests since 1988. According to a monitoring survey results below, it is considered that the aeroplantation of seeds is an effective measure for restoration of vegetation.

- Relatively good results were obtained in bare lands or areas covered with coppices.

- Aeroplantation should be complemented with manual replanting of late secondary and climax species.

2.11 Environment

2.11.1 Air quality conditions

The study area has a remarkable agglomeration of air pollution sources emitted from the industrial complex in Cubatão. Facing serious pollution over the entire Cubatão municipality in early 1980's, air pollution control over the pollution sources has been enforced since 1984 and has attained remarkable results. The initial emission load of 557 tons per day in 1984 was reduced by 66% to around 187 tons per day in 1989. Fig.24 shows that the concentration of SO_3 had increased in line with production of the industrial establishments from 1971 to 1979, but the concentration of SO_2 has rapidly decreased during the 1980s.

In 1988, the air quality in Vila Nova and Centro at an acceptable level, but Vila Parisi still showed relatively high values of Suspended Particulate Matter (SPM), of which the maximum concentrations did not comply with the national environmental standard. This was mainly due to the major pollution sources and unfavorable meteorological conditions which could cause high concentrations.

2.11.2 Gases Hazardous to vegetation

Among the various kinds of hazardous gases observed in the study area, such gases as Sulfurous oxides (SOx), Fluoride(HF), Ozone, Ammonia and Nitrogen Oxides (NOx) are considered to be the main pollutants causing vegetation degradation.

To examine the quality of these gases, a specific survey was conducted by CETESB in the Moji river basin in 1985. Based on its results and monitoring data in recent years, the possibility of damage to the vegetation by each pollutant has been evaluated by using the criteria of dose-effect relationships between pollutant and vegetation.

From the evaluation results, HF was identified as the most significant hazardous gas, because the concentrations of 1-hour maximum and daily mean exceed the values which could cause acute damage to vegetation. The second was ozone, a photochemical oxidant.

According to recent study reports, other pollutants such as SPM which contains a high level of sulfuric and nitric acid ions and photochemical oxidants could be other causes of vegetation damage.

2.11.3 Air pollution and degradation of vegetation

The spatial distribution of air pollution intensity was assessed by the overlay of spatial distribution maps of SOx and HF as shown in Fig.25. By using the data of the vegetation maps, the periodical change of affected vegetation by each air pollution intensity area was analyzed as shown in Fig.26. The following characteristics can be observed from the results.

- The number of meshes classified as "Not Affected Vegetation Area" has diminished since 1972, and almost all "Not Affected Vegetation Areas" disappeared in 1985. Moreover, the "Strongly Affected Vegetation Area" appeared in 1985. This shows that the vegetation had been degradated before 1985, especially in the Moji river basin.

- The "Not Affected Vegetation Area" quickly decreased from 1972 to 1977 in the "Most Polluted Area" and "Highly Polluted Area". In the "Polluted Area" and "Moderately Polluted Area", the decline of "Not Affected Vegetation" has been noticeable since 1980. A time lag of vegetation damage has been observed between the areas of relatively high pollution levels and those of pollution levels. This suggests a clear relationship between air pollution intensity and vegetation damage.

III. MASTER PLAN

3.1 Sediment Run-off Disaster Prevention Plan

3.1.1 Basic approach

The basic concept for disaster prevention in this study area is to protect the industrial and urban areas against sediment run-off and floods, considering that the vegetation restoration is an important target to be achieved in mid-long terms.

In spite of significant and continuous efforts by the State of São Paulo, it must be recognized from experience in Japan it will take 20 or 30 years to restore the vegetation conditions. Accordingly, a master plan of the sediment run-off disaster prevention was formulated on the assumption that the present vegetation conditions will not be improved in near future.

(1) Protection area

A protection area having 12 Sabo subbasins as shown in Fig.27 was decided upon mainly in accordance with selection criteria below.

- Possibility of slope failure
- Past major sediment run-off
- Properties to be protected (industrial establishments and infrastructure including local residents)

(2) Design scale

A design scale of a 100-year return period was adopted for the following reasons.

- the importance of the protection area (toxic or explosive liquid and gases, generating station, highway, etc.)
- the uncertainty of natural disaster phenomena
- others (Japanese standard)

(3) Probable sediment run-off amount

The sediment yield from slope failures (Vs), sediment yield from torrent bed deposits (Vt) and potential sediment yield (Vs plus Vt) of each subbasin are basic factors for the sediment run-off prevention plan. Above mentioned, probable sediment run-off amount (Vs, Vt, Vs plus Vt) with return periods of 5, 25, 50 and 100 years were calculated by using probable 6-hour rainfall, peak discharge and other study results. Table 9 shows the probable sediment run-off amount.

(4) Probable sediment run-off discharge

Probable sediment run-off discharge is defined as the sediment amount passing through a control point. Three(3) representative formulae were applied to estimate of the probable sediment run-off discharge; the discharge ratio method, the stream power method and Takahashi's formula. Of the above formulae, Takahashi's formula was judged to be the most applicable due to its food correlation with the past sediment run-off records.

In comparing the potential yield (Vs plus Vt) of sediment run-off with the probable sediment run-off discharge from Takahashi's formula, the smaller figure was taken as the design sediment run-off discharge as shown in Table 10.

(5) Inundation area of design sediment run-off discharge

The inundation area of the design sediment run-off discharge, for use in estimating damage, was evaluated by using an experimental equation, aerial photograph interpretation and field investigations as shown in Fig.28.

3.1.2 Disaster prevention plan

(1) Applicable structural measures

From the geological and topographic points of view, Sabo dams, and channel works including groundsill works can be considered applicable structural measures. The following criteria were taken up in the plan.

sabo dams

- the maximum effective dam height between dam crest and riverbed elevation will be 10 m because of the soft foundation of sand/gravel and the downstream scoring.

- the location of damsite will be determined by the existence of waterfalls downstream.

- Sabo dams have two(2) functions, namely sediment storage and control.

channel works

- Channel works are designed downstream of Sabo damsite in order to prevent channel side erosion.

(2) Structural layout

32 Sabo dams and 11 channel works with a total length of 5,740 m are proposed in the master plan and their locations and dimensions are shown in Fig.29 and Table 11. Typical designs of Sabo dam and channel works are presented in Fig.30.

Main Dimensions of Structures

Sabo Subbasin No.	Structural Measures		
	Sabo Dams No.	Sabo Dams Effective Height	Channel Works (m)
1	1	10 m	860
2	3	7 m,10 m,10 m	560
3	2	10 m each	530
4	2	8 m,10 m	600
5	2	10 m,5 m	450
6	3	10 m each	700
7	6	10 m each	350
8	2	7 m,10 m	420
9	3	10 m each	150
10	2	8 m,10 m	-
11	3	10 m each	560
12	3	9 m,10 m,10 m	560
Total	32		5,740

3.2 Flood Disaster Prevention Plan

3.2.1 Basic consideration

(1) Objective areas

The objective areas are existing urban and industrial establishments on the fluvial plain. The objective rivers and the stretches to be improved were determined as shown in Fig.31 and summarized below.

Objective Rivers and Stretches

River		Stretch
Cubatão	:	RFFSA bridge at rivermouth - upstream of Sabesp weir
Perequê	:	Confluence with Cubatão - Union Carbide dam
Moji	:	Road bridge at rivermouth - Ultrafertil weir
Piaçaguera	:	Confluence with Moji - spillway of Copebras estate
Indio	:	Confluence with Moji - upstream of RFFSA bridge

(2) Design scale

Design scale of a 50-year return period was adopted for the mainstreams of the Cubatão and Moji, and a 25-year return period for their tributaries by the importance of protection area and criteria generally applied in the State of São Paulo.

3.2.2 Alternative schemes and selection of optimum plan

(1) Alternative schemes

Conceivable alternative flood control schemes were developed as presented in Fig.32, and outlined below.

Cubatão river system

Alternative C-1 : Channel improvement by flood dike for existing Cubatão (L = 6 km) and Perequê (L = 2 km) rivers.

Alternative C-2 : Construction of flood diversion tunnel (L = 0.6 km) and channel improvement by dike for existing Cubatão and Perequê rivers.

The alternative C-2 was composed of two(2) schemes; C-2(1) with a diversion discharge of 1200 m3/s, and C-2(2) with a diversion discharge of 900 m3/s.

<u>Moji river system</u>

Alternative M-1 : Channel improvement by flood dikes for existing Moji (L = 4.5 km) and their tributaries (L = 5 km).

Alternative M-2 : Construction of new channel with flood dikes on the lower Moji river and channel improvement by flood dikes for existing channels.

For the above alternative schemes, design discharge distribution is shown in Fig.33.

(2) Selection of optimum plan

The optimum scheme for master plan was selected least cost method. The financial cost excluding price contingency for each alternative scheme was estimated as follows.

Construction Cost

(Unit:US$$10^3$)

River	Alternative Schemes		
Cubatão	C-1 48,400	C-2(1) 46,040	C-2(2) 33,940
Moji	M-1 22,680	M-2 18,560	

From the above results, scheme C-2(2) was selected for the Cubatão river system and M-2 for the Moji river system.

3.2.3 Disaster prevention plan

The overall scheme of the proposed plan is schematically presented in Fig.34. The design discharge distribution for the proposed master plan is shown in Fig.35. The proposed master plan is outlined below.

(1) Cubatão river system

A diversion tunnel is proposed to directly divert the flood into the sea through the marsh area. The diversion tunnel is designed for a design discharge of 900 m3/s. The diversion works consists of diversion weir and overflow dike, inlet open channel (L = 400 m), tunnel (L = 600 m) and outlet open channel (L = 200 m).

The existing Cubatão river and the lower reaches of the Perequê river are to be improved by means of heightening of the existing dikes and construction of new dikes.

The proposed longitudinal profiles, cross sections and typical design of structures are presented in Fig.36.

Main construction works of the proposed master plan are as follows:

1) Construction of diversion works

- Open channel	:	600 m
- Tunnel	:	600 m X 2 Lanes

2) Channel improvement

- Length		
Cubatão	:	6.0 km
Perequê	:	0.7 km
- Excavation	:	511,000 m^3
- Embankment	:	157,000 m^3
- Bank protection	:	6,700 m^2

(2) Moji river system

The existing lower reaches of the Moji are proposed to be shifted to the north of the existing RFFSA railway line. The existing middle and upper reaches of the Moji are to be improved by means of channel excavation and construction of flood dikes. The Ultrafertil intake weir is to be reconstructed.

For the middle reaches of the existing Piaçaguera, a new channel is to be constructed by excavation of the low water channel. Also the Indio river is to be improved by deepening the existing channels.

The proposed longitudinal profiles, cross sections and typical design of structures are shown in Fig.37 and Fig.38.

1) Channel improvement of Moji

- Length	:	4.5 km
- Excavation	:	1,200,000 m3
- Embankment	:	200,000 m3
- Bank protection	:	6,300 m2

2) Channel improvement

- Length		
Piaçaguera	:	3.7 km
Indio	:	1.3 km
- Excavation	:	200,000 m3
- Embankment	:	50,000 m3
- Bank protection	:	18,500 m2

3.3 Forest Restoration Plan

3.3.1 Basic considerations

(1) Present conditions

The present forest restoration plan, of the State of São Paulo, identified as long-term plan, can be divided into two(2) stages as shown in Fig.23.

First stage comprises planting and aeroseeding of pioneer species over the degraded area aiming at creating capoeiras that protect from soil erosion and slope failures. Second stage is replantation of the climax species in Capoeira areas in order to accelerate the regeneration process of the Atlantic forest.

According to the monitoring survey conducted by CETESB in February 1990, it is concluded that the planting and the aeroseeding at the first stage brought effective results and will warrant the creation of capoeira formation in the next five(5) to eight(8) years.

Therefore, the first stage is judged to have been established satisfactorily.

The second stage can be identified and initiated simultaneously to the implementation of the sediment run-off and flood disaster prevention plan.

(2) Replantation area

Replantation areas of twenty(20) areas located at strategic points with a catchment area of 40 x 20 m, 0.4 ha, respectively, were selected by CETESB and IBt as shown in Fig.39.

3.3.2 Forest restoration plan

The forest restoration plan with the target year 2000 consists of selection of climax species, seedlings production, service road restoration, topographic works, planting works, maintenance works and support works. One thousand trees will be planted in each proposed area after selection of climax species by conventional technics.

3.4 Non-structural Measures

Non-structural measures are effective and of vital importance to minimize damage by the natural disasters, in combination with existing structural measures.

Non-structural measures in the study area have been formulated by the Special Commission. Of these, a civil defense plan consisting of evacuation and management plans has been effectively undertaken.

However, the following points can be suggested from experience in Japan:

a) Preparation of a hazard map and its publication are required. Although this will present difficulties, such information is indispensable for enlightening residents and persuading industrial establishments.

b) The existing warning system of the civil defense plan is divided into four(4) stages and subdivided into several levels. It is considered reasonable to judge the warning stage based on a criteria curve, however it is desirable and practical to simplify the existing judgment systems. Moreover, the criteria for the above need to be updated as new related data is accumulated.

c) Existing observation stations need to be well managed in order to collect rainfall data promptly and accurately.

d) More and accurate information should be promptly distributed to industrial establishments and residents. Therefore, it is desirable to simplify the existing transmitting system since the existing system is complicated..

e) Evacuation training should be adequately carried out by COMDEC for industrial establishments and residents. Training of COMDEC members who are responsible for evacuation activities is also indispensable.

3.5 Implementation Program

3.5.1 Project components

The main components of the master plan for sediment run-off and flood disaster prevention works ,and forest restoration plan are tabulated as follows:

Project Components

Sediment Run-off and Flood Disaster Prevention Works

Item	Component	Type	Quantity
- Sediment run-off disaster prevention works			
	Sabo dams	Concrete	180,000 m^3 (32 sites)
	Channel works	Wet masonry	5.7 km (11 sites)
	Groundsills	Concrete	2 Nos.
- Flood disaster prevention works			
(Cubatão Basin)	Dike		157,000 m^3
	Excavation		256,000 m^3
	Dredging		256,000 m^3
	Revetment	Wet masonry	6,700 m^3
	Riverbed protection	Concrete	1 No.
	Diversion tunnel	Concrete	600m X 2 Nos.
(Moji Basin)	Dike		250,000 m^3
	Excavation		846,000 m^3
	Dredging		584,000 m^3
	Revetment	Wet masonry	24,800 m^2
	Riverbed protection	Concrete	3 Nos.

Forest Restoration Plan

Item	Quantities
Selection of climax species	-
Seedling production	24,000 units
Service roads restoration	35 km
Topographic works	80,000 m^2
Planting works	20,000 units
Maintenance works	20,000 units
Support works	-

3.5.2 Implementation schedule

The master plan consisting of the sediment run-off disaster prevention, the flood disaster prevention works and the forest restoration plan is formulated to be implemented up to in two stages by the target year 2000.

The implementation schedule of the master plan was prepared taking into account the construction sequence and conditions including priorities, as shown in Fig.40 and Fig.41. The total project period is assumed to be 10 years, in which the project period will be divided into two(2) stages.

Assuming that all the foreign currency component is financed by an international financing agency, first five(5) years (1991 - 1995) is scheduled to include the following activities: preparation of the implementation program (I/P), project appraisal, exchange of note (E/N), detailed design (D/D), tendering and construction of the structures with high priority in the first stage.

The procedure for implementation of construction of other facilities in the second stage is scheduled to start immediately after the construction in the first stage is commenced as shown in Fig.40 due to limited period.

3.5.3 Project cost

(1) Terms and conditions

The construction cost for the master plan was estimated on the basis of preliminary design, layouts and construction planning. The following basic assumptions and conditions were adopted for cost estimation.

a) Price level

The price level for estimation of costs and benefits was set at the end of June 1990.

b) Official exchange rate

The official exchange rates were fixed as follows:

US$ 1.00 = Cr$ 60 = ¥ 150

c) Currency of cost estimate

The construction cost was estimated by dividing it into foreign and local currency components in accordance with the origin of materials. The currency of the cost estimate was expressed in United States dollars (US$) for the foreign and local currency components, which include the following items:

Foreign currency component

- cost of plant and equipment
- cost of foreign portion of local materials
- cost of engineering services for consultant

Local currency component

- labor wages
- cost of local materials
- compensation cost
- administration cost
- local portion of engineering services
- cost of spare parts

d) Labor wages, material and equipment costs

The direct construction costs of civil works was estimated from unit costs multiplied by the corresponding work quantities. The unit cost of each work item, which was estimated on the basis of the construction plan, consists of labor wages, material and equipment costs.

The labor wages were generally considered as the local currency component and were calculated based on the minimum wage and the social charges.

The cost of materials available on the local market was in principal counted into the local currency component. However, certain proportions were assumed to be included in the foreign currency component according to their use of imported raw materials and production facilities. The latter is termed an indirect foreign currency portion.

The cost of equipment was counted on the basis of current competitive prices in Japan. The equipment cost consists of depreciation costs, repair costs and administration costs.

e) Constitution of capital cost

The construction cost was estimated in accordance with the direct construction cost, costs for compensation, administration, engineering services, and physical and price contingencies. Physical contigency is provided for the physical changes of work quantities and conditions, whereas price contingency is considered to cover price escalation in the whole construction period.

Main cost items are enumerated below:

<u>Direct cost</u>

- preparatory works
  5 to 15 percent of construction cost
- construction costs

<u>Compensation cost</u>

- residential property
- factory industrial property
- residential area land
- non-residential area land
- factory area industrial land

<u>Administration cost</u>

- five(5) percent of direct construction cost for local currency portion

<u>Engineering services</u>

- 10 percent of direct construction cost

Physical contingency

- 15 percent of the total cost

Price contingency

- three(3) percent for both foreign and local currency portions

(2) Unit costs for major works

The unit costs for major works were estimated based on data for labor wages, material and equipment costs. These estimates were made through discussions between the study team and the agency concerned (DAEE), and were judged to be reasonable in comparison with the unit costs of similar projects in this country.

(3) Construction cost for master plan

The financial construction costs for the master plan were estimated for the sediment run-off and flood disaster prevention works.

The financial cost for the sediment run-off disaster prevention works was estimated at US$ 75.0 million as presented in Table 12. The direct and indirect costs were estimated at US$ 45.9 million and US$ 29.1 million, respectively. A summary of the financial cost excluding price contingency in each basin is shown in Table 13.

The financial costs for the flood disaster prevention works in the Cubatão and Moji river basins were estimated at US$ 43.2 million and US$ 22.7 million as presented in Table 14. The direct and indirect costs were estimated at US$ 25.5 million and US$ 17.7 million for the Cubatão river basin and US$ 13.9 million and US$ 8.8 million for the Moji river basin, respectively. A summary of the financial cost excluding price contingency of alternative schemes is shown in Table 15.

The total financial cost for the master plan was estimated at US$ 141.1 million, as tabulated in Table 16.

3.6 Project Justification

3.6.1 Conditions for estimate of economic costs and benefits

The economic costs and benefits were estimated applying the following conditions and assumptions.

a) The project life of the structures was assumed to be 50 years after completion of the construction works.

b) The price level for estimation of costs and benefits was set at the end of June 1990.

c) The official exchange rates were fixed as follows:
US$ 1.00 = Cr$ 60 = ¥ 150

d) As for transfer payments such as taxes and duties, it was assumed that goods and services procured locally would include the transfer payment of 10 % in market prices and that those imported from abroad would exclude any transfer payment.

e) Economic wages of local labor were assumed to be 50 % of the actual market wages in consideration of the social conditions of (a) the unemployment situation in this country in recent years, and (b) social charges included in the wages, which consist of social security and fringe benefits, accounting for around 50 % of the total wage payment.

f) Regarding compensation, it was assumed that the economic cost was equivalent to 30 % of the financial cost, considering marginal productivity of the land to be acquired.

g) Economic benefit was assumed to be 90% of the financial benefit by applying the standard conversion factor, taking into account the combined effects eliminating internal transfer and shadow pricing.

h) Taking account of present land use and the distribution of existing damageable assets, the following assets were considered as direct damageable items: (a)residential property, (b)industrial establishments and (c)commercial and service establishments.

i) In regard to other damage items such as infrastructure and indirect damages, the following rates were applied: 0-25% for infrastructure to damageable properties, and 10-100% for indirect damage to the total direct damages, depending upon the importance of the properties and the social impacts due to disasters.

3.6.2 Economic cost

The financial construction cost generally consists of six(6) items as follows:

a) direct cost
b) compensation cost
c) administration cost
d) engineering services
e) physical contingency
f) price contingency

Of these costs, price contingency was excluded in the economic construction costs. Other costs were converted into the economic costs by adjustment based on the aforesaid conditions and assumptions.

The economic cost for the sediment run-off disaster prevention works was estimated at US$ 54.4 million comprising US$ 41.1 million for direct cost, US$ 0.06 million for compensation cost, US$ 2.1 million for administration cost, US$ 4.1 million for engineering services and US$ 7.1 million for physical contingency.

The economic cost for the flood disaster prevention works in the Cubatão river basin was estimated at US$ 30.9 million comprising US$ 23.3 million for direct cost, US$ 0.06 million for compensation cost, US$ 1.2 million for administration cost, US$ 2.3 million for engineering services, and US$ 4.0 million for physical contingency.

The economic cost for the flood disaster prevention works in the Moji river basin was estimated at US$ 16.9 million comprising US$ 12.7

million for direct cost, US$ 0.08 million for compensation cost, US$ 0.6 million for administration cost, US$ 1.3 million for engineering services and US$ 2.2 million for physical contingency.

Operation and maintenance(O&M) costs are incurred annually during the project life after completion of construction. The rate of 1.0 % of the construction cost was assumed to be O&M cost for the sediment run-off disaster prevention works and 0.5 % of that for the flood disaster prevention works. From the above, O & M costs for the sediment run-off and flood disaster prevention works were estimated at US$ 0.36 million and US$ 0.17 million, distributed as US$ 0.11 million and US$ 0.06 million for Cubatão and US$ 0.06 million and Moji river basins, respectively.

3.6.3 Economic benefit

The economic benefits were estimated as the reduction in damages or losses to damageable properties, which will be brought about by implementation of the designed disaster prevention works. With the design scale of 100-year return period for the sediment run-off disaster prevention works at the master plan stage, the benefits were considered to be commensurate with the reducible amount of annual mean sediment run-off damages corresponding to the design scale.

Meanwhile, the benefit of the flood protection works, which will accrued from implementation of the project with the design scale of 50-year return period, was estimated on the basis of the effect of reduction in annual mean flood damages to assets and properties in and around the flood protection areas. In addition, the benefit was also estimated on the basis of conceivable socio-economic projections up to the year 2020 in the study area.

(1) Sediment run-off damages

Most of the target properties which would be vulnerable to the sediment run-off disaster were identified as the industrial establishments located in the foot of Serra do Mar. Large scale petrochemical refinery establishments, in particular, are the most serious targets, followed by the substation facilities and state highway.

Taking into account the identification of damageable properties above, the sediment run-off damage was estimated for each establishment. Damageable properties of respective industrial establishments were estimated on the basis of depreciable assets and inventory stocks, which were basically valuated from the sector-wise asset holdings in the state, and value of production of each establishment, adjusted by the price index. Damage rates to properties was assumed to be 50% for buildings, equipment and installations, and 80% for moveables, vehicles and inventory stocks.

Probable sediment run-off damage and annual damage were estimated for 12 Sabo subbasins under the present conditions below.

Probable Sediment Run-off Damage and Annual Damage

(Unit: US$ million)

Sabo Subbasin	Return Period				Annual Damage
	5	25	50	100	
1	-	-	-	-	-
2	0.4	6.0	7.0	7.7	0.8
3	0.3	4.6	8.1	8.1	0.6
4	0.3	0.5	0.6	0.7	0.2
5	0.1	0.1	0.1	0.2	0.1
6	0.2	0.3	0.3	0.8	0.1
7	1.9	3.6	4.6	6.3	0.8
8	0.5	0.6	0.6	0.6	0.1
9	0.1	0.6	0.8	1.3	0.1
10	0.1	0.6	1.4	1.9	0.1
11	1.4	2.2	2.7	3.1	0.5
12	0.9	2.4	9.5	12.7	0.6

Note: 1 US$ = 60 Cr$

(2) Flood Damage

Damageable properties in each flood protection area were identified from the topographic maps, aerial photographs and field investigation, by using a mesh survey with a grid of 500m interval squares. The potential flood damage was then estimated as the product of three(3) components: number of properties by type, unit value of each property and damage rate corresponding to the inundation depth.

In the flood protection area of approximately 12.0 km^2 in Cubatão river basin, damageable properties were identified as follows: 8,400 residences, 90 medium and small manufacturing establishments, 420 commercial and services establishments, and six(6) major industrial establishments. On the other hand, in the flood protection area of around 8.0 km^2 in Moji river basin, the following damageable properties were also identified: 760 residences, 70 small scale commerce and services shops, and nine(9) major industrial establishments.

Probable flood damages and annual damages were estimated for both river basins under the present conditions below.

Probable Flood Damage and Annual Damage

(Unit: Cr$ million)

Basin	Return Period						Annual Damage
	2	5	10	25	50	100	
Cubatão	1.1	1.8	2.5	4.3	6.6	7.8	1.2
Moji	0.9	1.4	2.1	2.4	2.8	3.1	0.9

Note: 1 US$ = 60 Cr$

3.6.4 Economic evaluation

An economic evaluation was carried out to ascertain the economic viability of the master plan by comparing the economic costs and benefits. The economic Internal Rate of Return (EIRR) was applied as a criterion for economic evaluation.

Based on the cost stream disbursed in accordance with the construction schedule, and the benefit flow to be accrued from the proposed project, the EIRR was calculated at 11.2% for the master plan of the sediment run-off disaster prevention works. The economic analysis by Sabo subbasin is summarized below.

Economic Evaluation of Sediment Run-off Disaster Prevention Works

Sabo Sub-basin	EIRR (%)
1	-
2	12.7
3	14.7
4	2.4
5	1.8
6	2.1
7	17.0
8	9.1
9	3.9
10	11.8
11	11.9
12	12.9
Master Plan	11.2

Economic evaluation of the flood protection works, however, showed an EIRR of 5.4% for the Cubatão river basin, and 8.3% for the Moji river basin.

3.6.5 Project justification

Based upon the results of the economic evaluation above, the master plan for the sediment run-off prevention works with a design scale of a 100-year return period could be justified. Moreover, taking into account unmeasurable social impacts and intangible damage which could be caused by sediment run-off disasters, this master plan was judged to be highly viable for implementation.

With regard to the master plan for flood protection works, major industrial establishments are at high risk of repeated frequent inundation by overflowing from the Moji river and its tributaries. If future land use in the Moji river basin is taken into consideration, the probable flood damage will be significantly higher than that of the present projection. If the above situation and economic evaluation are taken into account, the flood protection works of the Moji river basin will be seen to be as highly justified as the master plan with a design scale of a 50-year return period.

IV. SELECTION OF PRIORITY PROJECT

4.1 Sediment Run-off Disaster Prevention Plan

A priority project for a target year in the mid-1990s was selected from the master plan formulated above. The selection criteria were as follows:

(1) Selection of subbasins

Selection of subbasins was made as follows:

1st criteria : Subbasin with highly serious disaster potential, such as contamination and/or explosion of toxic liquid and gases was selected as the first priority without any other consideration such as economic evaluation.

2nd criteria : Other subbasins were selected from economic viability as evaluated by EIRR.

The following table shows the results of the above selection for the priority project.

Selection Results for Priority Project

Item	Subbasin No.											
	1	2	3	4	5	6	7	8	9	10	11	12
1st criteria		+	+				+	+				
2nd criteria	(-)	12.7	14.7	2.4	1.8	2.1	17.0	9.1	3.9	11.8	11.9	12.9
Selected Projects		*	*				*	*		*	*	*

Note: + means first priority subbasins having possibility of flowing out toxic gases and liquid in sediment run-off disaster
* means selected priority project

(2) Selected priority project

Nine(9) Sabo dams, six(6) channel works in seven(7) subbasins including groundsills were selected as shown in Fig.42.

These structural measures were designed for the probable sediment run-off discharge of about a 25-year return period, which is approximately equal to the past maximum discharge of 1985. The following table shows the structural measures for the priority project.

Structural Measures for Priority Project

Sabo Subbasins No.	Structural Measures		
	Sabo dams		Channel works (m)
	Nos.	Effective Height(m)	
2	1	7	560
3	1	10	530
7	3	10,10,10	350
8	1	7	420
10	1	8	-
11	1	10	560
12	1	9	560
Total	9		2,980

4.2 Flood Disaster Prevention Plan

The flood disaster prevention master plan was formulated against a 50-year return period for the mainstreams of the Cubatão and Moji, and a 25-year return period for their tributaries, the Perequê, Piaçaguera and Indio.

The Cubatão river was improved in 1975 immediately after the flood in 1971 and it is now observed to overflow its banks once in approximately five(5) years, while in the case of the Moji it overflows its banks every year.

According to the economic evaluation of the master plan, the plan for the Moji river system was considered to be viable, (EIRR=9%) in comparison with similar projects in this country.

From the viewpoint of the carrying capacities of the object river systems, the principal requirement of the mainstreams of the Cubatão and Moji rivers is to increase the channel capacities against floods which occur once in every 10 years or more often. Therefore, the priority project will be designed for a 10-year return period.

Accordingly, channel improvement and flood dike construction on the Moji river including the lower reaches of its tributaries were selected as the priority project. The length to be improved is around 4.5 km from its confluence with the Cubatão river to Ultrafertil dam.

4.3 Forest Restoration Plan

Forest restoration works to be done by 1995 were selected in accordance with the implementation program of the master plan. The work items are as follows:

- Selection of climax species
- Seedling production
- Service road restoration
- Topographic works
- Planting works
- Maintenance works

Work Items

The detailed work items of the priority project upto 1995 are summarized as follows:

- Selection of climax species

  The climax tree-species for the replantation will be selected among the species groups of primitive Atlantic forest in the south Brazil listed in Table 17. The final selection will be made on the basis of evaluation results of the pollutant level of 1991/92 foreseen in the pollution control plan.

- Seedling production

  Twenty-four thousand (24,000) seedlings of the selected species will be produced and distributed in the replantation areas. Of them, 1,000 seedlings will be used for each area, 20,000 in total, 4,000 for eventual loss.

Official green house of the State of São Paulo will be responsible for seedling production.

- Service road restoration

Service road restoration including road bed regularization and small drainage works is planned for smooth transportation to the replantation area. The total length of service road to be restored is 35 km.

- Topographic works

Topographic works such as topographic mapping will be conducted in order to demarcate the replantation areas.

- Planting works

The seedlings with their height of 0.4 to 1 m will be planted regularly taking into account fertilization related to the soil conditions.

- Maintenance works

Maintenance works such as disease and curse control, and substitution of the dead seedlings will be planned during one year just after completion of planting works.

- Support works

This works are of the project management and the replantation activities monitoring.

(2) Quantities of the works

The quantities of the forest restoration works in the priority project is summarized below:

Item	Quantities
Selection of climax species	-
Seedling production	24,000 units
Service roads restoration	35 km
Topographic works	80,000 m^2
Planting works	20,000 units
Maintenance works	20,000 units
Support works	-

(3) Project cost

The project cost for the priority project was estimated on the basis of the restoration plan in the master plan as shown below:

(Unit: US$ 1,000)

Item	Project Cost
(1) Direct Cost	
. Service road	175
. Topographic works	70
. Seeding production	96
. Planting works	80
. Maintenance works	20
. Management works	600
. Monitoring by aerophotos	60
Sub-total	1,101
(2) Contingency (20%)	224
Total	1,325

V. FEASIBILITY STUDY ON PRIORITY PROJECT

5.1 Preliminary Design and Work Quantities

5.1.1 Sediment run-off disaster prevention works

The preliminary design for the priority project was carried out based on the topo-maps at a scale of 1 to 500 for Sabo dams, and topo-maps at a scale of 1 to 5,000 and river cross sections for channel works and groundsills. The design for Sabo dams, channel works and groundsills in each basin are illustrated in Fig.43 and Fig.44.

As for the crest width of Sabo main dam, 3 m was designed from the viewpoint of stability of dam crest and the safety against the damage by sediment. For the downslope, the gradient of 1:0.2 was employed and the gradient of the upslope was obtained by the stability analysis. The excavation line of foundation and abutment portions for each damsite was decided based on the preliminary results of geological investigations.

The overflow section was provided at such position and direction that the overflow water concentrates to the center of the downstream to avoid any river bank erosion. The bottom width of overflow section was determined to be almost the same as a river width to minimize the overflow water depth. More detailed design criteria is presented in Annex-L.

The channel alignment was planned to be straight as much as possible. If it is difficult, the value of radius divided by channel width was determined to be greater than 5. The channel slope was designed to be less or equall to the half of original riverbed slope.

The channel cross section was decided by uniform flow or non-uniform flow calculation method. Manning formula was adopted to estimate mean flow velocity. The flow carrying capacity was designed below the ground level at the right and left sides. The channel width could be obtained taking into account the present river width, and relationships between the existing channel width and catchment area in Japan. The revetment with a wet stone masonry having a slope of 1 to 0.5 was employed at the both sides.

The height of groundsill should be designed at less than 5 m. The crest width was planned to be 1.0 m to 2.0 m. The downslope of groundsill was determined based on the stability analysis when the height of groundsill was greater than 3.5 m. It was designed to be the vertical when the height of grounsill was less than 3.5 m.

The work quantities of Sabo dam, channel works and groundsill were estimated by using the typical sections obtained from the topo-maps available. Estimated work quantities for the sediment run-off disaster prevention works are summarized in Table 18.

5.1.2 Flood disaster prevention works

The preliminary design for the priority project was conducted based on the topo-maps at a scale of 1 to 5,000 and river cross sections.

The design for plan of river alignment, river profile and river cross sections are illustrated on Figs.45 to 46.

The design of river plan, profile and cross sections were made based on the planning criteria in Annex-I. The side slope of new channel in the Moji river, which is one of the major works for flood disaster prevention plan was designed to be 1 to 2.0, because the slope of present river channel having a side slope of about 1 to 2.0 is stable even though N value of lowflow channel portion is less than 1 from the available geological investigation results near this area.

The revetment by the wet stone masonry was designed in the bending portion, the area where river flow is concentrated and the area close to the planned related facilities such as culvert, Ultrafertil intake weir and railway bridge.

The work quantities for the flood disaster prevention works were estimated by using the typical sections obtained from the topo-maps available as shown in Table 19.

5.2 Construction Plan

5.2.1 Conditions and assumptions

The contract system considering the participation of foreign contractors associated with Brazilian contractors are proposed to execute the project works.

The bill of quantities contract system will be applied based on the open competitive bid accompanied with the prequalification of bidders. The fund required for the implementation of project will be allocated by the national budget and supporting loan from an international financing agency. Throughout the implementation period, the project will be substantially managed and administrated by DAEE headquarters and its branch offices in association with other state agencies and engineering consulting firms. The projects will be proposed to be executed with the several packages taking into account the project scale, amount of construction costs and secure implementation, as follows.

Package A --- Sediment run-off disaster prevention works for basin No.2 and No.3

Package B --- Sediment run-off disaster prevention works for basin No.7 and No.8

Package C --- Sediment run-off disaster prevention works for basin No.10, No.11 and No.12

Package D --- Flood disaster prevention works in the Moji river

As for the working conditions, the workable days for earth works, rock works and concrete works were estimated at around 140 days, 210 days and 230 days from the meteorological data, respectively. Earth works were planned mainly in the dry season between May and November. The conditions of access to the site, power supply and communication system are generally well constructed and maintained. Therefore, the necessary preparatory works were temporary buildings, arrangement of spoil bank and minor works for access road, power supply and communication system for site use. The sufficient number of unskilled and skilled labor is available in and around the study area and daily working hour is set at eight(8) hours.