FEDERATIVE REPUBLIC OF BRAZIL

MINISTÉRIO DA AGRICULTURA
DEPARTAMENTO NACIONAL DE OBRAS DE SANEAMENTO

FEASIBILITY STUDY ON THE FLOOD CONTROL PROJECT IN THE LOWER ITAJAÍ RIVER BASIN

FINAL REPORT

MAIN REPORT

MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request from the Government of the Federative Republic of Brazil, the Government of Japan decided to conduct a study on the Flood Control Project in the Lower Itajai River Basin and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Brazil a survey team headed by Mr.Shigeo Ohnuma, NIPPON KOEI CO.,LTD, composed of members from PACIFIC CONSULTANTS INTERNATIONAL from October, 1988, to March, 1989, and from June to October, 1989.

The team held discussions with concerned officials 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 for their close cooperation extended to the team.

March, 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

FEASIBILITY STUDY
ON
THE FLOOD CONTROL PROJECT
IN
THE LOWER ITAJAI RIVER BASIN

Date : March 31, 1990

Mr. Kensuke YANAGIYA
President
Japan International Cooperation Agency
Tokyo

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit herewith the Final Report on the Feasibility Study on the Flood Control Project in the Lower Itajai River Basin. This report presents the result of the study performed on the basis of the Inception Report agreed between DNOS and JICA on November 1988.

The report consists of the main report and its supporting report and the data book. The main report presents the flood control plan including its background, conditions and assumptions. The supporting report describes the details of the conditions, methodology, etc. for planning. Besides, the data book compiles basic data of topographic survey, geotechnical investigation and coastal investigation, which were used for flood control planning.

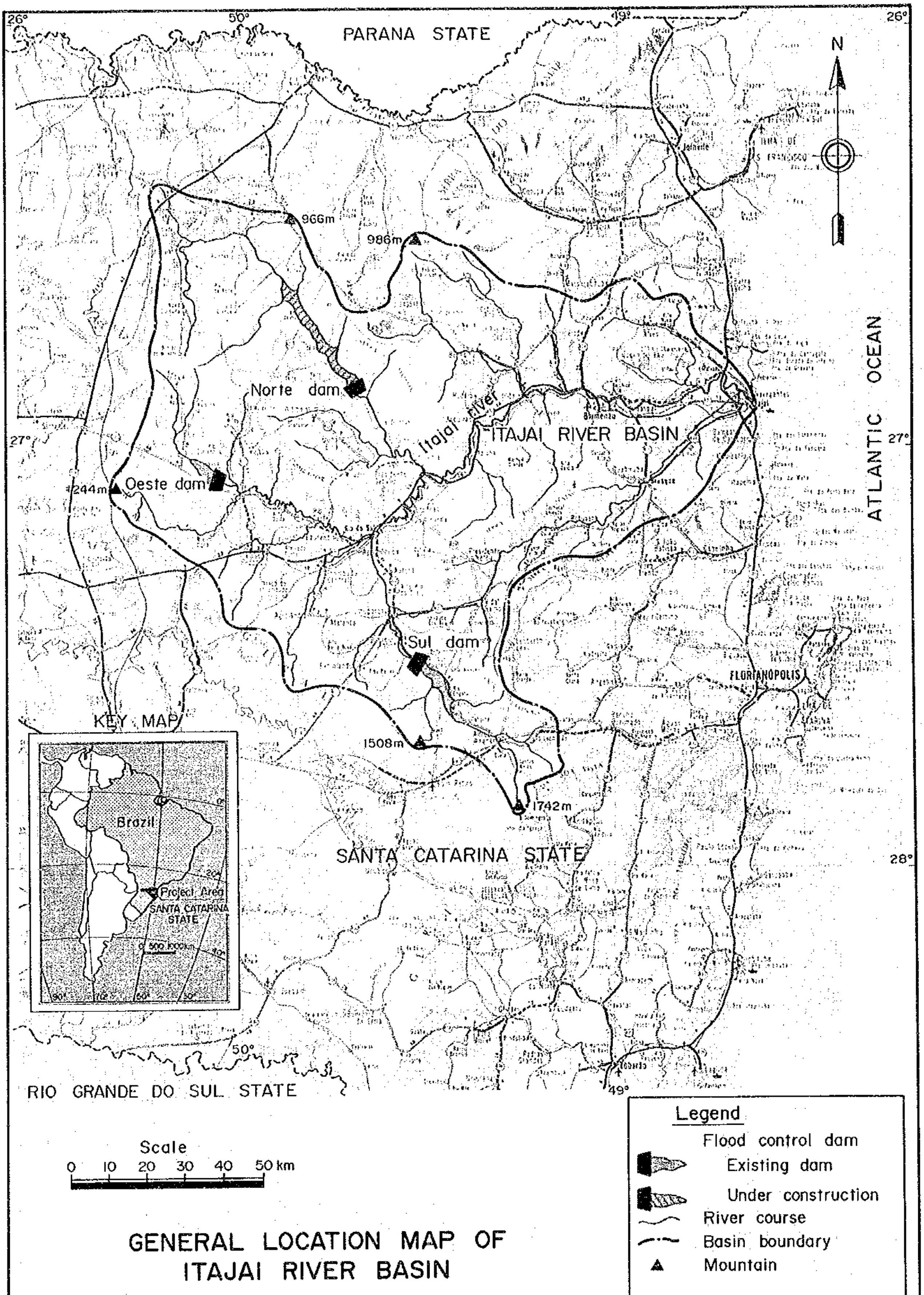
All members of the Study Team wish to express grateful acknowledgement to the personnel of your Agency, Advisory Committee, Ministry of Foreign Affairs, Ministry of Construction, Japanese Embassy at Brasilia, Japanese Consulate at Rio de Janeiro and Port Alegre, and the officials concerned of the Government of Federative Republic of Brazil for their close cooperation extended to the Study Team.

The Study Team sincerely hopes that the study results would contribute to socio-economic development and well-being in the lower Itajai river basin.

Yours sincerely,

S. Ohnuma

Shigeo OHNUMA
Team Leader



GENERAL LOCATION MAP OF ITAJAI RIVER BASIN

Summary

FEASIBILITY STUDY ON THE FLOOD CONTROL PROJECT IN THE LOWER ITAJAI RIVER BASIN

SUMMARY OF FINAL REPORT

1. This is a final report on the feasibility study on the flood control project in the lower Itajai river basin prepared in accordance with the content of the Inception Report agreed between DNOS and JICA in November 1988.

2. This report comprising main report, its supporting report and data book presents the result of the feasibility study on the flood control project in the lower Itajai river basin including urban drainage plan in Itajai city. The main report in this report presents the summary of the supporting report and technical and economical feasibility of the project. The supporting report describes details of the topographic survey, hydrological study, geotechnical investigation, coastal investigation, socio-economic and flood damage study, flood control plan including urban drainage plan, environmental study, construction plan and cost estimate, and study on flood forecasting and warning system. The data book compiles river cross sectional data in the lower Itajai river stretch and coastal and geotechnical data. The result of the feasibility study is presented hereinafter.

TOPOGRAPHIC SURVEY

3. The topographic survey to prepare the maps and river cross sections necessary for the feasibility study was executed during 5 months from the end of October by a local contractor under the supervision of the JICA Study Team. The topographic materials produced for the study works are as follows:

a) Topographic map on a scale of 1:5,000 with contour interval of 1 meter in the lower basin covering an area of about 120 km^2.

b) River cross sections of the Itajai river from the river mouth to the diversion weir site proposed in the master plan, the Itajai Mirim river, its existing short-cut channel and the proposed floodway route to Picarras. The surveyed length is 48 km in total, comprising 23 km in the Itajai river, 14 km in the Itajai Mirim river and short-cut channel, and 11 km along the proposed floodway route.

c) Topographic map for major structure site in the Itajai river on a scale of 1:1,000 with contour interval of 1 m covering an area of about 30,000 m^2.

d) Sounding map along Picarras coast including the offshore area on a scale of 1:2,000 with contour interval of 0.5 m covering an area of 48 km^2.

HYDROLOGICAL STUDY

4. According to the additionally collected hydrological data, the maximum discharge at Indaial after the large scale flood in 1984 was recorded at 1,680 m^3/sec on May 21, 1988, which corresponds to less than 2-year probable flood.

5. The result of the field reconnaissance clarified that the riverbed width of the Itajai Mirim short-cut channel was widened to 50 m in the stretch between the national road BR-101 and the confluence with the Itajai Mirim river after the master planning was performed. The flow capacity of the existing short-cut channel increases to 400 to 700 m^3/sec. Besides, the upstream inlet portion of the Itajai Mirim river was closed with the earth material produced from excavation for the widening. This means that the allocation of flood discharge to the Itajai Mirim river and short-cut channel quite differs from that in the master plan stage. Hence, the flood discharge distribution established in the master plan was revised in consideration of present condition of the Itajai Mirim river. The probable flood peak in the Itajai, Itajai Mirim and short-cut channel for the selected return period is as follows;

(Unit : m^3/sec)

River Stretch	Selected Return Period (year)		
	10	25	50
1. Branching point of floodway on the Itajai river	3,300	4,000	5,100
2. Itajai Mirim river and its short-cut channel	700	790	930
- Short-cut channel	670	760	900
- Itajai Mirim river /1	30 (65)	30 (75)	30 (85)

Note: /1: The values in bracket show the flood peak discharge from about 120 km^2 wide basin between upstream and downstream junctions of the short-cut channel. The discharge of 30 m^3/sec is the flood discharge in the Itajai Mirim river at the time of flood peak occurrence in the short-cut channel.

Consequently, the design flood of 50-year return period in the Itajai river stretch downstream of the confluence with the Itajai Mirim river is estimated at 6,030 m^3/sec. On the basis of the above flood discharges of the project stretches, distribution of the flood flow to the Itajai main stream and proposed floodway at their branching point is determined through the optimization study to select the most favorable floodway plan.

GEOTECHNICAL INVESTIGATION

6. Geotechnical investigation was carried out to obtain geotechnical data and information necessary for design of flood control structures in the project area. The investigation was performed on a local contract basis under supervision by the expert of the JICA Study Team during the period from October 1988 to March 1989. The result of investigation is summarized as follows;

a) The result of the core drilling along the Itajai main stream shows that the base rock lies at the depth of 25 to 30 m from the ground surface and above the base rock, soft alluvial deposits mainly consisting of clayey soils and fine sand are widely distributed in the project area, which has cone penetration resistance of less than 10 kg/cm^2 and N value of less than 5. The maximum thickness of soft deposits in the project area is judged to be approximately 25 m, below which relatively firm layers or base rock are distributed.

b) The quite soft deposits are partially distributed in the flat surface layer of the plain in the project area. Accordingly, the geotechnical conditions would have to be taken into account for designing of the flood control facilities. The engineering properties of the soft layers are derived as follows:

Location	N-value	Q_u (kg/cm^2)	C_u (kg/cm^2)	ø (degree)
- Area along the Itajai river including the diversion weir site proposed in the master plan study stage	0 - 5	0.11-0.28	0.04-0.19	10-14
- Originally proposed floodway route to Picarras	0 - 5	0.03-0.39	0.00-0.39	3-18
- Alternative floodway route to Navegantes	0 - 5	0.08-0.44	0.21-0.65	1-5
- Itajai Mirim river	0 - 5	0.14-0.20	-	-
- Itajai Mirim short-cut channel	0 - 5	0.10-0.23	-	-

Note : Q_u : Compressive strength under the unconfined condition
C_u : Compressive strength under the consolidated undrained triaxial condition
ø : Internal friction angle

c) Rock materials are obtainable from rock mass in the hilly area situated between Picarras and Itajai city. The rock mass consisting of gneiss and migmatite is estimated to have sufficient compressive strength of more than 1,000 kg/cm^2 and is therefore judged to be suitable as embankment material for the outlet facility of the floodway and concrete coarse aggregate.

COASTAL INVESTIGATION

7. Coastal investigation was carried out to obtain the basis for comparison of alternative plans of floodways especially for jetty structure as outlet facility on the Picarras and Navegantes coasts and also to obtain the basic data necessary for design of the floodway outlet facility. Main items of the coastal investigation are tide water level, wind direction and velocity, wave height, velocity of tidal current, sampling of coastal and seabed materials and suspended sand and laboratory tests of the samples, and sampling of sea water and its quality analysis. Coastal investigation on these items was carried out during the period from November 1988 to October 1989 using observation equipment supplied by JICA in cooperation with the DNOS's counterpart personnel under direction of the JICA Study Team.

8. Based on the result of coastal investigation, the parameters necessary for design of the jetty structure both at the Picarras and Navegantes coasts are derived as follows:

a) Design tide level		
Picarras coast	:	+0.43 m
Navegantes coast	:	+0.46 m
b) Design wave height in deep water	:	6.02 m
c) Significant wave height and period at project sites		
Picarras coast	:	3.6 m and 8 sec, respectively
Navegantes coast	:	5.7 m and 12 sec, respectively

9. In the optimization study to select the most suitable floodway routes from among the Picarras and Navegantes routes, the route to the Navegantes coast was selected from economical, environmental and social aspects.

The influence on the coastal phenomena due to the construction of the floodway was studied by means of numerical simulation based on the coastal data obtained through the site survey during about one year. The numerical simulation method was used to assess the coastal change, change of tidal current and diffusion of discharged turbid water at the Navegantes coast. The result of these coastal analyses is summarized as follows:

a) It is predicted through the study on the coastal change that after the construction of the jetty erosion will take place in the north of the jetty, while sand deposit will occur in the south of the jetty. The extent of this coastal change during 10 years is predicted to be about 30 m for deposit and 20 m for erosion. Although the tendency of extension of sediment deposit toward offshore will gradually slow down as the coastal depth increases, it may be necessary to protect the existing coastal road from the erosion by protection works such as riprap wall in future stage.

b) The result of study on change of tidal current shows that the tidal current tends to slow down around area sheltered by the jetty and velocity of tide changes only within a range of 2 km from the jetty. Besides, the direction of flow changes only at the sea around the jetty.

c) The turbid water is discharged from the Itajai main stream even after the construction of the floodway. The result of study on diffusion of discharged turbid water shows that the turbid water having the suspended solid (S.S.) of 100 ppm extends up to the northern part of the floodway site in case that 2,000 m^3/sec of the flood peak is discharged only from the Itajai river and this diffusion is further extended up to about 3 km toward the northern area due to the construction of the floodway.

SOCIO-ECONOMY AND FLOOD DAMAGE STUDY

10. In the socio-economic study, the following two areas are introduced to identify the project background and basic information for formulation of the project.

a) Study Area: the area of 601 km^2 which is demarcated by the municipal boundaries of Itajai, Navegantes, Penha and Picarras, and relates both to the flood protection area and the alternative floodways.

b) Flood Protection Area: the area of 55 km^2 seriously damaged in the past large scale floods, which is surrounded by the BR-101 and BR-470 national highways and by the natural physical limits of the ocean to the east and the hills to the south. It includes two municipalities of Itajai and Navegantes.

The inundated areas in the study area due to 1983 and 1984 floods were estimated to be about 130 km^2 and 132 km^2 respectively (Refer to Fig. 2.4) on the basis of the results of the flood mark survey. They accounted for more than 20% of the study area. In the flood protection area, inundated areas were estimated at 31 km^2 and 34 km^2 , accounting for about 60% of the total area respectively. In the most seriously inundated area, the duration of the inundation was about two weeks in 1983 and one week in 1984. In the two municipalities within the flood protection area, the flood records reported that around 62,000 people and 23,000 houses were affected in 1984 and that approximately Cr$ 18 billion (US$ 8 million) at 1984 prices would be required for restoration of economic and social facilities.

11. Present land use in both the study area and the flood protection area is summarized as follows (Refer to Fig. 2.1):

(Unit: km^2)

Item	Study Area		Flood Protection Area	
Built-up area	62	(10%)	28	(50%)
Crop cultivation	84	(14%)	1	(2%)
Others	455	(76%)	26	(48%)
Total	601	(100%)	55	(100%)

Although the study area is still used mainly for agricultural purposes such as crop production and animal husbandry, the flood protection areas are mostly urbanized except for some rural areas in the Navegantes part on the left side of the Itajai river. In the urban area of Itajai, 13 km^2 remains as grassland and bush, but majority of them are already planned to be developed as industrial and residential zones. Since the 1970's, Itajai has been rapidly urbanized along the Itajai river, as infrastructure was set up and the city developed into a marketing distribution center (Refer to Fig. 2.2).

12. Population and its density in both the study area and the flood protection area are estimated in 1989 as follows:

Item	Study Area		Flood Protection Area	
Population	146,984	(100%)	115,800	(100%)
- Urban	130,330	(89%)	111,520	(96%)
- Rural	16,654	(11%)	4,280	(4%)
Population density (person/ha)	2.5		21.1	
- Urban	11.4		24.7	
- Rural	0.3		4.5	

The population in the study area grew at 2.7% per annum in the 1980's, which is higher than that of the state at 2.1%. The urban population in particular has increased at a higher pace owing to centralization and immigration into urban areas. These phenomena are more accentuated in the flood protection area.

13. Economic conditions in the flood protection area are taken as those for the two municipalities, because the area is not delineated by administrative boundaries so that it is difficult to ascertain its conditions based on the census data. The total number of 35,775 of earning workers in the census was distributed as follows: 2,881 or 8% in the agricultural sector; 11,445 or 32% in the industrial sector; and 19,819 or 55% in the service sector. In fact, the service sector has led the municipal economy and also played an important role as a distribution center in the state. Industrialization has been promoted in addition to the marketing activities but the industrial sector does not have such an important position in the local economy as in Blumenau. In crop production, sugarcane and paddy production has been developed rapidly along the Itajai and Itajai Mirim rivers and the BR-101 during the last few years. Thus, the agricultural production contributes more to the local economy than before. The fishery has been the leading sub-sector in the primary sector, and its production accounts for almost 50% of the state. In 1980's, however, its production has not increased and the fishery is stagnant.

14. GRDP in the state was Cz$ 3,741 billion in 1988. In real terms, it declined by 1.1%, after it had steadily grown up to 1987. GRDP per capita was Cz$ 873,000 (equivalent to US$ 2,970) and declined at 2.0% per annum. GRDP per capita in the two municipalities was estimated at Cz$ 125,000(US$ 3,330) in 1987 based on the total industrial production, which was 1.1 times larger than that of the state (US$ 3,030) in 1987.

15. The primary purpose of the flood damage study is to count the damage amount by different magnitude of flood, from which damage amount to be mitigated by the proposed structural plan will be derived as flood control benefit. The feasibility study of this sector principally consists of analytical comments on actual flood damage records and probable flood damage to be simulated. Since actual damage records are only confined to both floods occurred in 1983 and 1984, simulation of probable flood damage will be required to achieve the primal purpose of flood damage study.

16. The probable flood damage was estimated based on the topographic map on a scale of 1:5,000 prepared by JICA in 1989, and hydrological study on four types of large scale floods in 1978, 1980, 1983 and 1984. A grid of 250 m interval square was superimposed on the map of flood protection area. The flood water level in the flood protection area is estimated by means of non-uniform flow calculation. The flood damage is calculated square by square. In every square, the damage is calculated based on the number of property by type and its unit value and damage rate corresponding to the inundation depth. These estimates are performed

not only under the present socio-economic condition but also in the future condition. Among the flood damages thus estimated for four flood patterns, the maximum value is employed for estimate of annual flood damage. The annual flood damage to be mitigated by the structural plan to cope with 10-year probable flood is estimated at NCz$ 32.1 million under 1989 condition and at NCz$ 88.7 million under 2020 development conditions.

FLOOD CONTROL PLAN

17. The present condition of the project stretch of the Itajai river, Itajai Mirim river and its short-cut channel is clarified through the field investigation as described below;

a) The project river stretch in the Itajai is about 23 km in length between the river mouth and around 4.6 km upstream of the existing BR-101 national road bridge. The Itajai river flows down through the alluvial plains with repeated semicircular meanders. The river bed slope is so gentle as being about 1:12,000. It joins the Itajai Mirim river at about 7.8 km upstream from the river mouth.

   The river width ranges from about 170 to 400 m and river bank elevation varies from 0 m to 4 m. The river depth is around 10 m on an average. The bankful flow capacity is in a range of less than 1,000 m^3/sec to 3,500 m^3/sec. To examine the river bed variation of the Itajai main stream, river cross sections obtained through the topographic survey in the feasibility study stage were compared with those for 1983. The result of this examination shows that no outstanding change of the river bed elevation took place during the period of 1983 to 1989.

b) Most of the Itajai river basin in the project area belongs administratively to the Itajai and Navegantes cities. Itajai city spreads along 8.5 km long stretch on the right bank of the Itajai river and Navegantes city is on the left bank.

   The both banks along 12.5 km stretch of the Itajai river upstream of the river mouth are intensively utilized up to their edges for shipyards, cement factories, wharfs, shipbuilding yards, oil storage tanks, etc., except for the low land area in the meandering portion which is generally utilized as pasture. There is a regular port in the mouth of the Itajai river, which is equipped with berth facilities for 20 to 30 thousand tons class ships. To maintain the port functioning,PORTOBRAS has periodically carried out dredging works of the sediment deposit in the port.

The dredged quantity in 8 years from 1978 to 1985 was about 5 million m^3 corresponding to around 630,000 m^3/year.

c) The Itajai Mirim river covers about 11 km long stretch between the confluence with the Itajai river and crossing of the national road BR-101. It flows down meandering irregularly through pasture and agricultural land in the southern part of the project area and finally joins the Itajai river after passing through the residential area of the Itajai city. Its river width is about 40 to 80 m and river bank elevation varies from 0 m to 4.5 m. The river depth is about 4 m on an average and river bed slope is about 1:10,000. The bankful flow capacity is in a range of 100 to 200 m^3/sec.

The Itajai Mirim short-cut channel connecting the meandered Itajai Mirim stretch between 0.9 km and 19.5 km upstream of the confluence with the Itajai river has a channel length of 3.2 km in a stretch downstream of the national road BR-101. The channel width is about 50 to 80 m and its depth is about 3 m. The bed slope of the channel is 1:2,560. The bankful flow capacity is in a range of 400 to 700 m^3/sec.

d) Groins for maintaining the river course were constructed at 8 places in the Itajai river mouth, which jut out from the left bank jetty into the river channel. The length of the groins is about 150 m and its interval is about 130 m. Except for these structures, there are no river structures in the project stretch of the Itajai river.

There are also such related structures on the Itajai river as two ferry sites, two lanes of water pipes laid out along the river bed for supplying domestic water from Itajai to Navegantes and pumping facilities for paddy cultivation located on the left bank, approximately 1 to 5 km downstream of the existing BR-101 bridge. Nine bridges are provided in the project area. They are one in the Itajai river, six in the Itajai Mirim river and two in the Itajai Mirim short-cut channel.

18. The flood control plan in the lower Itajai river basin was formulated under the following criteria;

a) It has been planned to proceed with the flood control plan by such stage-wise development as provisional, mid-term and long-term plans. Among them, this flood control is targeted for the provisional plan. The design flood in the Itajai river for the provisional plan is 3,300 m^3/sec. While, the average flow capacity in the lower Itajai river stretch is about 1,500 m^3/sec. It is intended in this flood control plan that as much flood flow as possible is discharged through the Itajai main stream by effectively utilizing its river channel by increasing its flow capacity. To meet this intention, it should be planned to increase the flow capacity by means of dredging of the river channel and raising of the flood water level by levee construction. However, increase in the flow capacity of the Itajai river channel by means of raising of the design flood water level should be limited to the extent that it does not exert any influence on the design water level in the Blumenau-Gaspar stretch, which was formulated in the feasibility study of the river improvement project. The flood flow exceeding the increased flow capacity of the river channel is discharged through the proposed floodway.

b) The route and its dimension of the proposed floodway is determined through optimization study. For this optimization study, a natural diversion method without any gated weir on the proposed floodway and Itajai main stream is adopted for dividing the flood discharge just upstream of their branching point into two channels in consideration of difficulty of gate operation and its cost overburden.

c) To raise the design flood water level in the Itajai river stretch, a levee or parapet is obliged to be provided. The height of the parapet along the street is limited to less than 1 m above surface elevation of road sidewalk, and also the height of levee in the urban area should be limited to less than 1.5 m from the ground elevation of the surrounding from the viewpoint of landscape in the urban area.

d) The flow capacity in the Itajai Mirim river and its short-cut channel is enhanced by means of dredging and provision of levee or parapet.

19. A 50-year probable flood discharge was adopted for the optimization study on the floodway plan. The 50-year probable flood in the project river stretch upstream of the confluence with the Itajai Mirim river is estimated at 5,100 m^3/sec. The corresponding figure in the Itajai Mirim river just upstream of the confluence with the Itajai river is 930 m^3/sec. Then 50-year probable flood in the Itajai river stretch downstream of the existing confluence with the Itajai Mirim river comes to 6,030 m^3/sec assuming these flood peaks reach there simultaneously.

For optimization study on the proposed floodway, three alternative routes were contemplated. They are route to Picarras coast (Floodway-I) and route to Navegantes coast (Floodways-II and III). The Floodway-II branches from the Itajai river at just downstream of the existing BR-101 bridge, while Floodway-III branches at about 4 km downstream of the BR-101 bridge.

The optimum route and scale of the floodway were determined from the economical, environmental and social aspects. It is clarified in the hydraulic calculation for allocation of flood discharge to the Itajai river and floodway that a marginal flood discharge in the Itajai river downstream of Itajai Mirim confluence, which does not exert any influence on the design water level in Blumenau-Gaspar stretch, is less than 3,000 m^3/sec for Floodways-I and II, while that for Floodway-III is less than 1,000 m^3/sec. To lower the water level upstream of the branching point for Floodway-III, it was planned to provide a short-cut channel in the meandering portion just downstream of BR-101 bridge.

20. The result of cost comparison for each alternative clarifies that the floodway plan in case of 3,000 m^3/sec of flood discharge in the Itajai river is the most economical. The three alternative routes for the selected scale are compared from economical, environmental and social aspects. The result of this comparison is summarized as follows;

a) The amount of construction cost for Floodway-I is larger than that of Floodways-II and III due to its longer route and topographic conditions of hilly area along the route. From the environmental aspect, pollution of sea water at the Picarras coast which is developed as a bathing resort is predicted to be accelerated due to intrusion of the contaminated and muddy water from the Itajai river. The acreage of the diffusion of turbid water due to construction of the floodway is presumed to be almost the same for both the Picarras and Navegantes coasts. While the fishery activity is being carried out at the river mouth of the Itajai in spite of diffusion of turbid water discharged from the Itajai river. Considering this fact, it seems that there are no objection to the fishery activity for both the Picarras and Navegantes coasts even if the floodway is constructed.
b) Although the construction cost of Floodway-III is almost equal to that of Floodway-II, construction of Floodway-III is predicted to cause great environmental and social change since it is aligned along the town area of Machados and a lot of public facilities will have to be relocated.

It is concluded from these comparisons that Floodway-II is the optimal plan among three alternatives.

21. River improvement structural plan in the Itajai main stretch was established under the following criteria;

a) The design flood established in the design flood distribution for the provisional plan is 2,070 m^3/sec in the stretch between inlet portion of the floodway and Itajai Mirim confluence and 2,770 m^3/sec in its downstream stretch.
b) The design river bed slope is set at 1:12,000 so as to keep the present average river bed slope.
c) The river channel is designed as a single cross section. The width of river bed is 180 m corresponding to the present average river channel width. The side slope of the channel is 1:2.
d) Concrete parapet wall and levee are provided on the river banks in the low elevation areas to secure a freeboard of 0.5 m above the designed high water level estimated by means of the non-uniform flow calculation for 50-year flood. The parapet wall is provided along the urban area of Itajai and Navegantes. In the streets adjacent to the river channel, its height is limited to one meter at its maximum above the sidewalk in order to conserve the landscape. In principal, the maximum height of the levee is 1.5 m above the surrounding ground elevation.

The longitudinal profile, general plan and representative river cross sections of the river improvement plan thus designed are shown in Figs 3.4,3.5 and 3.6, respectively.

22. River improvement structural plan in the Itajai Mirim river was established under the following criteria;

a) The design flood is 65 m^3/sec in the stretch between the crossing of BR-101 bridge and confluence with the short-cut channel and 700 m^3/sec in the stretch downstream of the confluence.
b) The design river bed slope is set at 1:10,000 which is the same as the present average river bed slope.
c) The river channel is designed as the single section with a trapezoid shape having bottom width of 20 m and side slope of 1:2.
d) The upstream meandering stretch is improved by employing a short-cut channel at three portions to secure the area for construction of regulating pond for the urban drainage of Itajai city.
f) River dredging is performed along the whole project stretch to increase the flow capacity as well as to restore unsanitary environmental condition of river water

polluted by the accumulation of sewage owing to the low flow velocity of river water.

g) Both banks of the Itajai Mirim river are elevated by construction of levee to protect the Itajai city from flood caused by the Canhanduba river and back water from the Itajai main stream.

The longitudinal profile, general plan and representative river cross sections of the river improvement plan designed in accordance with the above criteria are shown in Figs 3.7, 3.8 and 3.9, respectively.

23. River improvement structural plan in the existing short-cut channel was designed under the following criteria;

a) The design flood is 670 m^3/sec.
b) The design river bed slope is set at 1:2,560 which is the same as the present average river bed slope.
d) The river channel is designed as the single cross sections with the trapezoid shape having bottom width of 40 m and side slope of 1:2.
d) The levee is provided at the river stretch with remarkably low elevation.

The longitudinal profile, general plan and representative river cross sections of the river improvement plan thus designed are shown in Figs 3.7, 3.8 and 3.10, respectively.

24. The design of structural plan of the floodway channel was carried out under the following criteria;

a) The design flood is 1,230 m^3/sec.
b) The design river bed slope is topographically set at 1:6,000 which is equivalent to two times that of the Itajai main stretch.
c) The floodway channel is designed as a trapezoid shape with bottom width of 50 m and side slope of 1:2.
d) The levee with a trapezoid shape of 5 m in crest width and side slope of 1:3 is provided at the place which is located at about 4 m at least from the edge of the side slope of the channel for the long term plan. The crest elevation is determined keeping 0.5 m of freeboard.
e) To protect the river bed from erosion at the branch point of the Itajai main stream due to variation of river bed slope, a ground sill supported by concrete pile and protected by concrete block in its up and downstream portions is provided.

Besides, a ground sill to maintain the design river bed slope is provided at about 4 km downstream of the inlet portion.

It is contemplated to provide a jetty at the outlet of the floodway to prevent sedimentation caused by littoral drift at the outlet portion and also to prevent sandbar formation. The jetty structure is designed under the following criteria;

a) The jetty structure is constructed almost at right angle against the coastal line and head of the jetty is gradually curved to avoid predominant waves.
b) The jetty is extended toward the place where its depth is equivalent to the channel depth to avoid movement of sediment by wave action,
c) Among the stone masonry, concrete block, caisson and riprap, the stone masonry is used as the jetty structure from the viewpoint of its stability and also from economical aspect, and
d) The jetty structure is designed as a trapezoid shape with the crest width of 10 m and side slope of 1:2.

The general plan, longitudinal profile and typical cross section of the floodway plan thus designed are given in Figs. 3.13 and 3.14, respectively. The layouts of the river bed protection at the branch point and ground sill are shown in Figs. 3.11 and 3.12, respectively. Details of the designed jetty structure are given in Fig. 3.15.

URBAN DRAINAGE PLAN

25. After the implementation of the proposed flood control plan, present drainage condition in the residential area in the Itajai and Navegantes cities will be remarkably improved since the river water level is lowered by the river improvement works. However, depression areas which are lower than the design high water level along the Itajai and Itajai Mirim rivers would be still in inundation condition due to inland water caused by rainstorm (Refer to Fig. 4.1). To relieve these areas from inundation, drainage plan is worked out by combining various drainage facilities.

26. The existing drainage system in the Itajai city comprises drainage channels and drain pipes with a diameter of 30 to 100 cm. The rainwater and sewage in the city area are directly drained to the Itajai and Itajai Mirim rivers through this drainage system. The drainage system has been expanded in accordance with the development of the residential area. There are no systematic urban drainage system in Navegantes city area.

New drainage plan in the Itajai city was prepared by DNOS in 1986. In this plan, central part of the Itajai city is divided into ten drainage basins and it was planned to drain perfectly the rainwater and sewage by means of the channels, pipes and drainage pumps. However, this new plan is so costly that it is not realized yet.

27. The study area for the drainage plan is herein defined as the area covering a part of Itajai and Navegantes urban areas which are lower than the design high water level of the Itajai river. It is divided into nineteen districts considering the topographic condition and present drainage network. They are grouped into three, namely, six districts along the right bank of the Itajai river, three districts along the left bank of the Itajai river and ten districts along the Itajai Mirim river.

28. To set up an adequate drainage plan, the following principle of the drainage plan was established considering topographic condition of the drainage basin, effective utilization of the existing drainage system and the problems relating to the existing drainage system;

a) A gravity flow type drainage method should be employed as far as possible to minimize the operation and maintenance cost for drainage. A flap gate should be installed at the outlet of the drainage facility to prevent river discharge from entering into the drainage basin.
b) In case that the gravity flow type drainage method is topographically impossible to be adopted, a regulating pond with as much capacity as possible should be provided at the downstream end of the drainage facility to reduce the peak runoff from the drainage basin, and supplementarily a pump facility should be installed to discharge the excess water from the pond.
c) The construction cost and operation and maintenance cost for the pump facilities are generally costly. To minimize number of pumping station and also to reduce the capacity of the pump, neighbouring drainage basins should be integrated.
d) For the drainage districts which are occupied by the depression area and there are only few houses, reformation of the area by means of filling the depression area with the earth material excavated from the proposed floodway channel should be contemplated.
e) The drainage facilities contemplated in this plan involve the regulating pond, pumping station, gate facilities and extension of the drainage pipe from the existing main drainage pipe to the proposed regulating pond. The improvement of the existing drainage pipe line network is not included in this plan.

29. The drainage facilities such as pump, regulating pond and drain pipe connecting the existing drain pipe to the regulating pond were designed under the following design conditions;

a) Probable flood hydrograph and its volume to design the capacity of pump and regulating pond are estimated by rational formula using probable 4-day rainfall with 10-year probability at Itajai or the neighboring station and actual rainfall distribution records on August 1984.
b) Probable flood peak discharge to design the connecting drain pipe is estimated by rational formula incorporating probable rainfall intensity-duration curve with 10-year probability.
c) Considering the increase in outflow discharge due to urbanization and development of the Itajai city, runoff coefficient in future stage is estimated at 0.9 for city area, 0.6 for farm, pasture and non-use land and 0.7 for forest area.
d) Design high water level in the regulating pond is set at the ground elevation at the pond site and pump capacity is designed so as to keep the pond water level equal to or less than the design water level assuming that water level of the Itajai river is set at the design flood water level.
e) The connecting drain pipe to the pond is designed so as to flow 10-year probable flood from the drainage district.

Based on these conditions, 4 regulating ponds and 4 pump stations were designed on the location as shown in Fig.4.4.

ENVIRONMENTAL STUDY

30. The environmental study in this stage was carried out to obtain the basis for comparison of the proposed three alternative floodway routes and also to make clear the matters to be contemplated for construction planning of the flood control project.

a) The study on the environmental change caused by construction of floodway was assessed as follows;

i) The river water of the Itajai is contaminated by fecal coliform, lead, mercury and cadmium, and in the muddy condition. The river water of Picarras, which flows into the Picarras coast is also polluted mainly by sewage. If the construction of Floodway-I is realized, pollution of sea water in the Picarras coast which is developed as a bathing resort is predicted to be accelerated due to intrusion of the contaminated and muddy water from the

Itajai river and it is considered that the Picarras will no longer be able to function as the resort. The acreage of the diffusion of turbid water due to construction of the floodway is presumed to be almost the same for both the Picarras and Navegantes coasts. While the fishery activity is being carried out at the river mouth of the Itajai in spite of diffusion of turbid water discharged from the Itajai river. Considering this fact, it seems that there are no objection for the fishery activity for both the Picarras and Navegantes coasts even if the floodway is constructed.

ii) Due to the construction of a jetty structure at the outlet of the floodway at the Picarras coast, the present natural landscape will be remarkably damaged. On the Navegantes coast, landscape of the coastal line is not so excellent as compared with that in the Picarras coast. Besides, there are no hotels in this coast. Thus, the impact for landscape due to construction of the Floodway-II will not be so serious as compared with Floodway-I. The floodway-III is almost the same as the route-II except its inlet portion where Machados town is located. The landscape of the Machados town area will drastically change due to separation of the town area by the floodway channel, but its impact will not be so serious as compared with Floodway-I since it does not rely on the tourism.

iii) The Picarras beaches are gradually diminishing due to coastal erosion. It is predicted that even after the construction of Floodway-I, the sand conveyed through the floodway channel will be insufficient for renourishing the beaches. While, after the construction of the floodway at the Navegantes coast, the erosion may take place in the left side of the jetty due to prevailing wave from SE direction, but its extent will be relatively small.

b) The environmental impacts which may take place during the construction of the flood control project were assessed to reflect the assessed result to the construction planning;

i) Due to the river dredging and excavation of the river channel, the pollution of the river channel will temporarily increase and consequently seaweeds attached at stones of the river bed, by which the fish feeds on, may be extinguished. Consequently they will be forced to search for another dwelling place. It will be necessary to carry out a research of valuable animals and vegetation to grasp the degree of influence for them.

ii) The air pollution caused by dust cloud of the vehicles and also noise and vibration will take place due to the execution of the flood control works, but they can be reduced by cleaning and watering the street and by limiting the speed of the construction vehicles.

iii) For people residing along riverside, the widening of the river and construction of the floodway will mean the loss of their houses. Discussions with the residents will be necessary regarding their new place of residence and administrative measures will become necessary.

CONSTRUCTION PLAN AND COST ESTIMATE

31. The construction plan of flood control project comprising construction of about 9 km long floodway to Navegantes coast, river improvement works of the Itajai main stream, Itajai Mirim and existing short-cut channel and urban drainage works for Itajai city was worked out under the following conditions and assumptions;

a) Considering the extent of the project works, it is herein proposed to execute the project works by an international contract system. Taking into account the scale of the works and total amount of construction cost, the project works are divided into two packages. They are package-A which covers the river improvement works for Itajai, Itajai Mirim and existing short-cut channel and urban drainage works in Itajai city and package-B which involves construction of the floodway. The construction works will be administrated and supervised by DNOS in association with an international consulting firm.

b) Based on the daily rainfall record at Itajai city, annual working day for construction works was set at 250 days in which rainfall intensity is less than 10 mm per day. The daily working hour is set at 8 hours.

c) For excavation of the channel of the Itajai and Itajai Mirim rivers, existing short-cut channel and downstream stretch of the floodway, dredging method is applied considering direct hauling of the excavated material to the spoil bank, soil condition of the materials to be excavated and so on. The workable day for dredging work is set at 300 days assuming that the minimum draft of dredger is 1.5 m.

32. The construction plan of the flood control projects is worked out based on the aforesaid conditions and assumptions as follows;

a) Major works of river improvement in the Itajai comprise river dredging of about 8.2 million m^3 for 23 km long river stretch, levee embankment and construction of parapet. To minimize the dredging cost, the dredging work is planned under the following principles;

i) Minimization of hauling distance from the dredging site to the spoil bank, and

ii) Effective utilization of the dredged material for land reclamation in the depression area along the Itajai river.

The dredging of the river channel is planned to be executed using three units of 1,100 PS class pump suction type dredger.

b) Major works of construction of floodway consist of about 7.5 million m^3 of excavation for 10 km long channel, levee embankment, relocation of about 2 km long existing BR-470 road, construction of 3 bridges and jetty construction. It is planned that about 6 km long upstream stretch of the floodway is excavated using 9 units of motor scraper with 23 m^3 class, and for about 4 km long its downstream stretch, dredging work using one unit of pump suction dredger with 1,100 PS is employed considering the geological condition of site and economical viewpoint. The excavation volume divided by the working type is 4.5 million m^3 for dry work and 3 million m^3 for the dredging work.

The jetty construction will be carried out from shore side by alternate works of dredging under the jetty portion and rock embankment.

c) The river improvement works of about 8 km long Itajai Mirim river comprise the river dredging of 150,000 m^3, channel excavation of 180,000 m^3 and levee embankment of 730,000 m^3.

The excavation of river bed of about 150,000 m^3 will be carried out by floating and portable type pump dredger having 150 PS class capacity. The dredged material will be used for filling up the locally low land area along the Itajai Mirim river after drying up. The excavation of about 180,000 m^3 in the meandering river channel portion will be carried out by combination of bulldozer, crawler loader, dragline and dump truck. Swamp type equipment will be used due to trafficability of the site. The excavated materials will be utilized as the embankment materials of the levee.

d) The improvement work of the Itajai Mirim short-cut channel comprises channel dredging of about 230,000 m^3 for widening of channel, levee embankment and construction of parapet wall. This improvement work will be carried out in later stage of construction after completion of the Itajai Mirim river improvement.

e) The urban drainage works in the Itajai city consist of excavation of 360,000 m^3 and earth embankment of 270,000 m^3 for construction of the regulating pond and construction of pump station and related pump and gate installations. These works will be carried out in dry condition of the sites and using low noise equipment.

33. The construction works of the project are scheduled to be executed during 10 years including 5 years required for a prerequisite works such as feasibility study, detailed design,financing and tendering. The construction fund to be required for implementation of the project was estimated based on the price level on September 1989 and official exchange rate of 1US$ = NCz$3.78 = ¥140. The estimated cost is summarized as follows;

(Unit: 10^3 US$)

Cost Items	F.C.	L.C.	Amounts
- Direct cost (Construction cost including preparatory works)	42,900	28,600	71,500
- Indirect cost (Land acquisition, administration and engineering service cost)	5,148	17,212	22,360
- Contingency (Physical and price contingency)	19,356	16,834	36,190
Total	67,404	62,646	130,050

Note : F/C : Foreign currency portion
L/C : Local currency portion

Based on the implementation schedule, the annual disbursement schedule was prepared. The annual investment cost ranges from about US$13 million to US$30 million.

ECONOMIC EVALUATION

34. The flood control benefit and economic construction cost to be required for economic evaluation are estimated in the following conditions;

a) The flood control benefit and cost are a guideline of assessing its economic viability. Economic benefit is given as the effect of reduction in annual mean flood damage to assets in and around the flood protection area under present socio-economic conditions. Since design flood is determined to be 10-year probable flood in the stage of the provisional plan, the benefit corresponds to a reducible amount of annual mean flood damage after the construction works against 10-year probable flood are completed. In addition, another economic benefit including the future land enhancement expected in the flood protection area is also discussed as the conceivable effect of the project.

b) Economic cost differs from financial cost in the sense of value judgment since the former is valued at real resource cost and the latter is resource cost valued at market prices. Thus, to estimate the economic costs of the proposed project, the financial costs estimated in the previous chapter were converted applying conceivable adjustment factors.

The economic viability of the project was evaluated by means of economic internal rate of return (EIRR) under the following conditions;

a) The economic life of the project is taken as 50 years after completion of the construction works.

b) The basic price level for cost and benefit estimates is set at the end of September, 1989.

c) Foreign exchange rate is set at NCz$3.78 to US$1.00 in obedience to the official exchange rate in the end of September 1989.

d) Operation and maintenance cost is assumed to be 0.5% of total direct construction cost.

The estimated EIRR is 7.1% and it is expected to increase to 11.9% under the future socio-economic conditions. Besides, sensitivity analysis was made for the following five cases, namely (i) construction period is extended from 5 years to 7 years, (ii) construction work of proposed floodway is executed after the completion of the river improvement work in the Itajai river, Itajai Mirim river and existing short-cut channel and the urban drainage work in Itajai and Navegantes cities to decrease annual investment cost. The river improvement and drainage works will mitigate flood damage up to 3-year probable flood. The construction period is extended from 5 years to 10 years due to this alteration, and (iii) in Case (ii), the floodway construction is not executed, (iv) construction work of the proposed floodway is executed before the river improvement work in the Itajai river, Itajai Mirim river and existing short-cut channel and urban drainage work. The construction period is extended from 5 years to 10 years, and (v) in Case (iv), only construction work of the floodway is executed.

In these cases, EIRR is estimated as follows under both present and future economic conditions:

Case No. of Sensitivity Analysis	Present Condition	Future Condition
Case (i)	6.4%	11.0%
Case (ii)	6.7%	11.7%
Case (iii)	6.4%	10.9%
Case (iv)	6.6%	11.5%
Case (v)	5.9%	10.2%

In Cases (iii) and (v), the annual financial burden is largely lightened compared with the proposed flood control project, and construction fund to be required is US$ 48 million for the Case (iii) and US$ 53 million for the Case (v). The both cases will mitigate flood damage up to 3-year probable flood. However in the Case (v), the expected flood control effect cannot be acquired unless the floodway work is completed. While, even if a partial river improvement work is completed in the Case (iii), the flood protection level in the envisaged flood prone area does not increase due to the flood flow from unimproved river stretch. Consequently similarly to the Case (v), the expected flood control effect will not be also obtained unless all the river improvement works are completed. The result of the sensitivity analysis in both cases shows that EIRR for the Case (iii) is slightly higher than that for the Case (v) but EIRR for both cases is lower than that for the proposed flood control project.

STUDY ON FLOOD FORECASTING AND WARNING SYSTEM

35. To improve the flood forecasting and warning system (FFWS) introduced by DNAEE, an integrated FFWS was proposed. The outline of the proposed FFWS including flood forecasting and warning procedures and method is presented in the followings;

(1) It is intended in this FFWS to issue the flood forecasting and warning to the following 18 municipalities along the Itajai river and its tributaries widely spread in the basin;

	River Basin	Number of Target Municipalities	Municipality
1.	Itajai do Sul river	3	Ituporanga, Agronomica, Aurora
2.	Trombudo river	1	Trombudo Central
3.	Itajai do Oeste river	1	Taio
4.	Itajai do Norte river	1	Ibirama
5.	Benedito river	1	Timbo
6.	Itajai Mirim river	1	Brusque
7.	Itajai main stream	10	Rio do Sul, Ascurra, Rodeio, Apiuna, Indaial, Blumenau, Gaspar, Ilhota, Itajai, Navegantes
	Total	18	

(2) It is proposed to proceed with the flood forecasting method dividing into the following three stages;

a) 1st stage; It is intended to improve the existing system for the purpose of;

i) Obtaining the meteo-hydrological data at the mountainous area and existing damsites on real time basis, and

ii) Monitoring the flood water level in the target areas.

To meet these purposes, the existing observation stations will be improved by means of an application of telemetering system to the existing system and installations of additional telemetered rainfall gauges at the mountainous areas upstream of the existing dams and telemetered water level gauges at up and downstream of the existing damsites and at the flood prone area. The system thus telemetered will be used not only for flood forecasting by means of statistical method by correlation of meteo-hydrological data but also for obtaining the fundamental data for establishment of mathematical simulation model based on the rainfall data.

b) 2nd stage; The flood forecasting by means of mathematical flood simulation model method will be made for all the target areas in the basin. To meet this requirement, telemetered rainfall gauges will be additionally installed at the mountainous areas.

c) 3rd stage; The radar rain gauge system to obtain area rainfall data in addition to spot rainfall data will be installed not only to identify the movement of rain cloud timely, but also to utilize this phenomenon for dam operation for flood regulation.

(3) It is proposed to carry out flood warning by loud speaker in major cities and by patrol cars and motorcycles in other target areas instead of the means by newspaper, radio and television applied at present.

(4) The proposed FFWS comprises the following five components;

a) Hydrological observation network consisting of telemetered rain and water level gauges.
b) Telemetering system required for sending data from gauging stations and receiving them for processing and analyzing.
c) Data processing system, mainly consisting of a computer system for processing and analyzing data transmitted by the telemetering system, and for forecasting flood based on these data.
d) Flood warning system to inform flood oncoming to the inhabitants along the Itajai river and tributaries in the target areas.
e) Communication system for communicating between the related agencies and offices so as to exchange information and to manage FFWS.

(5) The following new offices and stations are organized in the proposed system;

a) FFWS Central Office (Florianopolis)
b) FFWS Control Center (Blumenau)
c) Master Station (Rio do Sul)
d) Monitor Station (Itajai)
e) Gauging stations (at 48 sites)
f) Warning stations (at 16 sites)
g) VHF repeater stations (at 7 sites)
h) UHF repeater stations (at 4 sites)

The data collected from Master Station is processed at Control Center to estimate the extent of oncoming flood and its arrival time. When the river water level at a warning point is forecasted to rise up to a certain warning level, warning is issued after final instruction is received from the Central Office. The Control Center will send warning and flood information to the inhabitant in the target areas through warning station and by patrol cars. The schematic relation between these offices and stations is illustrated in Fig. 9.2.

36. The major equipment for the proposed FFWS includes hydrological observation network, telemetering system, data processing system, flood warning system and communication system as stated below;

a) It is planned to install the telemetered 31 rain gauges and telemetered 17 water level gauges in the basin. The telemetered rain gauges comprise 26 gauges to be set at or near the existing gauges of which 6 gauges are proposed to be shifted from outside of the basin area to inside of the basin, and 5 gauges to be additionally provided in the mountainous areas in main tributaries. The telemetered water level gauges consist of 16 gauges to be installed at the existing gauges and one gauge to be additionally installed as tidal water level gauge.

   It is judged that the existing Fraiburgo radar rain gauge located outside of the basin is unsuitable for the proposed FFWS due to the topographic and operational conditions. Instead of this radar, a radar having detecting range of 120 km is proposed to be installed in Rio do Sul which is located at almost the center of the basin.

b) In order to receive data from the hydrological observation network at the Master Station and send them to the Control Center at real time, the telemetering system will be installed.

c) The data processing equipment aided by a computer is installed in the Control Center in Blumenau and Master Station in Rio do Sul.

d) Flood warning system comprises the warning control equipment, terminal equipment and mobile warning facilities.

e) To inform the forecasted result and flood warning to the related agencies, the communication system by means of simplex and multiplex exclusive lines is installed to connect the stations and offices.

37. It has been proposed to develop the proposed FFWS by dividing into three stages as shown in Fig. 9.6. The system component in each stage is as follows;

Major Component	Unit	Stage		
		1st	2nd	3rd
Telemetered rain gauge	Nos	15	16	-
Telemetered water level gauge	Nos	16	1	-
Control Center in Blumenau	No	1	-	-
Master Station in Rio do Sul	No	1	-	-
UHF repeater station	Nos	2	2	-
VHF repeater station	Nos	7	-	-
Telemetering system between station and office	Unit	1	-	-
Multiplex network	Unit	1	-	-
Monitor Station in Itajai	No	-	1	-
Central Office in Florianopolis	No	-	1	-
Expansion of multiplex network	Unit	-	1	-
Installation of warning equipment	Unit	-	1	-
Installation of radar gauge system	Unit	-	-	1

The required construction period is estimated to be 10 years comprising 4 years for the prerequisite works such as feasibility study, financing, detailed design and tendering and 6 years for the stage construction including training works.

38. The cost required for establishment of the proposed FFWS is estimated based on the price level in September 1989 and expressed by US$ equivalent using the exchange rate of US$1 = ¥140 = NCz$3.78. The project cost estimated by dividing into three stages is summarized as follows;

(Unit: US$ thousand)

Cost Item	1st Stage		2nd Sage		3rd Sage		Total
	F/C	L/C	F/C	L/C	F/C	L/C	
(1) Direct cost (Construction cost including preliminary works)	6,975	1,712	6,334	1,348	6,476	220	23,065
(2) Indirect cost (Administration and engineering service costs)	1,395	776	1,267	654	1,295	379	5,766
(3) Contingency (Physical contingency)	837	249	760	220	777	60	2,883
Total	9,207	2,737	8,361	2,202	8,548	659	31,714
	(11,944)		(10,563)		(9,207)		

Note; F/C ; Foreign currency portion
L/C ; Local currency portion
The Figure in bracket show total of F/C and L/C in each stage.

FEASIBILITY STUDY
ON
THE FLOOD CONTROL PROJECT
IN
THE LOWER ITAJAI RIVER BASIN

FINAL REPORT
MAIN REPORT

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ABBREVIATION

(1) Federal and State Organizations and Agencies

ACARESC	:	Associacao de Credito e Assistencia Rural de Santa Catarina
BNDES	:	Banco Nacional de Desenvolvimento Economico e Social
CASAN	:	Companhia Catarinense de Aguas e Saneamento
CEDEC	:	Coordenacao Estadual de Defesa Civil
CELESC	:	Centrais Eletricas de Santa Catarina
CEPA	:	Instituto de Planejamento e Economia Agricola de Santa Catarina
CIDASC	:	Companhia Integrada de Desenvolvimento Agricola de Santa Catarina
COMDEC	:	Commissao Municipal de Defensa Civil
DHN	:	Diretoria de Hidrografia e Navegacao
DNAEE	:	Departamento Nacional de Agua e Energia Eletrica
DNER	:	Departamento Nacional de Estradas de Rodagem
DER	:	Departamento de Estradas de Rodagem
DNOS	:	Departamento Nacional de Obras de Saneamento
EMAT	:	Empresa de Assistencia Tecnica
EMATER	:	Empresa de Assistencia Tecnica e Extencao Rural
EMBRAPA	:	Empresa Brasileira de Pesquisa Agropecuaria
EMPASC	:	Empresa de Pesquisa Agropecuaria ria de Santa Catarina
ELETROSUL	:	Centrais Eletricas do Sul do Brasil S.A.
FATMA	:	Fundacao de Amparo a Tecnologia e Meio Ambiente
FGV	:	Fundacao Getulio Vargas
FIESC	:	Ferecao das Industiais e dos Comercios de Santa Catarina
FURB	:	Fundacao Educadional da Regiao de Blumenau
GAPLAN	:	Gabinete de Planejamento e Coordenacao Geral
IBAMA	:	Insutituto Brasileiro de Meio Ambiente de Recorsus Naturais Renovais
IBDF	:	Instituto Brasileiro de Desenvolvimento Florestal
IBGE	:	Instituto Brasileiro de Geografia e Estatistica
IPND	:	I Plano Nacional de Desenvolvimento
ITAG	:	Instituto Tecnico de Administracao e Gerencia
MA	:	Ministerio da Agricultura
MDUMA	:	Ministerio do Desenvolvimento Urbano e Meio Ambiente
PORTOBRAS	:	Empresa Brasileira de Portos
SAMAE	:	Servico Autonomo Municipal de Agua e Esgoto
SC	:	Santa Catarina
SEDUMA	:	Secretaria de Estado do Desenvolvimento Urbano e do Meio Ambiente
SEPLAN	:	Secretaria do Planejamento

SEPLAN/SC	:	Secretaria de Estado de Coordenacao Geral e Planejamento
SICT	:	Secretaria de Estado da Industria do Comercio e do Turismo
SUDEPE	:	Superintendencia do Desenvolvimento da Pesca

(2) International Organizations

JICA	:	Japan International Cooperation Agency
IBRD	:	International Bank for Reconstruction and Development

(3) Abbreviation of Measurement

Length

mm	:	millimeter
cm	:	centimeter
m	:	meter
km	:	kilometer

Time

s or sec	:	second
min	:	minute
h or hr	:	hour
d	:	day
y or yr	:	year

Area

cm^2	:	square centimeter
m^2	:	square meter
ha	:	hectare
km^2	:	square kilometer

Others

%	:	percent
℃	:	degree centigrade
10^3	:	thousand
10^6	:	million
10^9	:	billion

Volume

cm^3	:	cubic centimeter
l	:	liter
m^3	:	cubic meter

Derived Measure

m^3/s	:	cubic meter per second

Weight

g	:	gram
kg	:	kilogram
ton	:	metric ton

Money

Cz$	:	Cruzado
Cr$	:	Cruzeiro
NCz$	:	New Cruzado
US$	:	US dollar
¥	:	Japanese Yen

Electricity and Communication

bps	:	Baud per second	M-byte	:	Mega-byte
AH	:	Capacity of alkaline battery	kV	:	Kilovolt
Hz	:	Hertz	kVA	:	Kilovolt Ampere
kHz	:	Kilo Hertz	kW	:	Kilowatt
MHz	:	Mega Hertz	kwh	:	Kilowatt hour
GHz	:	Giga Hertz	V	:	Volt
K-byte	:	Kilo-byte	W	:	Watt

(4) Exchange Rate as of the end of September 1989

Official rate : US$ 1 = Ncz$ 3.78 = ¥ 140

Tourist rate : US$ 1 = Ncz$ 7.16 = ¥ 140

(5) Standard

JIS : Japanese Industrial Standards

(6) Others

Socio-economic Technical Terms

GDP : Gross Domestic Product

GRDP : Gross Regional Domestic Product

SCF : Standard Conversion Factor

VA : Value Added

PV : Production Value

Type of Structure

R.C. : Reinforced concrete

P.C. : Prestressed concrete

I. INTRODUCTION

1.1 Background of the Project

A basin-wide flood control plan in the Itajai river basin with a catchment area of 15,220 km^2 was worked out through a master planning during the period from April 1986 to January 1987. As a result of plan formulation, first priority was given to the river improvement in the Blumenau-Gaspar stretch and the second priority to the flood control in the lower Itajai river basin which comprises the construction of about 11 km long floodway and river improvement in the Itajai main stream, Itajai Mirim and its short-cut channel to protect Itajai and Navegantes city from flooding.

A feasibility study on the river improvement in the Blumenau-Gaspar stretch was carried out following the master plan study. The river improvement plan in the Blumenau-Gaspar stretch was worked out to cope with the design flood of 3,400 m^3/sec as the provisional plan, which is about three times the present flow capacity in the envisaged lower Itajai river stretch. To cope with the increase in flood peak discharge due to river improvement in the Blumenau-Gaspar stretch, it is necessary to proceed with the flood control plan in the lower Itajai river basin.

From the viewpoint of that situation, the Brazilian Government requested to Japanese Government a technical assistance for the feasibility study on flood control in the lower Itajai river basin. In response to this request, Japanese Government dispatched the JICA study team in October 1988 to conduct the field survey in the envisaged area.

1.2 Outline of the Project

The project works for the provisional plan to cope with 10-year probable flood comprise the construction of about 9 km long floodway to Navegantes coast, river improvement works for the Itajai main stream, Itajai Mirim and its short-cut channel and urban drainage works for Itajai city.

Main features of the project are summarized as follows;

(1) Construction of the floodway

a) Construction of floodway channel

Total length	;	9 km
Design flood	;	1,230 m^3/sec
Shape of floodway	;	Trapezoid with 50 m in bottom width and side slope of 1:2
Excavation	;	7.5 million m^3
Levee embankment	;	140,000 m^3
Construction of new bridge	;	3 Nos
Relocation of BR-470 road	;	2 km

b) Construction of jetty structure

Total length	;	1,158 m in left side and 898 m in right side
Type of jetty	;	Rock rubble mound
Shape of jetty	;	Trapezoid with side slope of 1:2 and crest width of 10 m
Dredging	;	510,000 m^3
Stone filling	;	1.3 million m^3

(2) River improvement works in Itajai river

River stretch to be improved	;	23 km
Improved method	;	Reformation of river channel by means of dredging and levee construction
Design flood	;	2,770 m^3/sec (in lowest stretch)
Dredging work	;	8.2 million m^3
Levee embankment	;	750,000 m^3

(3) River improvement works in Itajai Mirim stretch

River stretch to be improved	;	8 km
Design flood	;	65 m^3/sec
Improved method	;	Reformation of channel by means of dredging, reformation of channel alignment by means of short cutting and levee construction.

Dredging	;	150,000 m^3
Excavation	;	180,000 m^3
Levee embankment	;	730,000 m^3
Bridge heightening	;	4 places

(4) River improvement work in existing short-cut channel

River stretch to be improved	;	4 km
Design flood	;	670 m^3/sec
Improved method	;	Widening of channel and levee construction
Dredging	;	230,000 m^3
Levee embankment	;	140,000 m^3

(5) Urban drainage works

Design rainfall	;	4-day rainfall with 10-year probability
Total drainage area	;	43.9 km^2
Drainage method	;	Combination of regulation by pond and drainage by gravity and pump
Excavation	;	360,000 m^3
Embankment	;	270,000 m^3
Pumping station	;	4 places
Drainage sluice	;	5 places
Flap gate	;	14 places

1.3 Content of Report

This report comprising main report, its supporting report and data book presents the results of the feasibility study on flood control plan in the lower Itajai river basin including urban drainage works in Itajai city. The main report describes the summarized result of the surveys and studies performed for the feasibility study, and the supporting report presents the details for the respective fields including topographic survey, hydrological study, geotechnical investigation, coastal investigation, socio-economic and flood damage survey, flood control plan, environmental study, construction plan and cost estimate and study on flood forecasting and warning system. The data book compiles river cross sectional data in lower Itajai river stretch, and coastal and geotechnical investigation data.

1.4 Acknowledgement

The study team wishes to express a sincere gratitude and appreciation to all the officials concerned and their staff for their substantial collaboration rendered during the feasibility study stage. The study team acknowledges invaluable assistance received from DNOS which was the counterpart executing agency in this study.

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II. PROJECT AREA

2.1 Natural Condition

2.1.1 Topography and river feature

The project area covers the downmost stretch of the Itajai river, about 23 km of the river course between river mouth and about 4.6 km upstream from the existing bridge of the national road BR-101. The northern and southern parts of the project area are bounded by about 300 m high mountains. The Itajai river flows down through a flat plain repeating semicircular meandering and the Itajai Mirim river, a tributary of the Itajai river, joins the Itajai river at about 7.8 km upstream of the river mouth.

The river bed slope of the Itajai in the project area is so gentle as being about 1:12,000. The river width ranges from about 170 m to 400 m and river bank elevation varies from 1 m to 4 m. The river depth is around 10 m on an average. The bankful flow capacity is in a range of less than 1,000 m^3/sec to 3,500 m^3/sec.

In order to examine the river bed variation of the project stretch of the Itajai river, river cross sections surveyed in this stage were compared with those for 1983, which were used for the master plan study. The result of this comparison clarifies that no outstanding change of the river bed elevation took place during the period of 5 years.

The Itajai Mirim river in the project area covers about 11 km long stretch between the confluence with the Itajai river and crossing of the national road BR-101. It flows down meandering irregularly through pasture and agricultural land in the southern part of the project area and joins the Itajai river after passing through the residential area of Itajai city. Its river width is about 40 to 80 m and river bank elevation is in a range of 0 m to 4.5 m. The river depth is about 4 m on an average and river bed slope in the project stretch is around 1:10,000. The bankful flow capacity is in a range of 100 to 200 m^3/sec.

The Itajai Mirim river has about 3.2 km long short-cut channel connecting the meandered stretch between 0.9 km and 19.5 km upstream of confluence with the Itajai river. The channel width of the short-cut channel is 50 to 80 m and its depth is about 3 m. The river bed slope of the channel is about 1:2,560. The bankful flow capacity in the channel ranges from 400 to 700 m^3/sec.

2.1.2 Meteo-hydrology

The climatic observation in the project area has been carried out only in Itajai city by EMPASC since 1980. The climatic condition in the project area represented by the observation is as follows;

The annual mean air temperature at the Itajai city is 20.1°C and monthly fluctuation ranges from 15.2°C to 24.6°C. The maximum air temperature was 39.5°C in February 1986 and the lowest one was 0.3°C in June 1981.

The annual mean relative humidity is 86% at Itajai. The mean monthly relative humidity is rather stable throughout a year.

The annual evaporation amount is estimated at 1,130 mm which corresponds to the daily evaporation rate of 3.1 mm. The annual mean wind velocity at Itajai is 1.5 m/sec.

The annual rainfall at Itajai during the period of 1968 to 1989 is 1,696 mm. The annual monthly rainfall changes from about 100 mm in April to August to 200 mm in January to March.

Water level of the project river stretch is affected by the tidal water level of the Atlantic Ocean and then discharge measurement has never been carried out. The discharge observation stations which are located nearest the project area are Indaial on the Itajai river and at Brusque on the Itajai Mirim river. The annual mean discharge at the river mouth of Itajai is estimated at about 360 m^3/sec in proportion to their catchment area ratio.

2.1.3 Geology

The geology in the project area is characterized by the alluvial plain formed by soft deposit layer with depth of about 30 to 35 m. The foundation rock consisting of metamorphic sandstone and migmatite lies below the alluvial deposits.

The soil layer in the area along the Itajai river is composed of quite soft deposit. Although the height of the proposed levee is mostly less than 2 m in height, this soft soil condition will have to be reflected to the method of construction and selection of construction equipment.

The alternative floodway route to the Navegantes coast passes through the alluvial soft plain and clean sand area near the coast. The clean sand layer with depth of more than 15 m is judged to spread along the Navegantes coast.

These soil conditions will have to be considered for stability analysis of the excavated side slope of the proposed floodway.

The soil layer along the Itajai Mirim and its short-cut channel consists of soft sandy or clayey layer. Since it is planned to reform the Itajai Mirim river by short cutting and to widen the channel in the short-cut portion, the soil condition will have to be incorporated in making the stability analysis of side slope.

2.2 Land Use

2.2.1 Present land use

In this Section, the following two areas are introduced to identify the project background and basic information concerned to socio-economic and administrative matters for formulation of the project.

(1) Study area: the area of 601 km^2 which is demarcated by the municipal boundary of the four municipalities of Itajai, Navegantes, Penha and Picarras.

(2) Flood protection area: the area of 55 km^2 which is surrounded by the BR-101 and BR-470 national highways and by the natural physical limits of the ocean in the east and the hills in the south. The area includes two municipalities of Itajai and Navegantes, and also the area which was seriously damaged in the past large scale floods.

The land use was primarily classified into four categories: built-up area of urban activities; agricultural area; grassland and pasture for cattle breeding; and forest and bush. Secondarily, agricultural area was divided into three sub-categories: paddy field; sugarcane field; and other crop land which produces vegetables and fruit. The land use map in the study area is shown in Fig. 2.1, which is delineated in line with these categories.

The total land in the study area is currently used as follows: (1) 62 km^2 or 10% of the total land is built-up area; (2) 84 km^2 or 14% is agricultural production; (3) 193 km^2 or 32% is grassland and pasture; and (4) 262 km^2 or 44% is forest and bush area. Agricultural land of 84 km^2 is further divided as follows: (a) 29 km^2 for paddy production; (b) 40 km^2 for sugarcane; and (c) 15 km^2 for other crops.

The flood protection area is almost urbanized, particularly in Itajai city. Since the categories between bush and grassland are ambiguous in urbanized areas, grassland and bush are put into one item. Water area, such as the river, is distinguished to make an inundation area clear and to make it easier to estimate the flood damage. The total land is used as follows at present: (1) 27.5 km^2 or 50% of the total land is built-up area; (2) 1.3 km^2 or 2% is agricultural; (3) 20.6 km^2 or 38% is grassland, pasture and bush; and (4) 5.5 km^2 or 10% is river area. The built-up area of 27.5 km^2 is further divided into the following two categories: (a) 22.4 km^2 for residential use; (b) 5.1 km^2 for other industrial or commercial activities. Since the second half of 1960's Itajai has been rapidly urbanized along the Itajai river as shown in Fig. 2.2. 13 km^2 in the urban area of Itajai still remains as grassland and bush, but most of them are already planned to be developed as industrial and residential zones. The agricultural land in the flood protection area is used only for paddy production in Navegantes. In some grasslands, animal husbandry is carried out, but it is operated in a small scale and is a temporary activity.

2.2.2 Land use plan

The two municipalities of Itajai and Navegantes have been urbanized so quickly that the both governments enacted a guideline as a countermeasure against urban sprawl in order to lead the town properly to sound urbanization. In a guideline, a zoning plan is established for sound utilization of urban area, which is demarcated on the basis of present land use. The governments give a permission or approval to a plan of founding a new building based on this legal recognition of the zoning plan. This zoning plan is illustrated in Fig. 2.3.

Population and regional economy in the flood protection area are anticipated to increase at comparatively high speed, although its pace is lower than before, as shown in the following table (refer to Section 2.3):

Item	Average annual growth rate (%)		
	1970 - 1980	1980 - 2000	2000 - 2020
Population	3.7	2.5	1.3
GRDP	13.4	5.2	4.0
GRDP per capita	9.9	3.3	2.7

By the year 2020, the population in the flood protection area increases from 115,800 in 1989 to 183,500. The population in the flood protection area in 2020 becomes about 2.1 times of the population in 1980, and in the same manner GRDP, 6.1 times. The increment of the population is 67,674, which is distributed as follows: 60,285 in the urban area of Itajai; 6,679 in the urban area of Navegantes; 710 in the rural area of Navegantes. Supposing that the population density in both municipalities keeps the same level, residential area would increase from 17.5 ha in 1989 to 27.9 ha in Itajai and from 4.7 ha to 7.0 ha in the urban area of Navegantes. Thus, the non-utilized land at present such as grassland, bush and reserved area might be used for living purposes. Since Itajai city has some reserved area for urban expansion, urban area is expected to expand along the reserved area, as long as the municipal guideline functions well for the urbanization. The changes of land utilization in the area will compel the both municipal governments to take a drastic development policy. This active leadership for urbanization would create the sound urban environment in the future. In the same manner, industrial establishments will increase in the flood protection area as the regional economy grows in the future. These incremental establishments will be absorbed in the respective zones.

2.3 Socio-economy

2.3.1 Population

The study area had a population of 116,000 in the latest census year of 1980. In 1989, it is estimated to have a population of 147,000. The population has increased by 31,000 over nine years. The average growth rate of the population is 2.7% per annum, which is larger than both the growth rates of Santa Catarina state (2.1%) and the country (2.2%) during the same period. In particular, the urban population increased at higher rate of 3.2%. On the other hand, the rural population decreased at the rate of 0.7% per annum. The population density in the study area is 245 persons/km^2. The density of urban area is 1,139 persons/km^2 and the rural one, 34 persons/km^2. The urban area in the municipality of Itajai recorded the highest density of 2,333 persons/km^2 among four municipalities.

The flood protection area is estimated to have a population of 115,800 in 1989. The population is divided into two municipal divisions as follows: 100,960 in Itajai and 14,840 in Navegantes. All the people in Itajai live in the urban area, corresponding to 96% of the total urban population in the municipality of Itajai. The population in Navegantes is further divided into two parts: 10,560 in urban area and 4,280 in rural area. The urban population of the Navegantes portion in the flood protection area accounts for 95% of the total urban population in the municipality of Navegantes. The rural population comprises 72% of the total rural population of Navegantes.

The population density is estimated at about 2,116 persons/km^2 on an average. The density in the urban area is 2,470 persons/km^2, but the density in the rural area is

450 persons/km^2. In the Itajai portion, the urban density reaches to 2,600 persons/km^2, since the central zone which is the most densely inhabited zone in the study area is included in this portion.

The population of the two municipalities has grown at the average rate of 2.9% for the decade of the 1960's and 3.2% for the next decade. During the 60's, the growth rate was lower than that of the state (3.2%), but during the next decade, the growth rate became much bigger than that of the state (2.3%). This means that the two municipalities have grown more quickly during the 70's than during the 60's. In earlier times, the two municipalities developed slower than the other more developed municipalities in the state, such as Joinville and Blumenau. Since the 70's, however, the two municipalities developed at higher rate than the average of the state. The rapid increase of population to support the regional development might be caused by immigration into the two municipalities from outside areas, in addition to the natural increase in the municipalities. In fact, the population in the municipalities grew at a higher rate than that of the state, even in the 80's.

The number of families in the two municipalities was about 23,500 in 1980. During the 70's, it grew at the average rate of 5.0% per annum which was higher than the growth rate of population during the same period. As a result, an average family size decreased from 5.1 persons per family in 1970 to 4.3 persons per family in 1980.

The number of housing units in the municipalities was 22,384 in 1980. It is slightly smaller than the number of families, demonstrating the housing shortage problem seen in the municipalities. The supply of homes could not keep up with the increase of population because of its rapidity. The problem has become serious from year to year, since the number of residences per family went down from 1.0 in 1960 to 0.95 in 1980.

The number of earning workers was registered at 35,775 in the two municipalities. Of this total, 19,819 or 55.4% worked in the service sector (or tertiary sector). The hotel and catering sub-sector of the tertiary sector absorbed the largest number of 7,316, accounting for 20.5% of the total. The number in the tertiary sector grew at the average rate of 6.1% annually during the 70's. 11,445 people worked in the industrial sector (or secondary sector) in 1980, which was the second biggest share among the main three economic sectors, accounting for 32.0% of the total. However, it grew at 8.9% per annum during the same period, which resulted in higher growth than the tertiary sector. On the other hand, the primary sector occupied only 2,881 or 8.1% of the total in 1980. It increased slightly at an annual rate of 0.3%. Accordingly, the major economic activities in the two municipalities are still in the field of trading and services, and the municipalities have industrialized at a high pace during the 70's.

Up to the year 2020, a population in the flood protection area grows to 183,500 or 2.1 times of the population in 1980 (87,300). The population is divided into two municipalities as follows: 161,300 or 88% in Itajai and 22,200 or 12% in Navegantes. The urban population in 2020 accounts for 97% of the total population. As a result, the total population and the urban population in the flood protection area grow at the average annual rate of 1.87% and 1.91% from 1980 to 2020, respectively. On the contrary, the rural population increased at the average annual rate of only 0.75% for the same period of 40 years.

An average family size decreased from 5.2 in 1960 to 4.3 in 1980 continuously. Provided that this decrease in family size continued up to date, the size would be about 4.0 through the regression analysis on the basis of the past transition. Since this size is significantly small as compared with that of the industrialized countries, it could be kept to be the same size even in the future. Then, based on this assumption, about 45,900 families will live in the flood protection area, though 29,000 families existed in 1989.

2.3.2 Economic profile

The two municipalities function as the marketing center for external trade through Itajai port as well as the internal trade. Recently, their sphere of business covers not only the Itajai river basin but also the state and its surroundings. Corresponding to these trading activities, manufacturing industries have been established along the Itajai river and the national arterial roads. On the other hand, the primary sector has correspondingly declined in the municipalities, although it has experienced the exceptional development of sugarcane production in the last few years.

(1) Primary sector

The primary sector is generally divided into five sub-sectors: crop production, livestock production, fishery, forestry and rural industry. The total production of these five sub-sectors amounted to Cr$1,290 million in the two municipalities of Itajai and Navegantes in 1980 at the current prices. It accounted for only 1.3% of the state production (Cr$96.6 billion). Among the five sub-sectors, fishery is the leading sector in the municipalities, which accounted for 83.5% of the total production value.

The main crops cultivated in the municipalities are rice, sugarcane and cassava in order of production value in 1980. Rice (paddy) is cultivated with the area of 964 ha (net area) in the flat low land along both the Itajai river and the Itajai Mirim river courses. The production was 3,340 tons, so unit yield of paddy was 3.5 tons/ha. The paddy production amounted to Cr$32 million at current prices, accounting for 39.7% of the total production in the municipalities. The production of other main crops such as sugarcane and cassava totaled 28,100 tons and 3,500 tons, respectively. Their production values reach Cr$18 million and Cr$11 million, accounting for 22.6% and 13.7% respectively. However, the crop production in 1987 changed drastically. The area harvested for sugarcane totaled 2,480 ha. It means that during seven years 2,000 ha of newly cultivated area was added to the area harvested (494 ha) in 1980. The area harvested for paddy production reached 1,930 ha, doubling the area harvested in 1980. Although the production of other crops increased slightly, its increment was small as compared with the production in 1980. Thus, the amount of sugarcane resulted in Cr$78 million in 1987, accounting for 60% of the total production in the municipalities. In the same manner, the paddy accounted for 18.6%. In the flood protection area, however, only 125 ha of paddy field exists in the Navegantes side as agricultural crop land.

The important livestock and its products in the municipalities are chicken, beef and milk in order of production value. The amount of chicken production reached Cr$61 million, accounting for 51% of the total production. The total production in the municipalities bears 0.3% of the state production.

The total production of fishery in the municipalities was 85,000 tons in 1980 and its value was Cr$1,077 million accounting for 50.3% of the total state production. The sea food products are distributed not only into local fresh food markets all over the state, but also preserved by freezing and canning factories along the Itajai river. These products are also important as export products. Thus, fishery has kept a quite important position in the municipal economy. In 1987, however, its production decreased to 55,000 tons and its value was Cr$954 million, although its share increased to 75.6% of the state total. The production in 1987 was exceptionally low, but the production did not increase in the last few years not only in the two municipalities, but also in the whole state. Fishery production has reached a mature level under present fishing techniques. They are now studying methods of improving of fishery industry.

The main rural industry products in the municipalities were cassava-related products and cheese in order of production value in 1980. The total value of production was Cr$6.3 million in 1980, accounting for only 0.19% of the state production. The municipalities supply raw materials such as sugarcane, but do not have any remarkable rural industry.

(2) Secondary sector

The secondary sector is usually divided into four sub-sectors: (a) mining, (b) manufacturing, (c) construction and (d) public utilities such as water supply, electricity supply and telephone. The manufacturing sub-sector is the most representative and predominant industry among the four sub-sectors. According to the municipal information, there are 301 manufacturing establishments in the two municipalities in 1989, distributing as follows: 245 establishments in Itajai and 56 in Navegantes. The major industrial products are (a) non-metal products and (b) food products.

According to the economic census in 1980, the manufacturing and mining sub-sectors recorded 281 establishments, 5,480 workers and a production value of Cr$7,321 million at current prices. They accounted for 2.5%, 2.0% and 1.9% of the state, respectively.

The main industrial product types in the municipalities were (a) food industry and (b) non-metallic industry in order of production value. They accounted for 36.5% and 20.5% of the total production of the mining and manufacturing sub-sectors in the municipalities, respectively. In terms of workers, they absorbed 27.7% and 11.8%, respectively. Regarding the number of establishments, the respective types occupied only 18.1% and 19.2%. Accordingly, the production value per establishment of these types achieved the sizable amounts of Cr$52.4 million and Cr$27.8 million, respectively. Besides, their productivity per worker recorded good efficiency as compared with other industrial types. However, their average number of workers per establishment does not mean to have absorbed such a large number as other industrial types. On the whole, the scale of industry in the municipalities was much smaller than that in Blumenau.

The third industrial type was the paper industry (9.1%) in order of production value, the transport producing industry (11.0%) such as shipbuilding in order of the number of workers, or the timber industry (11.4%) in order of the number of establishments. Figures in parentheses show the occupation rates of each category to the total in the municipalities.

The economic census in 1980 presented the asset holdings of manufacturing industry in the state of Santa Catarina as of December 31, 1980. An average manufacturing entity had the following tangible fixed assets: Cr$2.4 million of site and building; Cr$3.4 million of machinery and production equipment; Cr$0.5 million of installation; Cr$0.1 million of office furniture; and Cr$0.5 million of transportation facilities such as vehicles. At the same time, it had the following stock inventory: Cr$1.9 million of raw material and semi-manufactured products; Cr$1.3 million of manufactured products; and a small amount of other products for resale.

(3) Tertiary sector

The tertiary sector in the two municipalities is characterized as a mixed market of the large number of small-scale establishments and the small number of slightly larger wholesaling establishments. According to the municipal information, there are 815 commercial establishments and 695 service establishments in the two municipalities in 1986. These numbers are somewhat smaller than those in the census year 1980.

In 1980, there were 832 commercial establishments and 842 service establishments in the two municipalities. These numbers corresponded to 3.5% and 3.7% of the total number of establishments in the state, respectively. The annual sales of commercial sector was Cr$26,489 million and that of service sector was Cr$1,263 million at 1980 current prices. Respective sales accounted for 11.8% and 4.2% of those of the state, respectively. Thus, sales per establishment was Cr$34 million for the commercial sector and Cr$1.5 million for service sector. Of all the tertiary sub-sectors, the wholesale sector attained the largest sales pers establishment, i.e., Cr$227.5 million. Its total sales bore the biggest share in the sector, accounting for 68.9% of the total.

In tertiary sector, 7,857 workers were involved in the two municipalities in 1980, distributed as follows: 4,846 in the commercial sector, accounting for 4.8% of the state; and 3,011 in the other service sector, 3.6%. Although the average number of workers per establishment in the tertiary sector was 4.6 persons, about 14 persons or 3 times of the average number of workers per establishment were absorbed in the wholesale sub-sector. The productivity of labor in the wholesale sub-sector was also at a high level as compared with other sub-sectors. This means that the wholesale sub-sector is well developed in comparison with the other sub-sectors. In fact, the municipalities, especially Itajai, are playing an important role as a marketing channel in the state.

The economic census in 1980 also showed assets holdings of the tertiary sector in the state as of December 31, 1980. An average entity had the following tangible fixed assets: Cr$413,000 of its site and building; Cr$194,000 of equipment; Cr$71,000 of office furniture; and Cr$98,000 of transport facilities such as vehicles. At the same time, it had Cr$703,000 of inventory stock such as merchandise and raw materials.

2.3.3 Gross regional domestic product

The gross regional domestic product (GRDP) in the state of Santa Catarina was Cz$3,741 billion in 1988. Its sectoral distribution was as follows: Cz$640 billion or 17.1% of the total in primary sector; Cz$1,474 billion or 39.4% in secondary sector; and Cz$1,627 billion or 43.5% in tertiary sector. In real terms, GRDP declined by 1.1% in 1988, after it had steadily grown up to 1987. GRDP per capita in the state was Cz$873,000 (equivalent to around US$2,970), which is 16% larger than that (US$2,560) in 1980 in real terms.

GRDP in the two municipalities is estimated at Cz$15.2 billion in 1987. The primary sector grew at a lower pace (8.6% per annum) than other sectors during the 70's, but has grown at a higher rate (11.7% per annum) than the others since 1980. This is due to the rapid development of sugarcane production in the last few years, as mentioned in the previous Section. Although it grew at a remarkable rate, the degree of contribution to the regional economy was not so large because its share of GRDP was comparatively small. The secondary sector grew less than the state average during the 70's. Even afterwards, it did not attain a remarkable growth, as the number of manufacturing establishments have scarcely increased since 1980. The tertiary sector grew considerably during the 70's. It contributed to the regional economy, since it bore a large share (65%) of GRDP in 1987.

GRDP per capita in the municipalities was estimated at Cz$125,000 (equivalent to around US$3,330) in 1987 at current prices. It was about 1.1 times lager than that of the state (about US$3,030). This ratio did not change remarkably since 1970, in spite of the fact that GRDP grew at higher pace than the state average. This might be because population in the municipalities has grown at such a high rate so that GRDP per capita did not grow at the expected rate.

GRDP in the two municipalities will reach NCz$29.6 million in the year 2000 and NCz$64.8 million in 2020 at 1987 constant prices. Per capita GRDP in the municipalities, which is calculated by GRDP and the aforesaid population projection, will grow from NCz$106.8 in 1980 to NCz$206.2 in 2000 and to NCz$350.7 in 2020. Hence, GRDP in

1980 is converted into 1987 prices by implicit deflator (857.57 times between 1980 and 1987) and denomination (Cr$1,000,000 = NCz$1). These figures correspond to 1.9 times in 2000 as large as per capita GRDP in 1980 of Cz$106.8 at 1987 constant prices and 3.3 times in 2020. This growth of per capita seems to be somewhat moderate as compared with the growth of the entire state. This is because population grows faster than the economic production. As a result, the difference between the two values of per capita GRDP reduces from 1.11 times in 1980, which is the ratio of the per capita GRDP of the municipalities (NCz$106.8) to the one of the state (NCz$95.8), to 1.07 times (NCz$350.7 to NCz$327.5) in 2020.

2.3.4 Transportation

In the study area, there are two national arterial highways maintained by the federal government. The BR-101 interconnects the northern and southern regions of the country. It cuts the study area into two portions along the coast as shown in Fig. 2.1. The BR-470 also cuts the study area into two portions along west bank of the Itajai river. A part of the road between Gaspar and the intersection within the BR-101 is still under construction.

Besides the national roads, there are three important arterial highways maintained by the state government. The SC-470 runs through the center of the study area along the right bank course of the Itajai river, connecting Itajai city to upstream cities such as Blumenau and Rio do Sul. The SC-486 runs through the Itajai municipality along the course of the Itajai Mirim river, connecting the BR-101 to upstream cities such as Brusque. The SC-413 runs in the west portion of Navegantes municipality, connecting the BR-470 to Luis Alves located in the northern part of the study area.

The major arterial highways, BR-101 and BR-470, dividing the flood protection area in the study area, are covered by asphalt paving. Major main streets in the area are paved with cobblestones or flagstones like old European cities. Most of other streets are macadam roads. New roads in developing areas or squatted areas still remain unpaved.

2.4 Flood Problem and Flood Damage

2.4.1 Past large scale flood and its rainfall characteristics

Large scale floods occurred in the whole Itajai river basin in July 1983 and August 1984 after the construction of the Sul and Oeste dams, and those floods caused large flood damage in the lower Itajai river basin. Rainfall characteristics and flooding condition in 1983 and 1984 floods are stated as follows;

In July 1983, the rain started from the night on July 5th and continued for 7 days up to July 12th in the entire Itajai river basin. The recorded maximum hourly rainfall is 22 mm/hr at Dr. Pedorinho in the Benedito river basin and the basin mean rainfall amounts in 1, 4, and 7 days are estimated to be 65 mm, 216 mm and 324 mm respectively. Flood peak discharges at the major water level gauging stations are 1,500 m^3/sec at the Sul dam, 1,000 m^3/sec at the Oeste dam, 2,000 m^3/sec at Rio do Sul, 2,500 m^3/sec at Ibirama, 4,400 m^3/sec at Apiuna and 4,800 m^3/sec at Indaial.

In August 1984, the rain started from the morning on Aug. 5th to Aug. 8th and the maximum hourly rainfall was 25 mm/hr recorded at Blumenau city. The basin mean rainfall in 1 and 3 days are 110 mm and 216 mm respectively and the heavy rainfall of around 150 mm/day occurred in the Itajai Mirim basin. Since rainfall pattern in 1984 is more intensive than rain storm in 1983, the shape of flood hydrograph is sharp and flood peak discharge is larger than in 1983. Flood peaks at major sites are 2,500 m^3/sec at the Sul dam, 1,200 m^3/sec at the Oeste dam, 1,860 m^3/sec at Rio do Sul, 400 m^3/sec at Ibirama, 4,400 m^3/sec at Apiuna, 860 m^3/sec at Timbo and 5,100 m^3/sec at Indaial.

2.4.2 Flood damage

Inundated areas due to 1983 and 1984 floods were identified in the study area along the lower Itajai river and the Itajai Mirim river as shown in Fig. 2.4. This inundation map was demarcated on the basis of the results of the flood mark survey. The inundated areas were about 130 km^2 in the 1983 flood and 132 km^2 in the 1984 flood. They account for more than 20% of the total study area. These areas were distributed administratively as follows.

(Unit : km^2)

Municipality	1983	1984
Itajai	91	95
Navegantes	22	20
Penha	4	4
Picarras	13	13
Total	130	132

The inundated areas in the flood protection area were about 40 km^2 during the floods both in 1983 and 1984, which covered about 65% of the flood protection area. The inundation depth was about 0.5 m to 1.0 m in the central area of the Itajai city and 2.0 m to 3.0 m in the low elevation area along the Itajai and Itajai Mirim rivers. The duration of the inundation in

1983 was around a half of month in the most seriously inundated area along both sides of Itajai river, although in 1984 it was less than a week even at seriously affected places.

The number of people affected by the floods was estimated at 60,000 in Itajai and 2,030 in Navegantes. Compared to the entire population of both municipalities, they turn out to be 60% and 15%, respectively.

The estimated flood damage in the municipalities of Itajai and Navegantes by inundation in 1983 and 1984 is summarized in the following table. In this table, only direct flood losses are observable in all their aspects, as some data disappeared and are lacking. Most of monetary figures of flood damage in the table show not only lost values, but also amounts estimated for repair costs.

Municipality	Unit	1983	1984
Itajai			
- Affected houses	Nos.	-	23,000
- Agriculture	Mil. Cr$	-	610.4
- Industry	Mil. Cr$	-	2,174.1
- Commerce & services	Mil. Cr$	-	2,951.1
- Public facilities	Mil. Cr$	69,505.5	11,907.5
- Relief activity	Mil. Cr$	0.5	-
Navegantes			
- Affected houses	Nos.	-	324
- Agriculture	Mil. Cr$	-	21.2
- Industry	Mil. Cr$	-	80.8
- Commerce & services	Mil. Cr$	-	27.1
- Public facilities	Mil. Cr$	424.1	295.7
- Relief activity	Mil. Cr$	-	-

2.5 Existing River Structures and Related Structures

A groin comprising eight rows with a length of about 150 m to maintain the river course mainly for navigation is provided jutting out in the left bank. There are no river structures except these groins in the Itajai river.

There is a sea port at about 3.5 km upstream of river mouth, which is equipped with berth facilities for 20 to 30 thousand ton class ships. There are also a lot of small to middle class shipyards along the both banks of the Itajai river. Besides, two ferry sites are located at about 2.4 km and 7.6 km upstream of river mouth to connect the municipalities of Itajai and Navegantes. In order to supply the municipal water from Itajai to Navegantes, two lanes water pipes with a diameter of 250 mm and 200 mm cross the Itajai river at 6 and 6.8 km upstream of river mouth respectively. In the upmost project stretch, a concrete bridge with length of 472 m and width of 8 m crosses the Itajai river to connect the national road BR-101.

In the river mouth of the Itajai, 700 m long jetty with a trapezoid shape of 10 m in crest width and side slopes of 1:3 is provided at both banks. The embankment body comprises rock material of about 4 ton in weight. Since these jetties were constructed 37 years ago, slope failure and slipping of surface rock are found at several portions.

In order to secure draught for navigation, river dredging was performed at four portions near the river mouth by PORTOBRAS. The dredged volume during 8 years after 1978 was about 5 million m^3.

In the Itajai Mirim river and its short-cut channel in the project area, no river structure is provided. Along the Itajai Mirim river, six concrete bridges with a length of 30 to 90 m and width of 6 to 13 m are provided. Two concrete bridges with a length of about 78 to 147 m and width of 9 to 12 m are provided along the existing short-cut channel.

III. FLOOD CONTROL PLAN IN THE LOWER ITAJAI RIVER BASIN

3.1 Formulation of Flood Control Plan

3.1.1 Criteria for plan formulation

The flood control plan in the lower Itajai river basin was formulated under the following criteria;

(1) It has been planned to proceed with the flood control plan by such stage-wise development as provisional, mid-term and long-term plans. Among them, this flood control plan is targeted for the provisional plan. The design flood in the Itajai river for the provisional plan is 3,300 m^3/sec. While, the average flow capacity in the lower Itajai river stretch is about 1,500 m^3/sec. It is intended in this flood control plan that as much flood flow as possible is discharged through the Itajai main stream by effectively utilizing its river channel by increasing its flow capacity. To meet this intention, it should be planned to increase the flow capacity by means of dredging of the river channel and raising of the flood water level by levee construction. However, increase in the flow capacity of the Itajai river channel by means of raising of the design flood water level should be limited to the extent that it does not exert any influence on the design water level in the Blumenau-Gaspar stretch, which was formulated in the feasibility study of the river improvement project. The flood flow exceeding the increased flow capacity of the river channel is discharged through the proposed floodway.

(2) The route and its dimension of the proposed floodway should be determined by optimization study. For this optimization study, a natural diversion method without any gated weir on the proposed floodway and Itajai main stream is adopted for dividing the flood discharge just upstream of their branching point into two channels in consideration of difficulty of gate operation and its cost overburden.

(3) To raise the design flood water level in the Itajai river stretch, a levee or parapet is obliged to be provided. The height of the parapet along the street is limited to less than 1 m above surface elevation of road sidewalk, and also the height of levee in the urban area should be limited to less than 1.5 m from the ground elevation of the surrounding from the viewpoint of landscape in the urban area.

(4) The flow capacity in the Itajai Mirim river and its short-cut channel is enhanced by means of dredging and provision of levee or parapet.

3.1.2 Optimization study on the proposed floodway

A 50-year probable flood discharge was adopted for the optimization study on the floodway plan. The 50-year probable flood in the project river stretch upstream of the confluence with the Itajai Mirim river is estimated at 5,100 m^3/sec. The corresponding figure in the Itajai Mirim river just upstream of the confluence with the Itajai river is 930 m^3/sec. Then 50-year probable flood in the Itajai river stretch downstream of confluence with the Itajai Mirim river comes to 6,030 m^3/sec assuming these flood peaks reach there simultaneously.

For the optimization study on the proposed floodway, three alternative routes were contemplated. They are route to Picarras coast (Floodway-I) and route to Navegantes coast (Floodways -II and III). The Floodway-II branches from the Itajai river at just downstream of BR-101 bridge, while Floodway-III branches at about 4 km downstream of BR-101 bridge.

To determine the optimal scale of the floodway plan, the following five alternative cases by varying the dividing flow to the floodway and Itajai main stream at their branching point were studied for the respective three alternative routes;

(Unit : m^3/sec)

Alternative Case	Itajai d/s	Itajai Mirim	Itajai u/s	Floodway
1	1,000	930	70	5,030
2	2,000	930	1,070	4,030
3	3,000	930	2,070	3,030
4	4,000	930	3,070	2,030
5	5,000	930	4,070	1,030

Note; (1) Itajai d/s means the stretch between river mouth and Itajai Mirim confluence.
(2) Itajai u/s means the stretch between Itajai Mirim confluence and branch point.

In order to examine the influence on the Blumenau-Gaspar stretch for each of the alternative cases, flood water level was calculated for the stretch from the branching point of each alternative floodway to the Blumenau-Gaspar stretch. Fig. 3.1 shows the relation between the flood water level at Gaspar, Ilhota and BR-101 bridge sites corresponding to flood peak for five alternative cases and design flood water levels set in the feasibility study on the river improvement plan in the Blumenau-Gaspar stretch. This Figure clarifies that;

(1) For Floodways-I and II, the water level at Ilhota and Gaspar is almost same as the design flood water level formulated in the master plan and feasibility study in case that the design discharge of the Itajai main stream downstream of confluence with the Itajai Mirim river is less than 3,000 m^3/sec. In addition, it is clarified that 3,000 m^3/sec is marginal for performing the river improvement work without relocation of the existing BR-101 and BR-470 national roads under the conditions of a freeboard of 0.5 m.

(2) In case of Floodway-III, it is unavoidable to have an influence on the design water level at Ilhota and Gaspar for any alternative cases and to relocate BR-470 national road for the design flood larger than 2,000 m^3/sec even for without freeboard condition. Then it is considered to lower the water level upstream of the branch point by means of introduction of short-cut channel in the meandering portion just downstream of BR-101 bridge.

Since the project benefit attributable to the flood control plan is applicable to every alternative case, the economic comparison among them is made based on the amount of the direct construction cost. The construction cost for Floodways-I and II was estimated for the cases that the design flood in the Itajai river downstream of confluence with the Itajai Mirim river is less than 3,000 m^3/sec. The result of this cost comparison clarifies that the floodway plan for the case of 3,000 m^3/sec is the most economical for both Floodways-I and II. In case of Floodways-III, a short-cut channel is considered as a supplemental measure to lower the water level upstream of the branching point.

The construction cost for the alternative cases in which the design flood in the lower Itajai river stretch is equal to 3,000 m^3/sec are summarized as follows;

(Unit; Million US$)

Floodway Route	Construction Cost /1
Floodway-I	129.24
Floodway-II	103.16
Floodway-III	104.46

Note : /1 Construction cost excluding that for urban drainage work

The three proposed alternative floodway routes are compared from the economical, environmental and social aspects as shown in Table 3.1 and the result of the comparison is summarized as follows;

(1) The amount of construction cost for Floodway-I is larger than that for Floodways-II and III due to its longer route and topographic conditions of hilly

area along the route. From the environmental aspect, pollution of sea water in the Picarras coast which is developed as a bathing resort is predicted to be accelerated due to intrusion of the contaminated and muddy water from the Itajai river. The acreage of the diffusion of turbid water due to construction of the floodway is presumed to be almost the same for both the Picarras and Navegantes coasts. While the fishery activity is being carried out at the river mouth of the Itajai in spite of diffusion of turbid water discharged from the Itajai river. Considering this fact, it seems that there are no objection for the fishery activity for both the Picarras and Navegantes coasts even if the floodway is constructed.

(2) Although the construction cost of Floodway-III is almost equal to that for Floodway-II, construction of Floodway-III is predicted to cause great environmental and social change since it is aligned along the town area of Machados and a lot of public facilities will have to be relocated.

It is concluded from these comparisons that Floodway-II is the optimal plan among the three alternatives.

3.2 Principle of Flood Control Plan

3.2.1 Proposed flood discharge distribution

The proposed flood discharge distribution for provisional plan to cope with 10-year probable flood is established under the following conditions and assumptions;

(1) 10-year probable flood in the Itajai river stretch upstream of the inlet site of the floodway is 3,300 m^3/sec.

(2) The design flood for a long-term plan to cope with 50-year probable flood in the Itajai main stream downstream of confluence with the Itajai Mirim river is set at 3,000 m^3/sec. In this case, the design flood in the Itajai stretch between the confluence with the Itajai Mirim river and inlet site of the floodway is set at 2,070 m^3/sec considering the flood flow from the Itajai Mirim river. The design flood for the provisional plan in the Itajai main stream downstream of the confluence with the Itajai Mirim river is set at 2,770 m^3/sec under the condition that the design flood in the Itajai stretch between confluence with the Itajai Mirim river and inlet site of the floodway is the same as that for the long-term plan.

(3) It is assumed that 10-year probable flood peaks from the Itajai and Itajai Mirim rivers join simultaneously.

The proposed flood discharge distribution thus established is shown in Fig. 3.2.

3.2.2 Principle of flood control plan

The flood control plan in the lower Itajai river basin was worked out under the following principle;

(1) The Itajai river channel in the project stretch should be effectively utilized to discharge as much flood flow as possible. To meet this requirement, the following measures are adopted;

- (i) The flood water level is raised by means of the provision of levee or concrete parapet as far as this rise of flood water level does not exert any influence on the study result in the Blumenau-Gaspar river improvement.
- (ii) The river dredging is employed to increase the flow capacity and to reform the river channel aiming at reducing roughness coefficient.
- (iii) A remarkably narrow river channel portion is widened by means of dredging unless there are densely settled houses.

(2) The floodway channel with a trapezoid shape and about 10 m in depth is aligned through a clayey silt and silty sand zones, and clean sand area near the Navegantes coast. Whether the revetment of slope of the floodway is needed will be determined after monitoring the channel condition without revetment in the provisional stage. However, side slope of the channel in the sand zone near the coast should be protected by riprap.

(3) The flow capacity of the Itajai Mirim river is affected by the water level in the Itajai river. The riparian area in the downstream stretch in the Itajai Mirim river is occupied by densely settled houses and the river stretch in its upstream part meanders remarkably. Considering these river stretch conditions, it is contemplated to increase the flow capacity by means of provision of levee and the river channel alignment should be reformed by employing a short-cut method to utilize the existing meandering river channel areas as the drainage facility area as stated in the succeeding Chapter IV.

(4) The flow capacity of the existing short-cut channel is also affected by the water level of the Itajai river, but its present capacity is in the range of 400 to 700 m^3/sec due to its steep river bed slope and large flow area in comparison with the Itajai Mirim river. Thus, it is contemplated to provide the levee at the river bank with locally low elevation.

(5) Even after the realization of the flood control plan, depression areas which are lower than the design high water level along the Itajai and Itajai Mirim rivers would be still in inundation condition due to inland water caused by rainstorm. To relieve these areas from inundation, the urban drainage plan should be contemplated by combining various drainage facilities.

3.3 River Improvement Structural Plan

3.3.1 Design of river improvement structural plan for Itajai main stream

The river improvement structural plan in the Itajai main stream is designed under the following criteria;

(1) The design river bed slope is set at 1:12,000 so as to keep the present average river bed slope.

(2) The river channel is designed as a single cross section since the water level in rainy and off-rainy seasons is not so different. The width of river bed is 180 m corresponding to the present average river channel width. The side slope of the channel is 1:2.

In this design, the special attention should be given to the followings;

The project stretch of the Itajai river remarkably meanders and the river channel at the meandering portion generally forms a triangular section due to the erosion of concave side. It is planned in this river improvement scheme to align the river channel along the present meandering stretch. In case that the river channel in the meandering portion is reformed by excavation of convex side to fix the design river bed width of 180 m, it is anticipated that the reformed river cross sections gradually change its shape due to the sediment deposit on the convex side of the river channel. To maintain the designed river cross section as it is, annual dredging will have to be carried out.

(3) Concrete parapet wall and levee are provided on the river banks in the low elevation areas to secure a freeboard of 0.5 m above the design high water level estimated by means of the non-uniform flow calculation for 50-year probable flood. The parapet wall is provided along the urban area of Itajai and Navegantes. In the streets adjacent to the river channel, its height is limited to one meter at its maximum above the sidewalk in order to conserve the landscape.

In principle, the maximum height of the levee is 1.5 m above the surrounding ground elevation. Typical section of the levee and concrete parapet is given in Fig. 3.3.

The longitudinal profile, general plan and representative river cross sections for the river improvement of the Itajai main stream designed in accordance with these criteria are shown in Figs. 3.4, 3.5 and 3.6, respectively.

3.3.2 Design of river improvement structural plan in the Itajai Mirim river

The criteria for design of river improvement structural plan in the Itajai Mirim river are as follows;

(1) The design river bed slope is set at 1:10,000 which is the same as the present average river bed slope.

(2) The river channel is designed as the single section with a trapezoid shape having bottom width of 20 m and side slope of 1:2.

(3) The upstream meandering stretch is improved by employing a short-cut channel at three portions to secure the area for construction of regulating pond for the urban drainage of Itajai city.

(4) River dredging is performed along the whole project stretch to increase the flow capacity as well as to restore unsanitary environmental condition of river water polluted by the accumulation of sewage owing to the low flow velocity of river water.

(5) Both banks of the Itajai Mirim river are elevated by construction of levee to protect the Itajai city from flood caused by the Canhanduba river and back water from the Itajai main stream. Typical section of levee is given in Fig. 3.3.

The longitudinal profile, general plan and representative river cross sections for the river improvement of the Itajai Mirim river designed in accordance with these criteria are shown in Figs. 3.7, 3.8 and 3.9, respectively.

3.3.3 Design of river improvement structural plan in existing short-cut channel

The criteria for design of river improvement structural plan in the existing short-cut channel are as follows;

(1) The design river bed slope is set at 1:2,560 which is the same as the present average river bed slope.

(2) The river channel is designed as the single cross sections with the trapezoid shape having bottom width of 40 m and side slope of 1:2.

(3) The levee is provided at the river stretch with remarkably low elevation. Typical section of the levee is shown in Fig. 3.3.

The longitudinal profile, general plan and representative river cross sections for the river improvement in the short-cut channel are shown in Figs. 3.7, 3.8 and 3.10, respectively.

3.4 Structural Plan for Floodway

The design of the structural plan of the floodway was carried out based on the topographic map with a scale of 1:5,000 and contour interval of 1 m, which was prepared by the topographic survey in the study period.

The design river bed slope is topographically set at 1:6,000 which is equivalent to two times that of the Itajai main stream. The width of the floodway is determined at 50 m for the design flood water level.

Since the floodway route is aligned through a soft alluvial layer, the side slope of the floodway was determined based on the stability analysis under the condition that the river channel becomes empty immediately after the completion of the floodway. The geotechnical values applied to the analysis are 10° for internal angle and 1.8 t/m^2 for cohesion. The side slope thus determined is 1:2. The levee with a trapezoid shape of 5 m in crest width and side slope of 1:3 is provided at the place which is 4 m apart from the edge of the side slope of the floodway for the long term plan. The crest elevation is determined keeping 0.5 m of freeboard against the design flood water level.

The general plan, longitudinal profile and typical cross sections of the floodway are shown in Figs. 3.13 and 3.14, respectively.

To prevent erosion of river bed in the Itajai due to variation of river bed slope by the floodway plan, river bed protection supported by concrete pile and protected by concrete block is provided at inlet portion of the floodway as shown in Fig. 3.11. Besides, a ground sill to maintain the planned river bed slope is provided at about 4 km downstream of the inlet portion of the floodway. The proposed ground sill is depicted in Fig. 3.12.

It is contemplated to provide a jetty at the outlet of the floodway to prevent sedimentation caused by littoral drift at the outlet portion and also to prevent sandbar formation.

The jetty structure is designed under the following criteria;

(1) The jetty structure is constructed almost at right angle with the coastal line and head of the jetty is curved to northern direction to avoid intrusion of the predominant waves.
(2) The jetty is extended toward the place where its depth is equal to the channel depth to avoid movement of sediment by wave action, and also to minimize the dredging cost, and
(3) Among the stone masonry, concrete block, caisson and riprap, the stone masonry or concrete block is used as the jetty structure from the viewpoint of its stability and also from economical aspect.

For design of the floodway, the following conditions are applied;

(1)	Design tide level	;	+0.46 m
(2)	Design wave height	;	5.7 m
(3)	Type of jetty	;	Stone masonry
(4)	Crest width	;	10 m

The side slope of the jetty is determined based on the stability analysis using the foregoing design parameters, and consequently the side slope of 1:2 is applied. The crest elevation is set at 6.2 m adding the design wave height to the design tide level. The structural design of the jetty is shown in Fig. 3.15.

The change of the coastal phenomena due to the construction of the floodway was studied by means of numerical simulation based on the coastal data obtained through the site survey during about one year.

The numerical simulation method was used to assess the coastal change, change of tidal current and diffusion of discharged turbid water at Navegantes coast. The result of these coastal analyses is summarized as follows;

(1) It is predicted for the study on coastal change that after the construction of the jetty, erosion will take place in the north of the jetty, while deposit occurs in the south of the jetty. The extent of the coastal change is predicted to be about 30 m for deposit and 20 m for erosion in 10 years after completion of the jetty. Although the tendency of extension of sediment deposit toward offshore will gradually slow down as the coastal depth increases, it may be necessary to protect

the existing coastal road from the erosion by protection works such as riprap wall in future stage.

(2) The result of study on change of tidal current shows that the tidal current tends to slow down around area sheltered by the jetty and velocity of tide changes only within a range of 2 km from the jetty. Besides, the direction of flow changes only at the sea around the jetty.

(3) The turbid water is discharged from the Itajai main stream even after the construction of the floodway. The result of study on diffusion of discharged turbid water shows that the turbid water having the suspended solid (S.S.) of 100 PPM extends up to the northern part of the floodway site in case that 2,000 m^3/sec of the flood peak is discharged only from the Itajai river, while this diffusion is further extended up to about 3 km toward the northern area after completion of the floodway.

3.5 Design of Related Structures

Three bridges are planned to be newly provided crossing the floodway. Out of these three new bridges, two bridges named No.1 and No.2 bridges are designed applying the design standard for the national road class bridge. The No.1 and No.2 bridges are located just upstream of the outlet site of jetty and at 0.35 km downstream of the its inlet site respectively.

The No.1 and No.2 bridges are designed under the following conditions;

a) The proposed No. 1 bridge, located at just upstream of the jetty, has to be designed to have a length required to span the cross section of the floodway for the long-term plan (50-year probable flood).

With regard to the No. 2 bridge, the construction is divided into two stages in order to reduce the cost overburden in the provisional plan, that is, the bridge length is designed to meet the floodway width in the provisional plan. In the stage of the successive flood control plan (the mid-term plan, otherwise long-term plan), the bridge length will be extended to span the cross section of floodway for long-term plan. The bridge is aligned to cross a centerline of the floodway at an angle of 65° in accordance with the proposed relocation route of BR-470.

b) Freeboard of 0.5 m is secured between the lowest elevation of girder and design high water level corresponding to 50 year probable flood for the both bridges.

c) Both bridges are designed to be of prestressed concrete (PC) type. The substructures of the bridges are supported by reinforced concrete (RC) piles of 40 cm in diameter, which are driven to the base rock.

d) The bridge width is determined at 9.8 m applying the design standard for the road bridge in Brazil, which consists of 7.2 m for roadway, 0.9 m for sidewalk and 0.4 m for curb in both sides.

The structural design of the bridges thus performed is shown in Figs. 3.16 and 3.17.

Besides, a new bridge with effective width of 4 m is planned to be constructed at about 3.2 km downstream of the inlet site in order to link the central area of Navegantes and the rural area on the left bank side of the floodway, which is to be isolated due to its construction.

Due to the construction of the floodway, relocation of BR-470 road is needed at two portions. They are about 900 m near the inlet portion and about 1,200 m between 4.5 km and 5.7 km stretch upstream of outlet of the floodway. The road to be relocated was designed under the same design criteria as those for the existing BR-470 road.

IV. DRAINAGE PLAN IN ITAJAI AND NAVEGANTES

4.1 General

The residential areas in the Itajai and Navegantes cities are planned to be relieved from flood from the Itajai river by means of flood control plan comprising the floodway scheme and river improvement plan in the Itajai main stream, Itajai Mirim river and existing short-cut channel. After the implementation of the proposed flood control plan, present drainage condition will be remarkably improved since the river water level is lowered by the river improvement works. However, depression areas along the Itajai river and Itajai Mirim river, which are lower than the design high water level, would be still in inundation condition due to inland water caused by rainstorm as shown in Fig. 4.1.

In this study, the drainage plan for these areas was worked out by combining several drainage facilities.

4.2 Existing Drainage System

The existing drainage system in the Itajai city comprises drainage channels and drainage pipes with a diameter of 30 to 100 cm. The rainwater and sewage in the city area are directly drained to the Itajai and Itajai Mirim rivers through this drainage system. The drainage system has been expanded in accordance with the development of the residential area, but it is found that a part of the drainage pipe is not connected with the Murta river, a small tributary of the Itajai river. Network of the existing drainage system is given in Fig. 4.2. There are no systematic urban drainage system in Navegantes city area.

New drainage plan in the Itajai city was prepared by DNOS in 1986. In this plan, central part of the Itajai city is divided into ten drainage basins and it was planned to drain perfectly the rainwater and sewage by means of the channels, pipes and drainage pumps. However, this new plan is so costly that it is not realized yet.

4.3 Present Situation of Envisaged Drainage Districts

The study area for the drainage plan is herein defined as the area covering a part of Itajai and Navegantes urban areas which are lower than the design flood water level of the Itajai river. It is divided into nineteen districts considering the topographic condition and present drainage network. The divided districts are shown in Fig. 4.3. They are grouped into three, namely, six districts along the right bank of the Itajai river, three districts along the left bank of the Itajai river and ten districts along the Itajai Mirim river. The drainage acreage for the respective districts divided are given in Fig. 4.3.

The rainwater and sewage in all of the six districts located along the right bank of the Itajai river are drained directly to the Itajai main stream through the existing pipelines and channels. Among the divided six districts, IR-4 and IR-6 are occupied mostly by the depression area and wasteland. A part of these depression areas is planned to be filled up by the dredged river bed material.

Majority of the districts IL-1 to IL-3 located in the left bank of the Itajai river is the depression area and remains as wasteland. It is planned that these depression areas are filled up by the dredged river bed material.

The rainwater in ten districts located along the Itajai Mirim river is drained to the Itajai Mirim river through the drainage pipes. Among ten divided districts, majority of the district areas, IM-1 to IM-5 and downstream areas of IM-6 to IM-10 are occupied by the depression area. It is planned that the depression areas in IM-4 and IM-10 are filled up by the river bed material dredged from the river channel of the Itajai Mirim.

4.4 Drainage Plan

4.4.1 Principle of drainage plan

To set up an adequate drainage plan, the following principle was established considering topographic condition of the drainage basin, effective utilization of the existing drainage system and the problems relating to the existing drainage system;

(1) A gravity flow type drainage method should be employed as far as possible to minimize the operation and maintenance cost for drainage. A flap gate should be installed at the outlet of the drainage facility to prevent river discharge from entering into the drainage basin area.

(2) In case that the gravity flow type drainage method is topographically impossible to be adopted, a regulating pond with as much capacity as possible should be provided at the downstream end of the drainage facility to reduce the peak runoff from the drainage basin, and supplementarily a pump facility should be installed to discharge the excess water from the pond.

(3) The construction cost and operation and maintenance cost for the pump facilities are generally costly. To minimize the number of pumping station and also to reduce the capacity of the pump, neighbouring drainage basins should be integrated.

(4) Majority of the drainage districts such as IL-1, IL-2 and IL-3 are occupied by the depression area and there are only few houses. For these districts, reformation of the area by means of filling the depression area with the earth material excavated from the proposed floodway channel should be contemplated.

(5) The drainage facilities contemplated in this plan involve the regulating pond, pumping station, gate facilities and extension of the drainage pipe from the existing main drainage pipe to the proposed regulating pond. The improvement of the existing drainage pipe line network is not included in this plan.

4.4.2 Design of drainage plan

The drainage facilities such as pump, regulating pond and drainage pipe connecting the existing drainage pipe to the regulating pond was designed under the following design conditions;

(1) Probable flood hydrograph and its volume to design the capacity of pump and regulating pond are estimated by rational formula using probable 4-day rainfall with 10-year probability at Itajai or the neighboring station and actual rainfall distribution records on July 1983 and August 1984.

(2) Probable flood peak discharge to design the connecting drainage pipe is estimated by rational formula incorporating probable rainfall intensity-duration curve with 10-year probability.

(3) Considering the increase in outflow discharge due to urbanization and development of the Itajai city, runoff coefficient in future stage is estimated at 0.9 for city area, 0.6 for farm, pasture and unused land and 0.7 for forest area.

(4) Design high water level in the regulating pond is set at the ground elevation at the pond site and pump capacity is designed so as to keep the pond water level equal to or less than the design water level assuming that water level of the Itajai river is at the design flood water level.

(5) The connecting drainage pipe to the pond is designed so as to flow 10-year probable flood from the drainage district.

Main features of the regulating pond, pumping facilities and connecting drainage facilities designed based on these design conditions are listed in Table 4.1 and illustrated in Fig. 4.4. The proposed drainage facilities and drainage method for the respective drainage districts are as follows;

(1) Drainage districts; IR-1

Since most of the area is occupied by unused area with low elevation along the Schneider river, filling up of the land is planned to prevent the flooding due to back water from this tributary.

(2) Drainage district; IR-2, 3, 5, IM-1, 2, 3, 5

These districts have a remarkably small depression area less than 0.2 km^2. A flap gate will be installed at the outlets of the existing drainage system.

(3) Drainage district; IR-4

It has been planned that most of the depression area along the Itajai river in this district is developed as industrial area, but it is still in unused condition due to habitual inundation. The remaining area is utilized as the residential area with low elevation. It is planned to elevate the ground level of the depression area up to the design flood water level. Since the most of the houses in the residential area are of divided high floor type with about 0.5 m in height, it is planned to fill up the land with the excavated material to about 0.5 m from the original ground surface on the average and to provide the regulating pond and pumping station.

(4) Drainage district; IR-6

It has been planned by Itajai municipality that the depression area along the Itajai river in this district is developed as residential and industrial areas. To meet this requirement, it is planned to fill up the land with the excavated material to more than design high water level. Since the remaining area consists of the residential area of about 0.5 m high floor type houses, it is planned to fill up to about 0.5 m and to provide the regulating pond and pumping station.

(5) Drainage districts; IL-1, 2, 3, IM-4, 10

Since there are no houses in these districts, only the filling up of the land up to the design high water level is planned. However, earth filling for IM-10 should be carried out in the future stage when the area is developed, since the earth material to meet the requirement is not available.

(6) Drainage districts; IM-6, 7

The hinterland of these districts forms mountainous areas. The rainwater from these mountainous areas is planned to be drained directly to the Itajai Mirim river by providing new drainage channel along the boundary zone between IM-7 and IM-8. The drainage in the remaining area will be performed by providing the regulating pond and pumping station.

(7) Drainage district; IM-8

The low land in this district will be filled up since there are no houses. However, this earth filling will be performed in the future stage when the area is developed, since earth material for filling up is not available. The hinterland in this district is the mountainous area and rainwater from this area will be drained directly to the Itajai Mirim river by providing new canal.

(8) Drainage district; IM-9

This district will be topographically divided into two zones. Rainwater in the western part of this district is drained directly to the Itajai Mirim river by providing new canal. The drainage in the remaining area will be made by providing the regulating pond and pumping station.