Supporting Report (B)
Flood Mitigation Plan

PREPARATORY SURVEY
FOR
THE PROJECT ON DISASTER PREVENTION
AND
MITIGATION MEASURES FOR THE ITAJAI RIVER BASIN

FINAL REPORT

VOLUME III : SUPPORTING REPORT
ANNEX B: FLOOD MITIGATION PLAN

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CHAPTER 1 INTRODUCTION

1.1 Outlook of the Itajai River

The Itajai River basin is located in the northern part of the Santa Catarina State (hereinafter called SC state) with a basin area of 15,221 km^2. The Itajai River originates in the mountainous range of Serra Geral and drains into the Atlantic Ocean in Itajai city. The length of the Itajai River from Itajai city to Rio do Sul city is approximately 190 km.

Main tributaries of the Itajai River are as follows (see Figure 1.3.1).

- Both the Itajai do Oeste and the Itajai do Sul Rivers join to gather to the Itajai River in Rio do Sul city.
- The Itajai do Norte River joins the Itajai River in Ibirama city at the point of 150 km from the river mouth of the Itajai River.
- The Benedito River joins the Itajai River in Indaial city at the point of 100 km from the river mouth of the Itajai River.
- The Itajai Mirim River joins the Itajai River in Itajai city at the point of 8 km from the river mouth of the Itajai River.

There are three flood control dams named Oeste Dam (catchment area 1,042 km^2), Sul Dam (1,273 km^2), and Norte Dam (2,318 km^2), which are located in the upstream areas of the Itajai do Oeste, Itajai do Sul and Itajai do Norte Rivers.

1.2 Background and Purpose of the Supporting Report Annex B

Both large floods in 1983 and 1984 brought huge damage to the municipalities in the Itajai River basin. In addition, the heavy storm attacked intensively the downstream region of the Itajai River basin in 2008, resulting in flood, flash flood and sediment disaster with huge damage associated.

In this Preparatory Survey, prevention and mitigation measures against these disasters have been comprehensively studied. And this Supporting Report B describes the structural measures against flood disaster.

The master plans of the flood prevention and mitigation measures (hereinafter called M/P) were elaborated for the 5-year, 10-year, 25-year, 50-year floods (50-year flood means a flood to be once in 50 years in average). Through discussions in the public hearings and the Counter Part Meeting (meeting with representatives of public and private entities operating in the basin of the Itajaí River), safety level for the 50-year flood was selected as the master plan for the Itajai River basin.

However, the achievement of 50-year flood protection level would require a huge investment and long period for evaluation and consensus building about various impacts on the social environment. Therefore, the safety level for the 10-year flood was proposed as the provisional safety level in stage-wise implementation.

The feasibility study (hereinafter called F/S) targets the following components of the measures proposed for the safety level for the 10-year flood except basin storage (small dams) and river improvements in the Garcia and Velha Rivers in Blumenau city

i) Water storage in paddy field.

ii) Heightening of the existing flood control dams and modification of their operations.

iii) Modification of the operations of the existing hydropower dams.

iv) Floodgates and river improvement in the Itajai Mirim River.

v) Reinforcement of the Flood Forecasting and Warning System (FFWS).

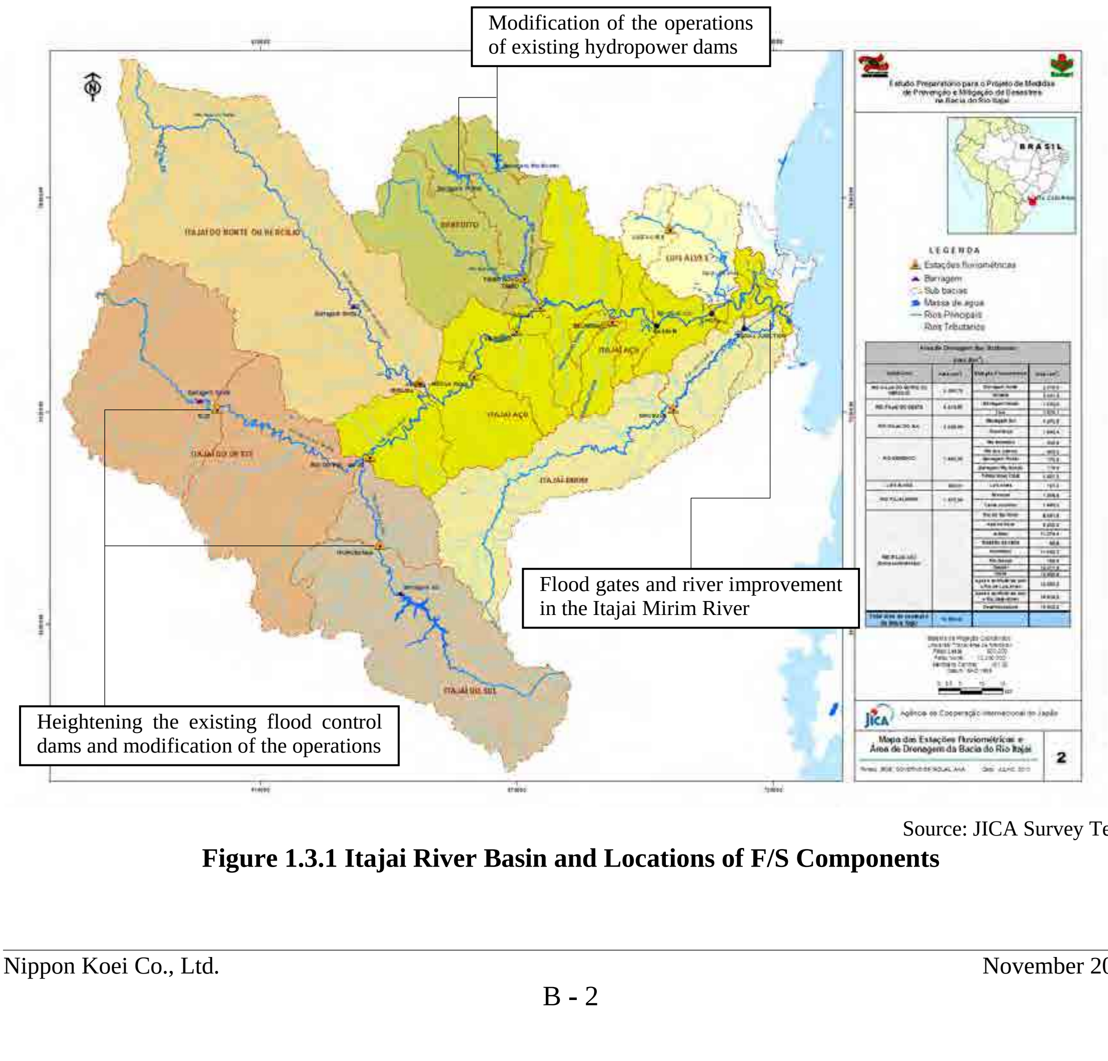
This Supporting Report B describes heightening of the existing flood control dams, modification of existing dams, and floodgates and river improvement in the Itajai Mirim River (see Figure 1.3.1). The water storage in paddy field and the FFWS are mentioned separately in Supporting Reports G and D. Supporting Report F mentions the feasibility design and cost estimation of these flood prevention and mitigation measures.

1.3 Composition of the Supporting Report Annex B

This Supporting Report B consists of nine chapters.

Chapter 2 to 5 mention the elaboration of the M/P. The flow capacity and existing river facilities in the Itajai River are mentioned in Chapter 2. Needs for the flood prevention and mitigation measures and the basic policy of the M/P are studied in Chapters 3 and 4. And the elaboration of the master plans for the 5-year to 50-year floods is studied in Chapter 5.

The results of the F/S are mentioned in Chapters 6 to 9. Chapter 6 describes the components of the F/S. Chapters 7 to 9 mention the results of F/S about the proposed heightening of the existing flood control dams and modification of their operations, modification of the operations of the existing hydropower dams, and the floodgates and river improvement in the Itajai Mirim River.



Source: JICA Survey Team

Figure 1.3.1 Itajai River Basin and Locations of F/S Components

CHAPTER 2 EXISTING RIVER FACILITIES

2.1 River Facilities

2.1.1 Flood Control Facilities

The most typical flood control facilities are three dams constructed in the tributaries (detailed explanation in sub-section 2.2); the Oeste, Sul and Norte dams. As these dams are exclusive for flood control purpose, reservoirs always remain empty for retaining flood water. Besides these dams, there are limited facilities such as revetment of concrete blocks at the water colliding portion on the right bank of the Itajaí River in Blumenau city, and small scale revetment works by means of simple gabions and ripraps. Almost no flood control works have been so far implemented by means of diking and widening of ricer channel to increase flow capacity.

In the Itajaí Mirim River, a straight shortcut channel was constructed to flush floods more rapidly near Itajaí city. However, it might be said that the shortcut channel could not solve flooding issues because of some opinions that this shortcut channel had caused an increase of flood discharge in the downstream reaches in Itajaí city.

Revetment works in the Itajai River in Blumenau city

Gabion works after the 2008 flood damage in the Garcia River, Blumenau city

2.1.2 Water Use Facilities

There exist several intake facilities for domestic and irrigation water supply constructed municipal governments. The water intake gate with pumping station is constructed on the shortcut channel Itajaí Mirim River to supply domestic water for Itajaí and Navegantes cities. The sluice gates at the intake functions as a protection of see water intrusion. At the confluences of the Benedito and Cedros Rivers, there is an intake with double-arch in Timbó city.

Water Gate at the Itajaí Mirim River, Itajaí city

Intake in the Benedito River, Timbó city

Table 2.1.1 Intake Facilities of Municipalities in Itajai River Basin (Questionneir Survey)

Municipalities	Name of Rivers	Objectives	Type of Facilities	Intake Rate
Navegantes	Rio Itajai Mirim~~Itajai Mirim~~	Water supply	Pump	
Luis Alves	Rio Luis Alves	Water supply	Pump	9 L/s
Indaial	Rio Itajai Acu	Water supply	Gravity	1.45 m^3/s
Benedito Novo	Ribeirao Carvao Riberao Ferro	Water supply	Weir (H=1m、L=6m) Weir (H=2m、L=10m)	2.061 L/s 16 L/s
Agronomica	Rio Trombudo	Irrigation	Pump	
Taio	Rio Taio	Water supply	Pump	50 L/s
Santa Terezinha	Corrego Beiger	Water supply	Pump	
Salete	Ribeirao Panela	Water supply	Weir (L=10m)	0.015 m^3/s

Source: JICA Survey Team

2.1.3 Hydroelectric Power Plant

In the Itajaí River and its tributaries, there are various dams for hydroelectric power generation and power stations. These facilities were constructed mainly by Celesc, a state owned company of the Santa Catarina State. Main features of the facilities are as follows:

(1) Rio Bonito and Pinhal Dams

The Rio Bonito and Pinhal Dams exclusive for hydropower generation owned by CELESC are located in the Cedros River, a tributary of the Benedito River as shown in Figure 2.1.1. Because of utilization for energy generation without flood control function, these dams are equipped with only power generation facilities and spillways. According to CELESC, these dams had been operated by lowering the maximum reservoir water level by 50 cm to create flood control capacity in reservoir based on the instruction of State Government. Although this flood operation had been carried out based on the information on rainfall forecast by EPAGRI/ CIRAM, no operation has been made in these years. This is mainly due to low accuracy of the forecast. There have been occurred some cases that no flood occurred after lowering the reservoir water level and flood arrived earlier before the lowering. Main features of the dams are shown in Table 2.1.2.

Table 2.1.2 Main Features of Rio Bonito and Pinhal Dams

Features		Rio Bonito Dam	Pinhal Dam
Construction year		1963	1949
Reservoir	Dimension of the Basin*	C.A.=119.8km^2	C.A.=179.9km^2
	Capacity	32 million m^3	18 million m^3
Dam	Model	Embankment dam	Embankment dam
	Crest elevation	EL.589.5m	EL.652.0m
	Dam height	19.0m	15.0m
	Crest length	118.0m	150.0m
	Dam volume	60,750m^3	26,460m^3
Spillway	Width	20m	25m
	Design discharge	150m^3/s	353m^3/s
Hydroelectric Power Plant	Name of the plant	Palmeiras	Cedros
	Number of turbines	3	2
	Generation capacity	24,602MW	8.4MW
	Maximum water consumption	11.1m^3/s	4.1m^3/s

Source: Questionnaire survey to CELESC by JICA Survey Team

(2) Salto Hydroelectric Power Plant

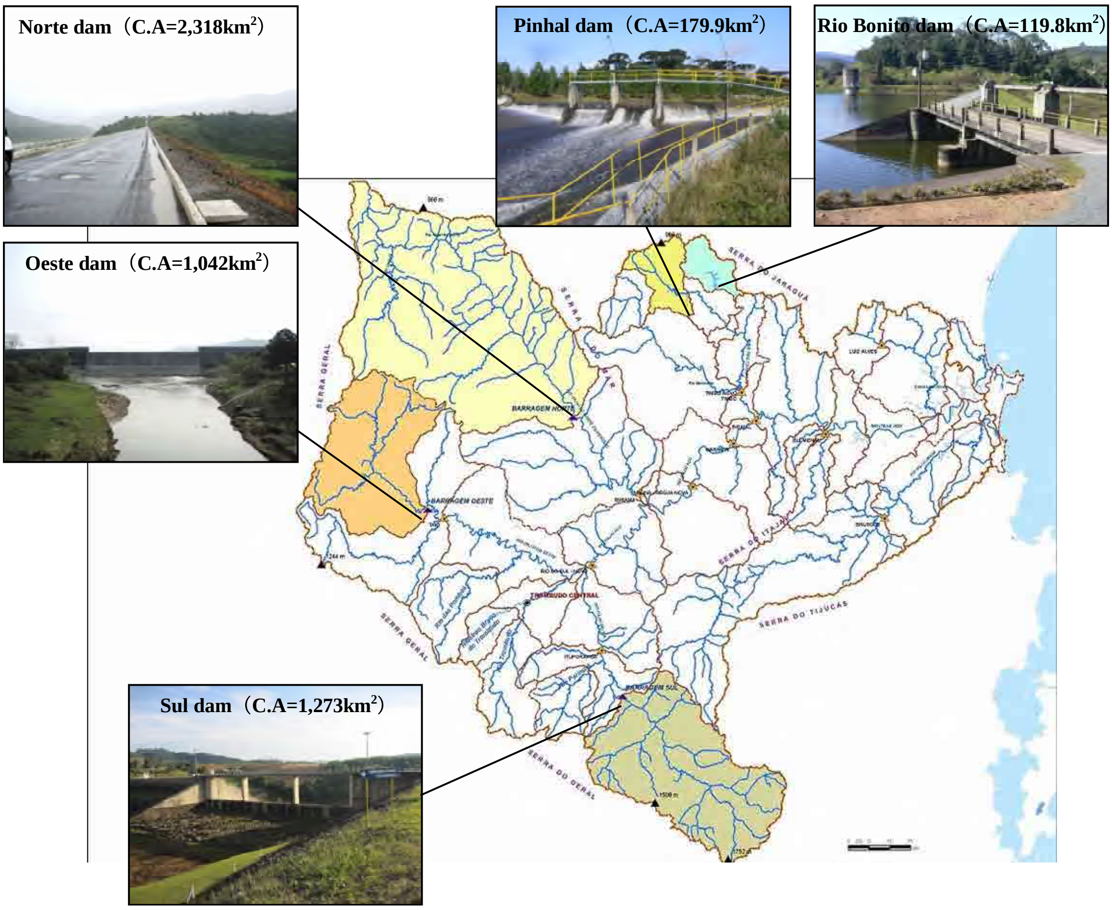
The Salto hydroelectric power plant was constructed in 1914 on the Itajaí River upstream Blumenau city. The intake dam and power plant are located at the right river course, where the

Itajaí River is divided into two river courses due to the existence of large sand bank (island). Main features of the power plant are summarized below.

Table 2.1.3 Main Features of Salto Hydroelectric Power Plant

Name of the plant		**Salto Hydroelectric Power Plant**	
Owner		**CELESC**	
Reservoir Hydrological characteristic	Dimension of the Basin*	C.A.=11,700km^2	
	Flooded area	0.03ha	
	Average discharge	220m^3/s	1977 - 1990
	Maximum daily discharge	1,907m^3/s	
	Monthly average minimum discharge	23.0m^3/s	
	Flood discharge for 100-year return	4,820m^3/s	
Dam (Spillway)	Dam profile	Tall type made of concrete	
	Discharge format	Free discharge	
	Dam height		Not identified
	Crest length	800m	
Generation	Outlet power	6.7MW（effective = 6.3MW）	
	Number of turbines	4	
	Maximum fall	10.1m	
	Maximum water volume utilization	89m^3/s	

Source: Questionnaire survey to CELESC by JICA Survey Team



Source: JICA Survey Team

Figure 2.1.1 Location Map of Major Existing Dams


Rio Bonito Dam and Spillway


Pinhal Dam and Spillway

2.1.4 Urban Drainage

Although the detailed information on the drainage system for main cities has not obtained, current issues on urban drainage were summarized in Table 2.1.4 below.

Table 2.1.4 Current Issues on Urban Drainage of Major Cities

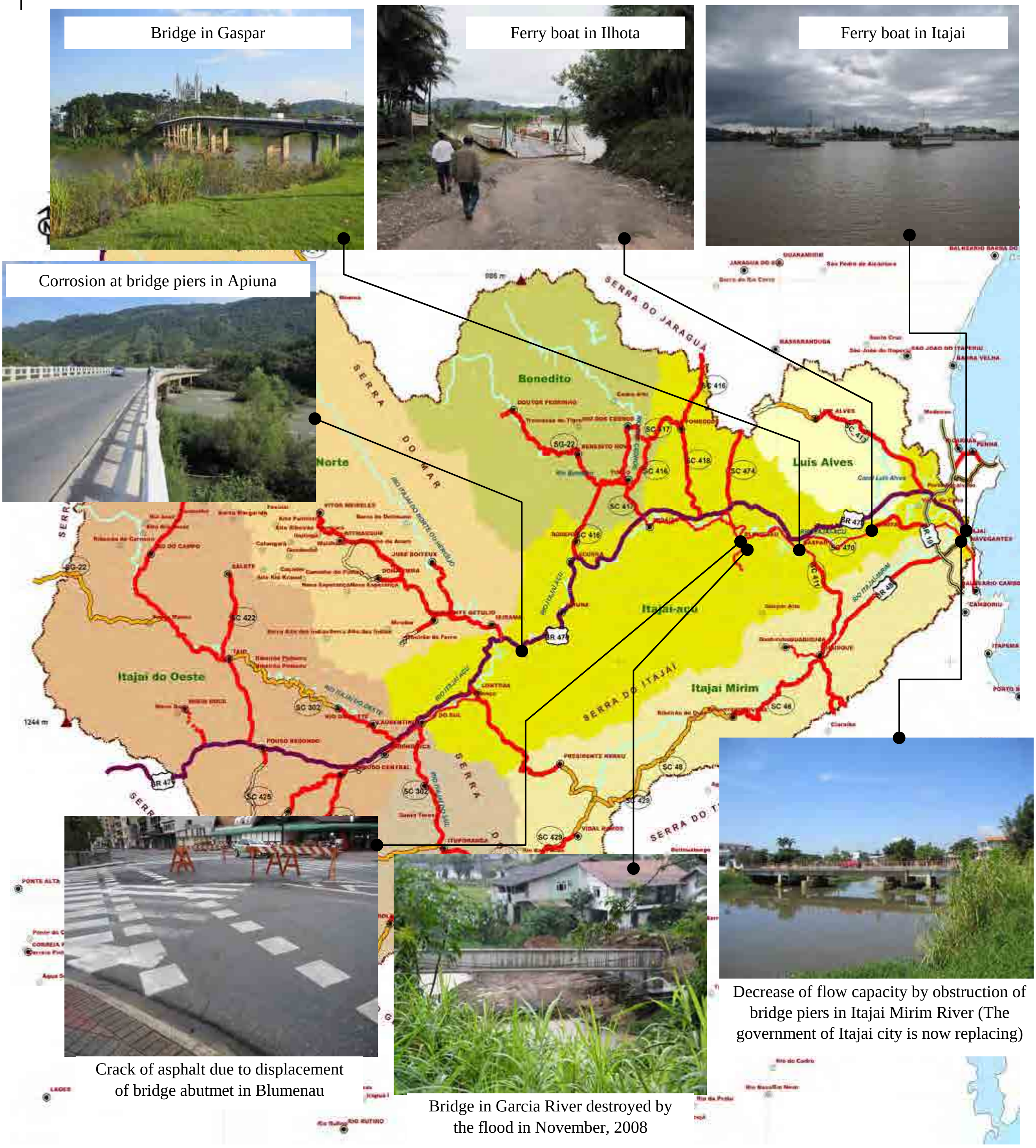
Municipality	Population (Person)	Urban Drainage Issues	Information Source
Itajaí	172,081	Only poor drainage system with 600mm in diameter of pipeline network. Under construction of new drainage canal with 1.5×1.0m and 15 km long (however, no sluice to avoid the tidal inflow is equiped)	Construction department of Itajaí city
Navegantes	57,324	No serious drainage issues because of higher elevation than in Itajaí	of Navegantes
Gaspar	55,489	No information	
Blumenau	299,416	A macro-drainage problem in Velha River. Poor drainage system in harmony with rapid urbanization	Civil Defense of Blumenau city
Indaial	50,917	No drainage and flood problems	
Rio do Sul	59,962	Poor development of sewage system and almost no function of urban drainage system	CRAVIL
Brusque	102,280	No information	

Source: Questionnaire survey to municipalities by JICA Survey Team

In Blumenau city, water gate was installed in the Fortaleza River near the confluence to the Itajaí River to avoid the reverse flood flow from the Itajaí River. An installation of pumping station with a capacity of 8,000 l/s is planned to drain the flood flow from the Fortaleza River to the Itajaí River during closure of the sluice gate. However, there are several opinions in the community that the water gate would hamper drainage of the Fortaleza River.

2.1.5 Bridge and Navigation

Though many bridges have built across the Itajai River and its tributaries, some of them have structural problems and some decrease the flow capacity of the rivers. The width of the downstream reach of the Itajai River is so large that installation of bridges is limited to BR-101. Transportation between right and left bank in Itajai, Navegantes and Ilhota cities is depend on ferry boats.



Source: JICA Survey Team

Figure 2.1.2 Typical Examples of Bridges on Itajai River

2.1.6 River Mouth Area and the Port

As mentioned earlier in sub-section 2.1.4, there are two ports in the mouth of the Itajaí River. They are the Itajaí Port at the right bank and the Portonave at the left bank. According to Itajaí Port, annual dredging of 3 million m^3 of the deposited sediments (fine sand, silt and clay) in the Port is necessary to maintain the water depth at 11 m for port function. On the other hand, the riverbed in the Port was seriously eroded due to the 2008 year flood, and thus the pier walls were destroyed (14 m deep to the pier foundation). The flow velocity in the Port was recorded 8.7 m/s during the 2008 year flood. At the river mouth, a jetty was installed to avoid blockage of river mouth due to sedimentation and groins (spur dike) are also installed to increase flow velocity by means of decreasing the flow area for controlling sedimentation in the mouth.

Itajai Port (left), Navegantes Port (right)

Jetty and Spur dyke in River Mouth

2.2 Flood Control Dams

The location map of 3 flood control dams is shown in Figure 2.1.1 and their main features are summarized in Table 2.2.1. The total drainage area of these 3 dams is 4,633km^2, which is equivalent to 31% of the total drainage area of the Itajaí River mainstream. The flood control capacity of three dams is evaluated in terms of the equivalent rainfall to be stored (= reservoir storage capacity/drainage area). The estimated equivalent rainfall of the Norte dam shows the highest value of 154 mm. This means that the Norte dam has the largest flood control capacity among the dams compared to its drainage area and thus the likelihood of becoming full of water in reservoir and resulting in overflowing through spillway due to heavy rainfall might be low.

On the other hand, the estimated equivalent rainfalls of the Oeste and Sul Dams are 80 mm and 73 mm. which are almost half value of the Norte dam. Therefore, the reservoirs of these two dams easily become full. Especially the Oeste Dam has been full of water due to the floods in 2001 and 2010, causing overflowing through spillway, although no overflowing occurred at the Sul Dam. This might be due to more heavy rainfall occurred during the floods in the upper catchment of the Oeste Dam and smaller releasing capacity compared to that at the Sul Dam.

Table 2.2.1 Main Features of Flood Control Dams

		Oeste Dam	Sul Dam	Norte Dam
Reservoir	Catchment area	1,042 km^2	1,273 km^2	2,318 km^2
	Reservoir area	950 ha	840 ha	1,400 ha
	Gross storage capacity	83,000,000 m^3	93,500,000 m^3	357,000,000 m^3
	Equivalent rainfall	80 mm	73 mm	154 mm
	Minimum water level	EL.340.0 m	EL.372.9 m	EL.257.0 m
	Maximum water level	EL.363.0 m	EL.408.0 m	EL.304.25 m
Dam	Completed year	1973	1976	1992
	Dam type	Gravity	Rock fill	Anchoring
	Dam height	25.0 m	43.5 m	58.5 m

		Oeste Dam	Sul Dam	Norte Dam
	Crest length	422 m	390 m	400 m
	Crest elevation	364.5 m (crown top)	410.0 m	306.5 m
Spillway (flood control)	Number of conduits	7	5	2 (with sluice) 5 (without sluice)
	Type	Sluice regulation	Sluice regulation	Part with Sluice regulation
	Conduit diameter	1500 mm	1500 mm	B2.6 x D2.6m x 2
	Elevation (center of the conduit)	340.05 m	nearly 368 m	nearly 251 m
	Discharge capacity (Normal HWL)	163 m^3/s (WL 360 m)	194 m^3/s (WL 399 m)	258 m^3/s (WL 295 m)
Spillway (Emergency)	Width	+- 100m	65m	
	Crest elevation	360.0m	399.0m	295.0m
	Discharge capacity (Water level: full reservoir level)	Emergency 175 m^3/s Normal 1,125 m^3/s Total 1,300 m^3/s (WL 363m)	Emergency 217 m^3/s Normal 3,053 m^3/s Total 3,270 m^3/s (WL 407m)	

*Shadowed cell: DEINFRA website (http://www.deinfra.sc.gov.br/barragens/sobre-as-barragens/)
*Equivalent rainfall = reservoir storage capacity / drainage area
*The discharge capacity was estimated based on the estimated H-Q curve estimated.

Oeste Dam

Norte Dam

Sul Dam

The operation manual of those dams was prepared by DEINFRA/DENOH in April of 2007, named “Manual De Procedimentos Para Operacao Das Barragens do Alto Vale do Itajai”. The gates are operated based on the river water level in the downstream cities. This operation manual summarized as Table 2.2.2.

Table 2.2.2 Summary of the Operation Manual of Oeste Dam and Sul Dam

Dam	Operation Manual
Oeste Dam	When the river water level in the city reaches the emergency level mentioned below, the gates begin to be closed. The number of gates to be initially closed depends on the amount of rainfall which continues to fall over the city, and the first dam to be operated will depends on the distribution of rainfall, i.e., smaller rainfall intensity in its drainage area. - The river water level forecasted in Blumenau is reaching over 8.50 m. - The river water level is reaching to 6.50 m in Rio do Sul – start to close gates together with Sul Dam. - When the river water level reaches 7.10 m in Taio – start to close first gate; when the river water level reaches 7.50 m - the seven gates shall be closed. - When the river water level reaches 8.00 m in Rio do Oeste – start to close first gate; when the river water level reaches 9.00 m, the seven gates will be closed.
Sul Dam	When the river water level in the city reaches the emergency level mentioned below, the gates begin to be closed. The number of gates to be initially closed depends on the amount of rainfall which continues to fall over the city, and the first dam to be operated will depends on the distribution of rainfall, i.e., smaller rainfall intensity in its drainage area. - The river water level forecasted in Blumenau is reaching over 8.50 m. - The river water level is reaching to 6.50 m in Rio do Sul – start to close gates together with Sul Dam. - When the river water level reaches 3.80 m in Ituporanga, or the flood over the spillway reaches to Ituporanga with water depth over 2.00 m.
Remarks	- Since the gates are closed, each reservoir should start to be monitored more carefully, to avoid that the storage exceeds the reservoir capacity and starts to spill out. The operator shall record water elevation and percentage of storage on the worksheet by relation between the water level and the storage. - The operation of the gates is executed through the command panel with buttons. At first, turn on the electric energy panel (located beside the command panel), turn on the hydraulic pump, then push the button “open” and/or “close” of each gate. Movement of each gate shall terminate automatically. The operation of plural gates at the same time is not advisable, should be done in sequence.

Source: Manual De Procedimentos Para Operacao Das Barragens do Alto Vale do Itajai, DEINFRA/DEOH, 4-2007

CHAPTER 3 EVALUATION OF FLOW CAPACITY

3.1 Profile and Cross Sectional Features of the Itajaí River

3.1.1 River Cross Section Survey

The river cross section survey in the Itajai River was carried out under the Preparatory Survey in the period of June to August in 2010. Among the surveyed 143 sections in total, 79 sections were in the Itajai River mainstream and 64 sections were for tributaries as summarized below.

Table 3.1.1 Quantity of River Cross Sections Surveyed

River Name	No. of Sections	Remarks
Itajaí-Açu River	79	Mainstream
Itajaí Mirim River	17	Including 5 sections in the old Itajaí Mirim River
Garcia Stream	7	Blumenau city
Velha Stream	5	Blumenau city
Fortaleza Stream	2	Blumenau city
Benedito River	11	Including 4 sections in the Cedros River
Itajaí do Norte River	7	
Itajaí do Oeste River	9	
Itajaí do Sul River	6	

Source: JICA Survey Team

3.1.2 Riverbed Gradient of the Itajaí River

Table 3.1.2 presents the average riverbed gradient by river stretch along the Itajaí River and major tributaries, which were estimated based on the results of river cross section survey.

Table 3.1.2 Average Riverbed Gradient by River Stretch

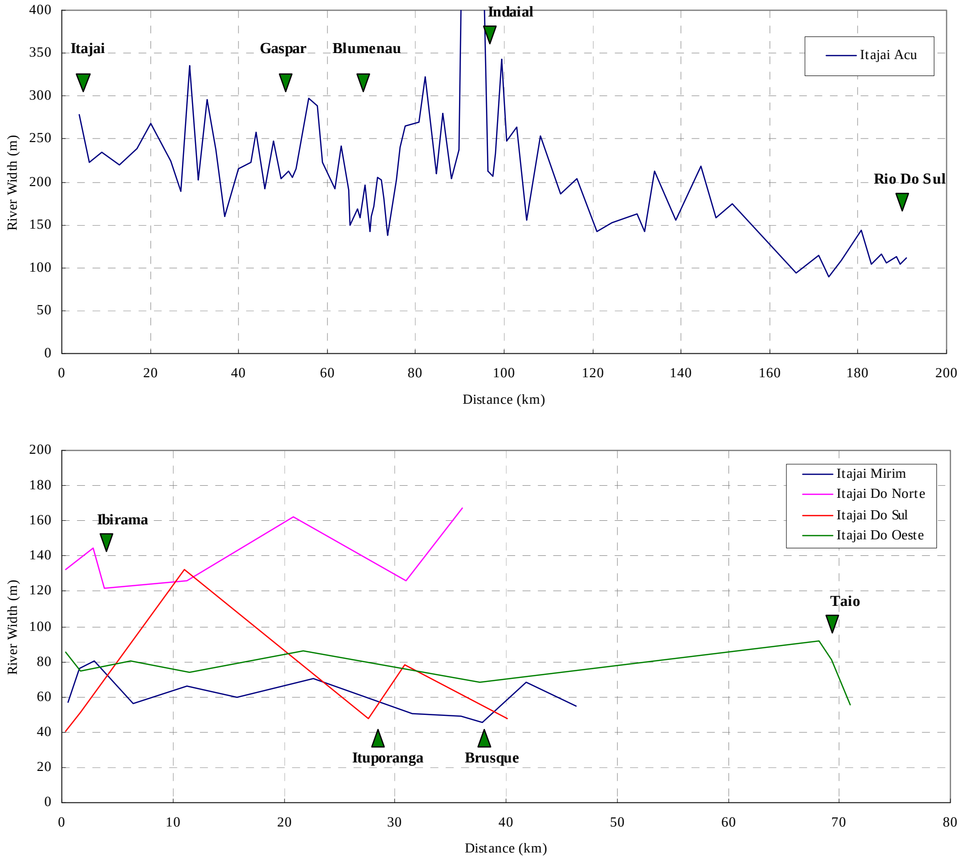
River	Stretch	Gradient
Itajaí-Açu River	Itajaí upstream Blumenau	1/20000
	Blumenau upstream to Indaial upstream	1/400
	Indaial upstream next to Itajaí do Norte confluence	1/1500
	Confluence with Itajaí do Norte until Lontras downstream	1/85
	Lontras downstream to Rio do Sul	1/3000
Itajaí Mirim River (Canal)	From the Itajaí-Açu confluence until the bifurcation at Itajaí Mirim Velho upstream	1/8000
	Bifurcation at Itajaí Mirim Velho upstream until Brusque upstream Brusque	1/1700
Itajaí Mirim Velho	From the bifurcation with the Canal until the Canal confluence	1/15000
Garcia Stream	From the Itajaí-Açu River confluence up to 3 km upstream	1/600
	Next 3 kms until 14 km upstream	1/200
Da Velha Stream	From the confluence until 2km upstream	1/200
	From 2 km upstream until 6 km	1/2000
Fortaleza Stream	From the confluence until 2 km upstream	1/500
Benedito River	Confluence until Timbó	1/2000
	Timbó to Benedito Novo	1/140
	Timbó to Dos Cedros River	1/2000
Itajaí do Norte River	Confluence to Presidente Getulio	1/170
Itajaí do Sul River	Confluence to Ituporanga	1/800
Itajaí do Oeste River	Confluence to Taió	1/5000

Source: JICA Study Team

3.1.3 River Channels

Variation of river channel width along the Itajaí River and main tributaries is illustrated in the figure below. The mainstream of Itajaí River varies from 200 to 300 m from the river mouth to near Indaial city. From its upstream reaches, river channel becomes gradually narrow, and the river width in Rio do Sul city is around 150 m. However, river channels in Gaspar and Blumenau cities are 200 m and 150 m, showing slight bottle necks portions.

On the other hand, among the main tributaries, the Itajaí Mirim River varies between 50 to 80 m, the Itajaí do Oeste River is between 70 to 90 m, and the Itajaí do Sul River shows a large variation between 50 to 80 m. The Itajaí do Norte River varies from 120 to 160 m.



Source: JICA Survey Team

Figure 3.1.1 Variation of River Channel Width of the Itajaí River and Main Tributaries

3.1.4 Hydraulic Condition

(1) Roughness Coefficient

Table 3.1.3 shows the Manning’s Roughness Coefficients for non-uniform flow calculation which was used to estimate the flow capacities in the Itajai River. They were set to fit the actual flood water level which were obtained from existing materials and interview survey.

Table 3.1.3 General Value of Roughness Coefficient and Application for Itajai River

River Situation	Roughness Coefficient	Application for Itajai River
Small river without weed in plain	0.025 ～ 0.033	This situation is not seen in the Itajai River.
Small river with weed and bushin plain	0.030 ～ 0.040	Old Mirim 0.040

Small river with much weed or gravel river bed in plain	0.040 ～ 0.055	This situation is not seen in the Itajai River.
Mountainous river with gravel and boulder	0.030 ～ 0.050	This situation is not seen in the Itajai River.
Mountainous river with big boulder	0.040 ～	This situation is not seen in the Itajai River.
Large river, river bed formed by clay silt and sand, without meandering	0.018 ～ 0.035	Itajai - Gaspar 0.030, Lontras - Rio do Sul 0.032, Itajai Mirim 0.032, Benedito River 0.032, Itajai d~~D~~o Oeste River 0.032, Itajai d~~D~~o Sul River 0.032
Large River, river bed formed by gravel	0.025 ～ 0.040	Blumenau – Ibirama 0.035, Upstream stretch of Itajai Mirim, Upstream stretch of Benedito River 0.035, Itajai d~~D~~o Norte River 0.035

Source: Manual for River Works in Japan, Ministry of Land, Infrastructure, Transport and Tourism

(2) Downstream Boundary Condition

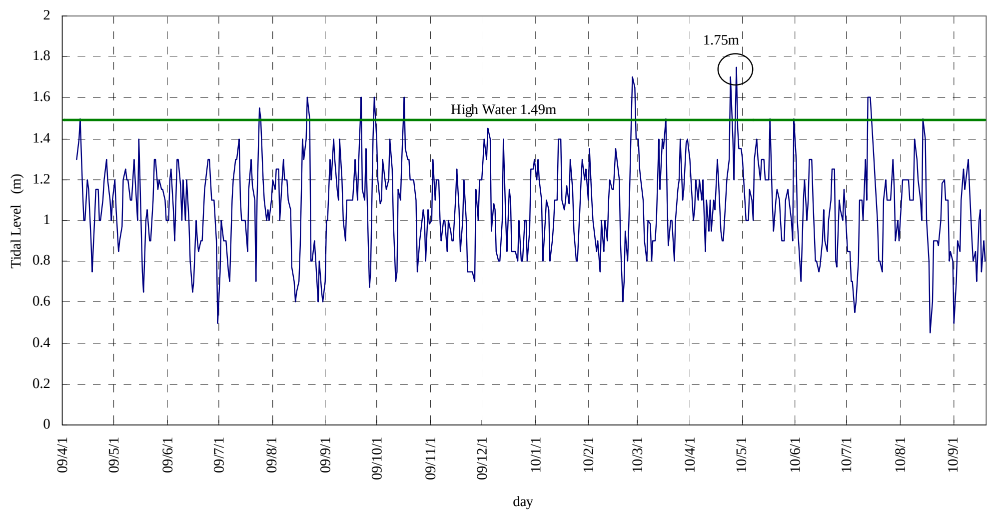
a) Downstream Boundary Condition of Itajai River (See Water Level)

Tidal level is observed at around 1 km upstream from the river mouth by “Itajai Pratico” (Pilots Association of Itajai and Navegantes Ports). The tidal levels are based on DHN (elevation control point of Brazilian Navy). Figure 3.1.2 shows variation of daily maximum water level (converted to IBGE, IBGE = DHN-0.463m) from November 2009 to May 2010.

High water level (average of monthly maximum water level) used for the Maste Plan is 1.49m in elevation based on IBGE.

b) Downstream Boundary Condition of Tributaries

Downstream boundary conditions of tributaries (water levels at the downstream ends of tributaries) equal to water levels at the confluences with the Itaja River.

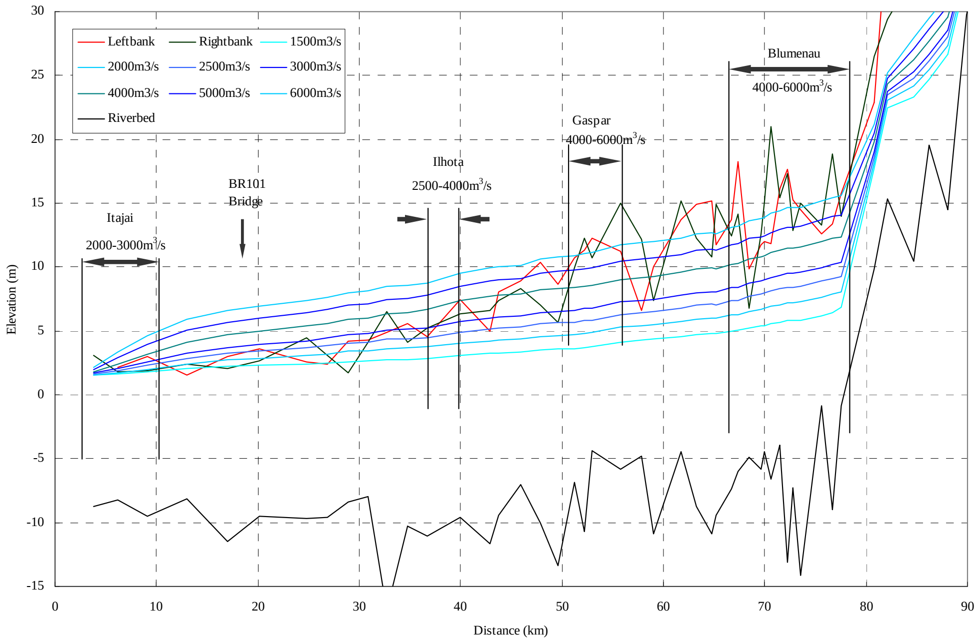


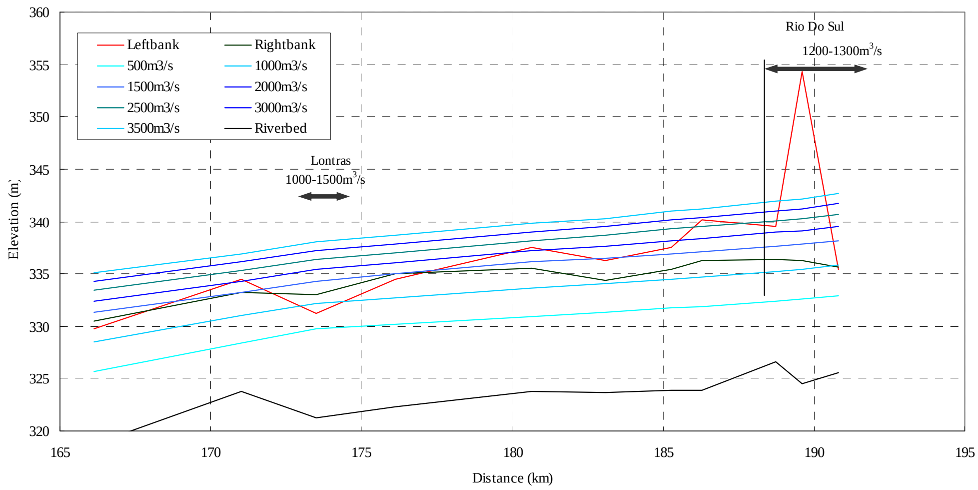
Source: Itajai Pratico

Figure 3.1.2 Variation of Daily Maximum Water Level at Itajai River Mouth

3.2 Estimation and Evaluation of Flow Capacity of River Channel

In order to evaluate the current flow capacity of river channels for the Itajaí River and main tributaries, non-uniform flow calculation was carried out by use of the river cross section data surveyed. In this calculation, several river water levels were calculated under several flood discharges referring to the estimated probable flood discharges as illustrated in Supporting Report Annex A. Conditions and assumptions of the non-uniform flow calculation are discussed in detail separately in the Supporting Report, Annex A Hydrology. The results of the calculation in the mainstream of Itajaí River are illustrated below.

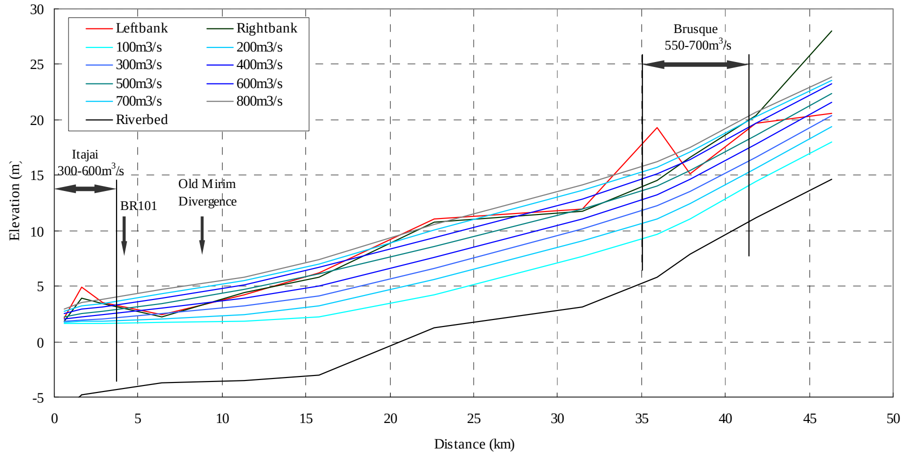


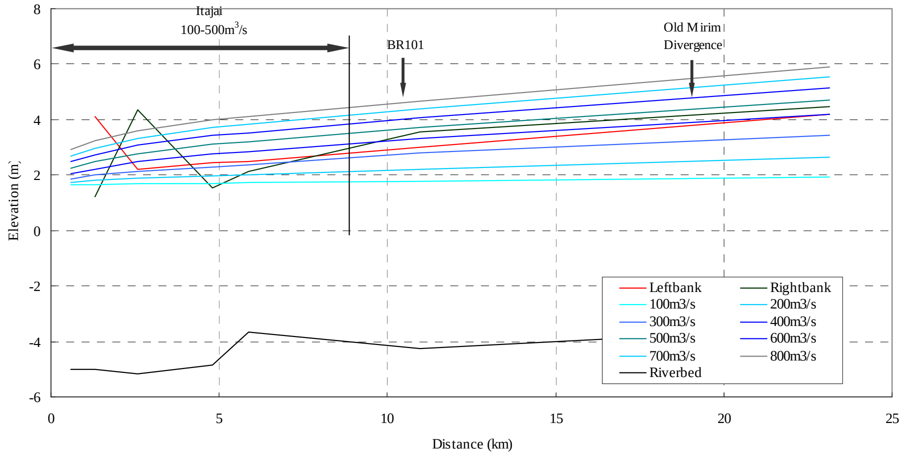


Source：JICA Survey Team

Figure 3.2.1 Results of Non-uniform Flow Calculation along the Itajaí River

The Itajaí Mirim River is divided into two river channels due to the past shortcut works in the upstream area from Itajaí city; the canal (shortcut channel) and old Mirim River (old river channel), and these two rivers join together again immediately upstream from the confluence to the Itajaí River. Distribution ratio of the flood discharge for the non-uniform flow calculation is assumed to be 2/3 to the canal and 1/3 to the old Mirim River based on the respective estimated flow capacity by the uniform flow calculation. The results of the non-uniform flow calculation of the canal and old Mirim River are illustrated below.

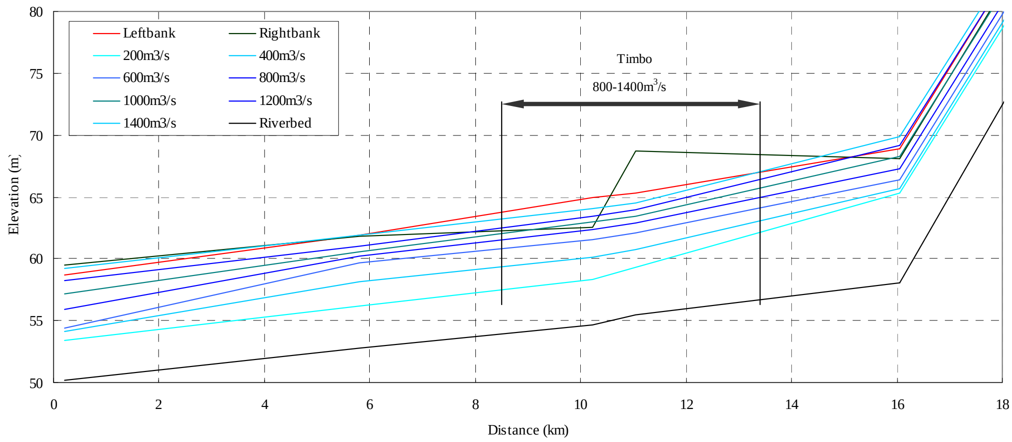




Note: Flood discharge in the figure is the total discharges of the canal and old Mirim River.

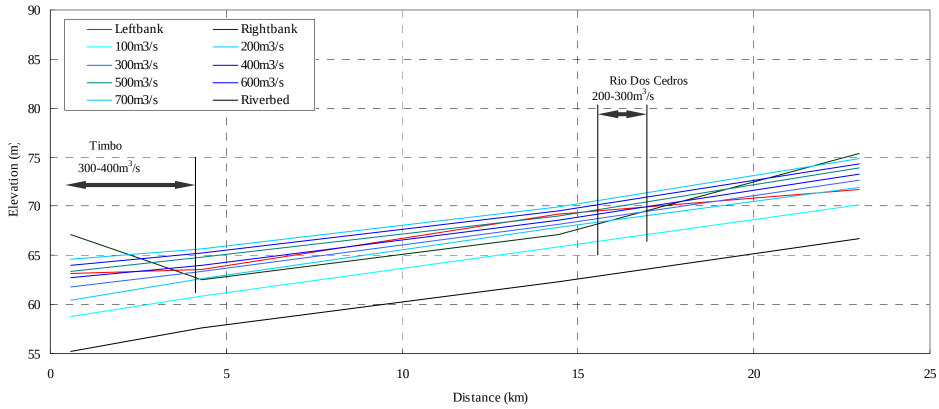
Source：JICA Survey Team

Figure 3.2.2 Results of Non-uniform Flow Calculation along the Itajaí Mirim River



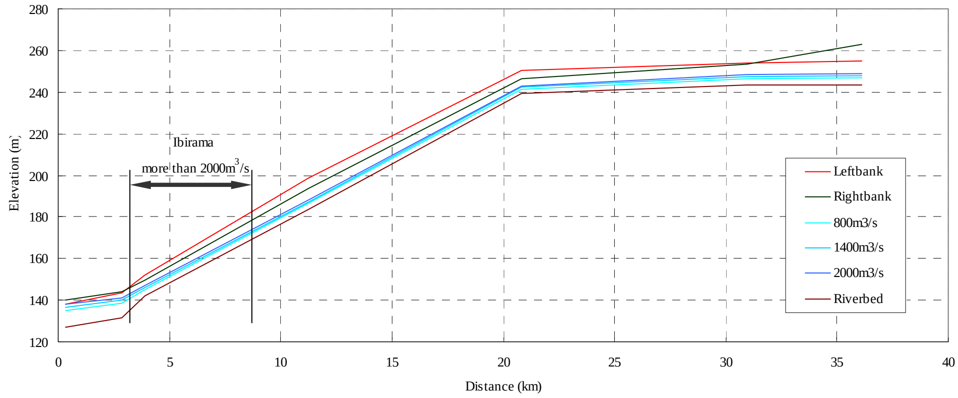
Source：JICA Survey Team

Figure 3.2.3 Results of Non-uniform Flow Calculation along the Benedito River



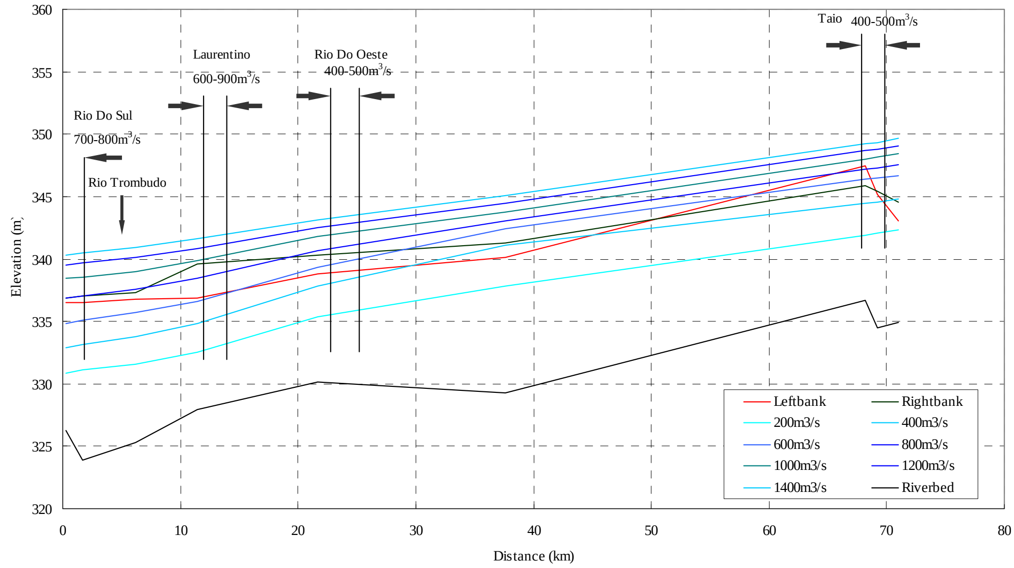
Source：JICA Survey Team

Figure 3.2.4 Results of Non-uniform Flow Calculation along the ~~Rio Do~~Rio dos Cedros River



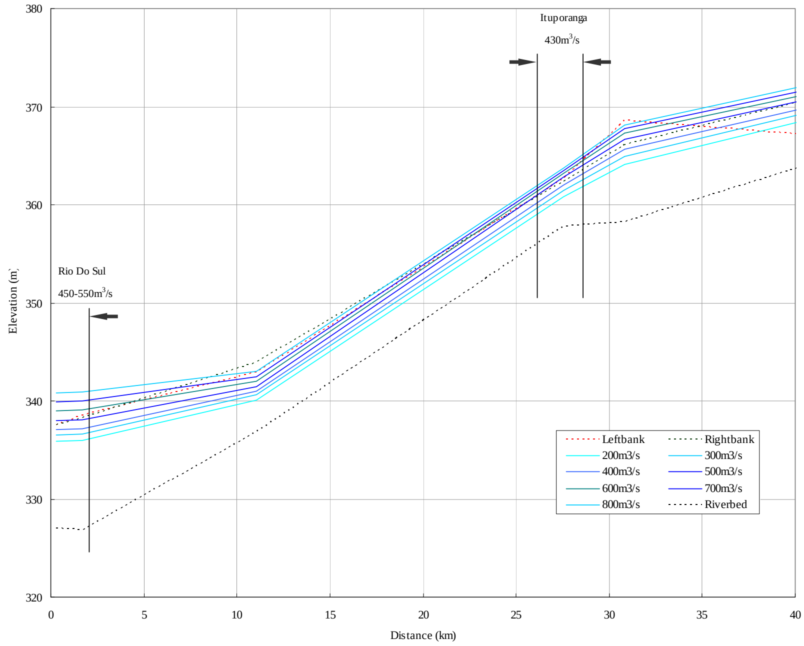
Source：JICA Survey Team

Figure 3.2.5 Results of Non-uniform Flow Calculation along the ~~Rio Do~~Itajai do Norte River



Source：JICA Survey Team

Figure 3.2.6 Results of Non-uniform Flow Calculation along the ~~Rio Do~~Itajai do Oeste River



Source：JICA Survey Team

Figure 3.2.7 Results of Non-uniform Flow Calculation along the ~~Rio Do~~Itajai do Sul River

Based on the results of non-uniform flow calculation, the flow capacity at various locations was estimated in terms of the bankfull discharge of river channel. The estimated flow capacity was evaluated compared to the probable flood discharges (see Supporting Report Annex A) as summarized below.

Table 3.2.1 Flow Capacity and Considerations (Itajaí River)

River	City	Flow Capacity (m^3/s)	Necessity of flood mitiagtion measures
Itajaí	Itajaí, Navegantes	2,000 to 3,000	Flow capacity: around 5-year flood discharge (especially the right bank of Itajai city is low) Experiences of flood damages in the past and seriousness: low elevation area of Itajai city has flequently suffered from inundations, **high necessity** of flood mitigation. Damage potential by floods: **high damage potential** due to large population and importance in the economical aspect of the SC State. Necessity of flood mitigation measures: **high priority** for mitigation measures
	Ilhota	2,500 to 4,000	Flow capacity: around 10 to 25-year flood discharge Experiences of flood damages in the past and seriousness: damages have occurred in case of huge floods. Damage potential by floods: **low damage potential** due to small population. Necessity of flood mitigation measures: **low priority** for mitigation measures.
	Gaspar	5,100 to 6,000	Flow capacity: around 25 to 50-year flood discharge (large capacity at the central of the city) Experiences of flood damages in the past and seriousness: damages have occurred in case of huge floods. Damage potential by floods: **high damage potential** due to large population. Necessity of flood mitigation measures: mitigation measures are required but **midium priority.**

River	City	Flow Capacity (m^3/s)	Necessity of flood mitiagtion measures
	Blumenau	4,200 to 6,000	Flow capacity: around 25 to 50-year flood discharge Experiences of flood damages in the past and seriousness: damages have occurred in case of huge floods. Damage potential by floods: **high damage potential** due to very large population and imortance in the economical and social aspects of the SC State. Necessity of flood mitigation measures: mitigation measures are required but **midium priority**, but as the flow capacities of small tributaries such as Garcia and Velha Rivers are 5 to 10-year, **flood mitigation measures along the tributaries are highly prior.**
	Indaial	5,700	Flow capacity: more than 50-year flood discharge Experiences of flood damages in the past and seriousness: there has been few flood damages Damage potential by floods: large population, but hard to suffer from flood. Necessity of flood mitigation measures: **no necessity** of mitigation measures.
	Lontras	1,000 to 1,500	low capacity: around 5 to 10-year flood discharge Experiences of flood damages in the past and seriousness: there has been few flood damages in the urban area. Damage potential by floods: **low damage potential** due to small population. Necessity of flood mitigation measures: **no necessity** of mitigation measures.
	Rio do Sul	1,220	Flow capacity: around 5-year flood discharge Experiences of flood damages in the past and seriousness: low elevation area of Rio do Sul city has flequently suffered from even small flood, **high necessity** of flood mitigation. Damage potential by floods: **high damage potential** due to large population and importance as the economical center of upper Itajai River basin region. Necessity of flood mitigation measures: **high priority** for mitigation measures.

Source: JICA Study Team

Table 3.2.2 Flow Capacity and Considerations (Itajaí Mirim River and Main Tributaries)

River	City	Flow Capacity (m^3/s)	Considerations Compared to Probable Discharge
Itajaí Mirim	Itajaí	300 (downstream reach after the confluence) 500～600 （Canal） 200～300（Old）	Flow capacity: less than 5-year flood discharge in downstream reach after confluence, around 25 to 50-year in Canal, less than 5-year in Old Mirim. Experiences of flood damages in the past and seriousness: low elevation area of Itajai city has flequently suffered from inundations, **high necessity** of flood mitigation. Damage potential by floods: **high damage potential** due to large population and importance in the economical aspect of the SC State. Necessity of flood mitigation measures: **high priority** for mitigation measures
	Brusque	550～700	Flow capacity: around 25 to 50-year flood discharge Experiences of flood damages in the past and seriousness: the present roads on the both banks function as a high water channel portion of the likely compound river channel, therefore, the roads have frequently suffered, but urban area has not suffered so frequently. Damage potential by floods: **high damage potential** due to large population in case of huge floods. Necessity of flood mitigation measures: mitigation measures are required but **low priority.**

River	City	Flow Capacity (m^3/s)	Considerations Compared to Probable Discharge
Benedito	Timbó	860	Flow capacity: around 5 to 10-year flood discharge Experiences of flood damages in the past and seriousness: there are informations of frequent inundations. Damage potential by floods: **midium damage potential** due to midium size of population. Necessity of flood mitigation measures: mitigation measures are required but **midium priority.**
Itajaí do Norte	Ibirama	more than 2,000	Flow capacity: more than 50-year flood discharge Experiences of flood damages in the past and seriousness: there has been few flood damages Damage potential by floods: midium population, but hard to suffer from flood. Necessity of flood mitigation measures: **no necessity** of mitigation measures.
Itajaí do Oeste	Rio do Sul	760	Flow capacity: less than 5-year flood discharge Experiences of flood damages in the past and seriousness: low elevation area of Rio do Sul city has flequently suffered from even small flood, **high necessity** of flood mitigation. Damage potential by floods: **high damage potential** due to large population and importance as the economical center of upper Itajai River basin region. Necessity of flood mitigation measures: **high priority** for mitigation measures.
	Taió	440	Flow capacity: around 5 to 10-year flood discharge Experiences of flood damages in the past and seriousness: urban area has suffered from frequent inundations. Damage potential by floods: **midium damage potential** due to midium size of population. Necessity of flood mitigation measures: mitigation measures are required but **midium priority.**
Itajaí do Sul	Rio do Sul	300～500	Flow capacity: less than 5-year flood discharge Experiences of flood damages in the past and seriousness: low elevation area of Rio do Sul city has flequently suffered from even small flood, **high necessity** of flood mitigation. Damage potential by floods: **high damage potential** due to large population and importance as the economical center of upper Itajai River basin region. Necessity of flood mitigation measures: **high priority** for mitigation measures.
	Ituporanga	450	Flow capacity: around 30-40 year flood discharge Experiences of flood damages in the past and seriousness: there are few record of flood damages Damage potential by floods: midium population, urban area extends on the hill, so hard to suffer from flood. Necessity of flood mitigation measures: **no necessity** of mitigation measures.

Source: JICA Study Team

CHAPTER 4 BASIC STRATEGY FOR FORMULATION OF MASTER PLAN FOR FLOOD MITIGATION

4.1 Needs for Flood MITIGATION

4.1.1 Interviews with Various Government Institutions and Universities

Various government institutions and universities are participating in this Preparatory Survey and understanding and cooperation thereof is of great importance. A participatory planning process for disaster prevention master plan is also required. Along this line, courtesy calls and interviews with various government organizations and universities as well as the Itajai River Basin Committee have been carried out to understand various needs for disaster prevention measures in the Itajai River basin. Totally around 70 interviews were made. In this chapter, the needs related to flood prevention and the basic strategy for master plan formulation are described. The needs for sediment disaster prevention are explained in the succeeding Chapter 6.

4.1.2 Expected Disaster Prevention Measures of the Itajaí River Basin Committee

Through discussions with the Itajaí River Basin Committee, the Committee showed the following views on flood prevention measures:

i) The Itajaí River is a natural stream. Therefore, a flood mitigation master plan must duly consider the environmental aspects, including the preservation of riparian vegetation.

ii) The Committee expects the flood management for minimizing flood damages by means of hindering the concentration of flood runoff from river basins, instead of conventional flood control measures by dikes. The flood mitigation plan in the Rhine River, where the Committee previously visited as the mission, aimed at mitigation of flood damages and restoration of nature. The Committee considers that no large-scale structures are necessary, and flood information and flood damage mitigation are really required.

iii) Fifty (50) years ago, there was flooding problem only in Blumenau city. In recent years, however, flooding problem has been increasingly serious in Gaspar and Itajai cities in the lower reaches of Itajai River.

iv) Recently small scale flooding has occurred in small communities in upper Itajai River basin. Although the communities became conscious of floods, they are not considering serious issues. They desire small temporary storage of flood water for agricultural water supply in the dry season (especially, in the Itajai do Oeste and Sul River basins, where recently agricultural development has been significant causing water shortage in the dry season). Besides, as sediment production due to soil erosion by small floods is another problem, small dam reservoir for water supply in the dry season or an increase of water retention capacity in cultivated lands are considered necessary.

v) No serious flooding in the Itajai mainstream has occurred in Blumenau city since the 1984 flood. However, recently flood damages due to flush floods with rapid water level rising and inundation in relatively narrow areas have been increasing in tributary basins. Particularly, flush floods are significant in the urban areas rapidly developed on mountain slopes in tributary rivers in Blumenau city.

vi) The cause of flooding in Itajaí city is river improvement in the Itajaí Mirim River done in Brusque city and landfills for developments in the flood plain between two cities. It is favorable to preserve flood plain as a retarding basin in the downstream reaches from

Brusque city as a flood control measure for Itajaí city.

vii) Programs such as riparian forest rehabilitation, intensification of disaster prevention, and promotion of water retention in upstream basins that were proposed in the Water Resources Management Master Plan for the Itajaí River Basin formulated by the Committee in March 2010 would be related with a master plan for flood prevention to be proposed by the Preparatory Survey.

4.1.3 Needs for Flood Mitigation by City

In the previous Supporting Report Annex A, needs for flood mitigation at major cities along the Itajai River was mentioned based on the records of past floods. Table 4.1.1 summarizes flooding characteristics and issues peculiar to major cities based on the results of discussions with various government institutions and universities as well as site visits.

Table 4.1.1 Flooding Characteristics and Issues by City along the Itajai River

City	Population	Results of Interview and Site Visits	Source of information
Itajaí River			
Itajaí	172,081	・Flood damages have occurred 7 times since 1980. ・Many affected residents because of large population	Reports
		・In the urban area, flooding of Itajaí Mirim River is more severe than Itajaí River. ・Rising of water level of the Itajaí River and tidal level blocks the drainage of Itajaí Mirim River ・Drainage system is vulnerable, and there is no pumping stations ・Bridge over Itajaí Mirim River influences the flow capacity. ・There is alarm system, but it is not satisfactory like in Blumenau city ・There is APP plan (green belt along the old Itajaí Mirim River	Planning and Construction Department of Municipal Government and UNIVALI Site Visit
		・High sediment inflow into the port, requiring annual dredging of huge volume of sediment ・Necessity of measures to reduce sediment production in the basin	Itajaí Port Site Visit
Navegantes	57,324	・Less frequency of flooding (3 times since 1980) ・Small flood damages due to higher ground elevation ・Necessity of measures to sedimentation problem in the port	Reports Planning and Financial Departments Site visit
Ilhota	12,149	・Less frequency of flooding (twice since 1980 from report, but 5 times according to the municipal government) ・There is low lands along the state highway SC-470, where frequent flooding occurs due to poor drainage ・There is a plan to build a new bridge over the Itajaí River	Reports Planning Department of Municipal Government
Gaspar	55,489	・Flood damages have occurred 7 times since 1980 with many affected residents ・The river is narrow in the urban area, and the existing bridge in city obstacles significantly the flow area in river channel.	Reports Site visit
Blumenau	299,416	・Flood damages have occurred 14 times since 1980 with many affected residents ・The 1983 and 1984 floods caused inundation by gradual water level increasing of the Itajai mainstream ・In the 2008 flood, Itajaí River did not overflow, however there were damages caused by flush floods in tributaries (Garcia, Velha, Fortaleza Rivers)	Reports Site visit

City	Population	Results of Interview and Site Visits	Source of information
		・Housing development on mountainous area has caused flush floods and landslides, and there are many illegal residences in the river area ・There are plans to construct bridge, revetment, drainage facilities and water gate with pumping station in tributaries (Fortaleza, Garcia, Velha, Itoupava Rivers) ・Urban development will expand to the North side in the future (Itoupava River) ・At present, no flooding problem in the Itoupava River ・Flood warning is announced based on the information from CIRAM and FURB/CEOPS through radio and internet, and CEOPS forecasts the river water level in 6 hours ahead	Planning and Construction Department of Municipal Government Site visit
		・Flood damage potential has been increased due to illegal residents along rivers ・Bank and house collapses are likely occur on the sandy bank without vegetation ・According to the environmental law, the Committee plans to afforest 30m wide protection area on river banks and considers that riparian forest is very important in view of flood control. ・It is problem to install the water gate in the mouth of the Fortaleza River ・The project by the municipal government of Blumenau to install concrete revetment on the left bank of Itajai River would be no flood control effects, only losing valuable vegetation on the river bank.	Itajaí River Basin Committee and FURB Site visit
Indaial	50,917	・Less frequency of flooding (3 times since 1980 but in small scale) ・The flow capacity of the Itajaí River is large.	Reports Site visit
Ascurra	10,996	・No flood damages have occurred.	Reports Site visit
Apiúna	6,945	・No flood damages have occurred.	Reports Site visit
Lontras	9,660	・Less frequency of flooding (3 times since 1980 but in small scale)	Reports Site visit
Rio do Sul	59,962	・Although the affected population is small, flood damage has occurred frequently (8 times since 1980)	Reports Site visit
		・Small scale flooding has occurred frequently (2 to 3 times per year) ・There are many problems of illegal residents and land use. ・There are operation problems at the Oeste and Sul dams ・Information from the dams (reservoir level, outflow, etc.) is insufficient (the outflow of the dam is unknown at the dam office) ・It is very difficult to widen the river channel in the urban area. ・Evacuation manual is under preparation.	Planning Department of Municipal Government and Civil Defense Site visit
		・The project to retain rain water in paddy fields is under preparation ・There is also a plan to store river water in paddy fields by small dams in small tributaries.	CRAVIL Site visit
Itajaí Mirim River			
Brusque	102,280	・Less frequency of flooding (3 times since 1980) ・Recently less flooding problems due to the river improvement ・No flooding in the urban area except the 1984 flood has occurred only with inundation of roads. ・Bank erosion at the colliding portion of meandering channel might cause impact to residences on the river bank.	Planning Department of Municipal Government and Site visit
Benedito River			

City	Population	Results of Interview and Site Visits	Source of information
Timbó	35,303	・Although the affected population is small, flood damage has occurred frequently (6 times since 1980) ・Due to abrupt releasing from the upstream two hydropower generation dams in the Rio dos Cedros River, flooding has occurred frequently. ・In June 2010, the City Councils of Timbo and Rio dos Cedros jointly submitted the petition containing the signatures of 1,200 residents to the Governor, requiring for lowering the normal operation reservoir water level ・In addition to the flood from the Benedito River, the flood from the Rio dos Cedros River joins together	Report DEINFRA FURB/CEOPS City Council Site visit
Benedito Novo	10,335	・No flood damages have occurred.	Report and Site visit
Rio dos Cedros	10,170	・Same as the Timbó city, frequent flooding has occurred due to abrupt releasing from the upstream two dams in the Rio dos Cedros River. ・In June 2010, the City Councils of Timbo and Rio dos Cedros jointly submitted the petition containing the signatures of 1,200 residents to the Governor, requiring for lowering the normal operation reservoir water level ・When the water depth in the Rio dos Cedros River exceeds 6 m, flooding starts in the urban area. Mapping of flood inundation map in the city has been completed.	Report FURB/CEOPS Mayor of the city and the City council Site visit
Itajaí do Norte River			
Ibirama	17,469	・No flood damages have occurred.	Report Site visit
Itajaí do Oeste River			
Laurentino	5,757	・Almost no flood damages have occurred.	Report
Rio do Oeste	7,033	・Almost no flood damages have occurred.	Report
Taio	17,522	・Although the affected population is small, flood damage has occurred frequently (6 times since 1980) ・Taio city is prone to inundation due to overflow of the Oeste dam. ・Urban area near the city hall was inundated in around 1.5 m by the April 2010 flood. There is some opinion that the inundation was due to earlier closure of the gates at the dam. ・The current flow capacity is around 1,000 m^3/s. However, the maximum releasing capacity under full opening of gates at the Oeste dam is around 160 m^3/s.	Report DEINFRA Site visit
Trombudo	6,520	・Less frequency of flooding (3 times since 1980 but in small scale)	Report and Site visit
Itajaí do Sul River			
Ituporanga	21,496	・Less frequency of flooding (2 times since 1980 but in small scale)	Report and Site visit

Source: JICA Survey Team

4.2 Basic Principles for Planning

As stated in the Minutes of the meeting of understanding on November 5th, 2009, basic principles of the Preparatory Survey for planning the master plan of prevention and mitigation of natural disaster were established as follows:

i) To avoid negative natural and social environmental impacts, especially involuntary resettlement and biodiversity loss

ii) To avoid adverse effects to the downstream reaches of the river from the sites subject to countermeasures such as increase of flood velocity and discharge that might cause bank erosion and flooding

iii) To enrich rainwater storage function of each river sub-basin in order to delay quick flood runoff

iv) To promote multiple use of the existing hydraulic structures and spaces in the basin

4.3 Basic Strategy for Formulation of Master Plan

Based on an exchange of views and opinions with various government institutions, universities and the Itajaí River Basin Committee as well as the basic principles, basic strategy for formulating a master plan for flood prevention was set up below.

i) At this moment, since it is considered to be difficult to set up a target flood security level for a master plan, four levels of flood prevention master plans are to be proposed for the selected target regions to be protected. The master plans to be created are for the levels of a flood occurred once in 5, 10, 25 and 50 years[1]. Then, the flood security level shall be selected through discussions with the Itajaí Basin Committee as well as the State Government (Governor and State Secretaries).

ii) In addition, selection of the target regions for flood protection, combination of flood control alternatives and their flood control effects shall be discussed together with the the Itajaí River Basin Committee[2] (Technical sub-committee on flood prevention).

iii) A master plan for flood prevention shall be formulated taking into consideration the ongoing concept of comprehensive flood control measures in Japan, which aims to hinder the concentration of flood runoff from various river basins. A “flood control measures to scatter floods” shall be given high priority for formulating a master plan by minimizing flood damages allowing flood inundation.

iv) Temporary retention of rain water in paddy fields and small retention ponds (small irrigation dam) that are proposed in the Water Resources Management Master Plan for the the Itajaí River Basin might be able to hinder the concentration of flood runoff to the downstream reaches and therefore subject to examination. According to CRAVIL, the target paddy area for retention is around 27,000 ha in total along the Itajai River from the upstream reaches of Rio do Sul city to Itajai city.

v) Among existing 3 flood control dams, increasing of flood control capacity by heightening of Oeste and Sul dams also might contribute to delay the concentration of flood runoff to the downstream reaches (especially effective for flood mitigation in Taio and Rio do Sul cities located in the downstream reaches of the dams).

vi) The existing flood plain spreading from Gaspar city to Itajai city that acts a natural retarding basin are currently used for agricultural land and pasture. This flood plain shall be preserved without land developments because it contributes to reduce flood flow in the downstream areas.

vii) As for the target region for flood prevention, Rio do Sul, Blumenau and Itajai cities might be of higher priority. In addition to delaying the concentration of flood runoff as much as possible by provision of various measures in the upper basins, possible flood control alternatives shall be conceived for comparison duly considering current flood inundation characteristics and the existing urban plan (land use plan).

viii) In addition to the flood from Itajai mainstream, flood inundation in Itajai city is due to the back water to the Itajai Mirim River from the Itajai mainstream (added by tidal influence),

[1] Study for the 50-year flood was solicited as a part of the Prepatory Survey at the first counterpart meeting held on May 19th, 2010

[2] Itajaí Basin Committee requested at the meeting held on May 7th and July 28th, 2010.

poor drainage system in the urban area, and flood inflow from the Itajai Mirim River. Flood control measures shall be created based on the evaluation of these impacts.

ix) As for the measures for flush floods, adjustment with urban plan (land use regulation and zoning) might be necessary, because there are many illegal residents on the river banks.

x) When higher security level as a 50-year flood prevention plan is required, only basin measures to scatter floods would be limited from the aspects of flood control effects. In such case, widening of river channel by providing composite section will be necessary. Regarding the utilization of high water channel of composite section, the program of riparian forest rehabilitation under the Water Resources Management Master Plan by the Committee will be incorporated into the master planning. In addition, floodway is likely to be required as a alternative to reduce duration and depth of flood inundation in the flood plain downstream from Gaspar city and the urban are in Itajai city.

xi) The target year of flood prevention master plan depends on the selected flood security level. In order to ensure consistency with the target year of 2030 as proposed in the long-term plan of the Water Resources Management Master Plan in the Itajai River basin, a master plan for flood prevention shall be achieved by 2030 at the least.

4.4 Basic Strategy for Strengthening of Existing FFWS

Considering the current problems of the existing FFWS for the Itajai River basin, a plan to strengthen the existing FFWS shall be formulated based on the following basic strategies:

i) Strengthening of the existing hydro-meteorological observation network with provision of additional gauging stations

ii) Improvement of accuracy observed data and data transmission by updating observation equipments and data transmission method

The following are the aspects for consideration.

4.4.1 Aspects of River Characteristics

i) Flood runoff has been increasing due to land developments and deforestation in the upstream basin of Rio do Sul city, it will be necessary to observe rainfall focusing on mountainous tributaries. It is however difficult to predict floods from tributaries by use of only released discharges of two flood control dams, because flood traveling time to Rio do Sul city is short.

ii) As frequent flooding has occurred in both Timbo and Rio dos Cedros cities due to abrupt releasing from two hydropower generation dams in the Rio dos Cedros River, it will be necessary to monitor the releasing discharge from two dams for timely announcement of early warning.

iii) On the lower Itajai mainstream from Blumenau city, water level gauging station shall be newly installed in Gaspar, Ilhota and Itajai cities to monitor flood water levels and changes due to tidal conditions.

iv) As for the Itajai Mirim River, where recent urbanization in tributaries surrounding Brusque city has increased flood runoff, rainfall and water level gauging station shall be newly installed in tributaries for timely announcement of early warning in Brusque city.

4.4.2 Aspects of Observation Equipment and Data Transmission Method

The observation equipments of gauging stations are superannuated and have not been sufficiently maintained. The gauging devices of rainfall and water level and the current data transmission system should be updated in view of accurate data transmission with high reliability. As observation equipments have been improved in recent years from the aspects of maintenance, the following shall be noted:

i) The existing river water level gauge is of a pressure type that was installed on the riverbed. Due to riverbed erosion or sediment deposition by floods, observation troubles have occurred at several stations, causing the burden on maintenance. However, a radar type water level gauge can be installed gently on bridge less susceptible to temperature and wind, and is of low energy consumption and price.

ii) If the current radio-link data transmission system is replaced by the cellular phone system and packet switching method, observed data can be sent directly to CEOPS by email every 10 minutes. In addition, as its power source can be secured by solar panel, the necessary equipments such as rain gauge, water level gauge, solar panel, battery, data logger and telephone center can be installed on only one pole without any auxiliary equipment like repeaters at the transmission point.

iii) Furthermore, replacement of the current digital system of GSM (Group Special Mobile) of 2G (Mobile Telephone System of Second Generation) to GPRS (General Packet) of 2.5G enables to enhance stable communication and the increased data communication with strengthened efficiency of broadband use.

iv) Due to the rapid spread of surveillance cameras, high-precision and lightweight CCTV (Closed Circuit TV) is available at low price. Therefore, CCTVs shall be intalled in Rio do Sul, Blumenau and Itajaí, cities to monitor flood situation in real time basis.

v) FURB/CEOPS is in charge of flood forecasting as a master station, where all of the observed data is gathered and stored in database. In addition, equipment to monitor the observed data via the internet will be installed at the office of Civil Defense in both Rio do Sul and Itajai cities to act as a monitor station. Moreover, a monitor center will be established in Florianopolis.

CHAPTER 5 FORMULATION OF THE MASTER PLAN FOR FLOOD MITIGATION

5.1 General

As described in Chapter 4, a master plan for flood disaster mitigation for the Itajaí River basin aims to hinder the concentration of flood runoff from various river basins taking into consideration the ongoing concept of comprehensive flood control measures in Japan. It is highly expected to hinder the concentration of flood runoff due to natural retarding effects by the lands subject to frequent flooding such as pasture, paddy and dry fields. "Flood control measures to scatter floods" should be given high priority for formulating the master plan by means of active use of flooding allowable lands above. The Itajaí River Basin Committee recommends the policy of "Living together with Flood" [3] and thus the "flood control measures to scatter floods" corresponds to this policy. However, when higher degrees of flood safety level are required such as for the 25-year and 50-year floods, only the method to scatter floods would be limited. In such case, structural flood control measures such as dyke, flood diversion channel and flood control dam would be added for comparative study as flood control alternatives.

Flood control measures are usually selected and justified in combination with various measures. Along this line, various flood control alternative measures are herein proposed for the comparative study under the Preparatory Study, fully considering regional flood control needs and flooding characteristics of the Itajaí River. In the Itajaí River basin, major cities are located along the mainstream and its major tributaries, where development of residences and commercial facilities has been in progress. Municipal governments in the basin are already aware of how difficult it is to implement structural measures such as widening of the rivers in the populated urban area, and therefore, an introduction of the non-structural measures such as strengthening of the existing FFWS is to be studied in addition to the introduction of natural retardation basins.

5.2 Selection of Cities for Flood Protection

Flooding and inundation resulting from floods are occurring in the regions of along the Itajaí River and its tributaries. It is considered unrealistic from economical and financial point of view to implement a flood control project for protecting the whole areas subject to habitual flooding and inundation in the Itajaí River basin. The Itajaí River Basin Committee showed the same opinion.

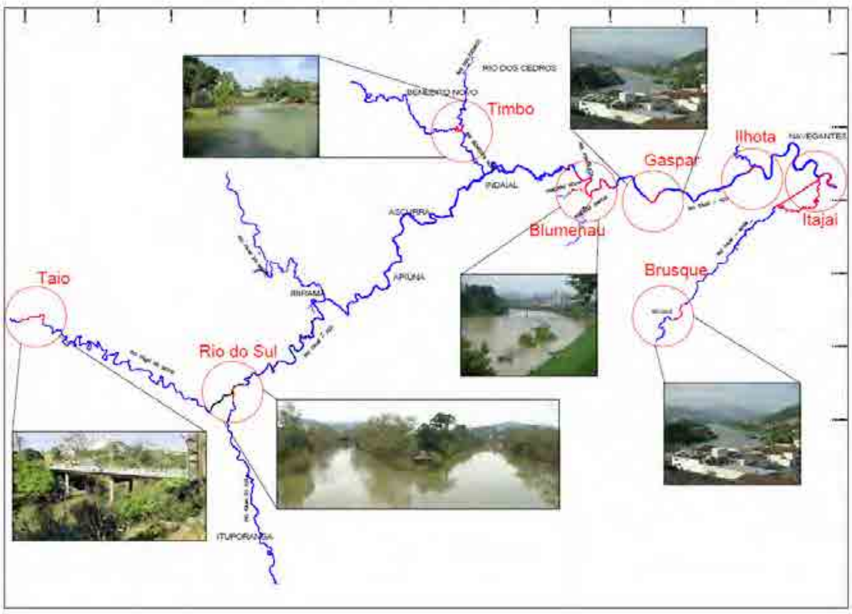
The river improvement project by dykes tends to become costly due to drastic increase of flood discharges in the downstream reaches resulting from the upstream river improvement works by dykes. To avoid such an increase of project cost, the areas with low flood damage potential along the river such as pasture, paddy and dry fields should be actively remained in the current condition, intentionally no dykes provided for protection. From this point of view, target areas subject to flood protection shall be major cities along the Itajaí River.

As explained in Supporting Report Annex A, eight cities were selected as higher priority for flood disaster mitigation based on the consideration of the frequency and damages caused by floods (see Tables 6.1.1 and 6.1.2) and the results of various visits and interviews to municipal governments (see Table 4.1.1 of this Supporting Report). The selected cities are Rio do Sul,

[3] Beate Frank, Adilson Pinheiro (organizers), Floods in Itajaí Basin: 20 years of experience), Blumenau 2003, Chapter 9 A Formalization of Flood Management within the Sphere of Itajaí River Basin

Blumenau, Gaspar, Ilhota, Timbó, Taió, Itajaí and Brusque cities.

As for the measures for the flush flood, urban streams in Blumenau city (Garcia and Velha Rivers) were selected as the target river, where urban developments on the hill slope together with residential development along the stream have been in progress in recent years, resulting in an increase of damage potential due to flush floods. In addition, Itajaí city located at the river mouth of the Itajaí River was also selected, where there are flooding affected by the backwater of the Itajaí mainstream and flood inflow from the Itajaí Mirim River.

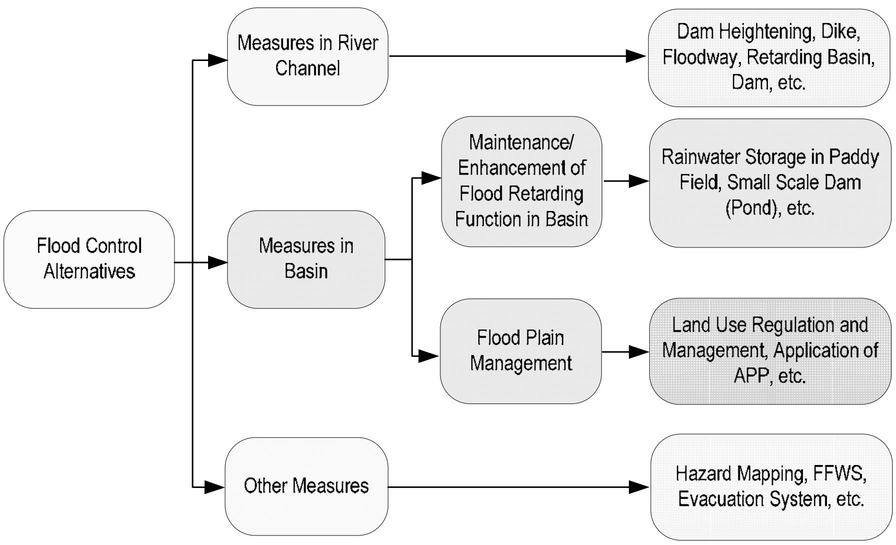


Source: JICA Survey Team

Figure 5.2.1 Selected Highly Prior Cities for Flood Mitigation

5.3 Selection of Flood Control Alternatives

Taking into consideration the current condition of river canal, flood inundation situation and topographic conditions, various alternatives of flood control measure that would be applicable to the Itajaí River basin are proposed as listed below.



Source: JICA Survey Team

Figure 5.3.1 Flood Control Alternatives Applicable to Itajai River Basin

The proposed alternatives are outlined below.

5.3.1 Measures in River Channel (Structural Measures)

(1) Heightening of Existing Flood Control Dams

As described in section 2.2, there are currently three flood control dams on the Itajaí River (see Table 2.2.1 for dam features). Among the dams, the Norte dam constructed in 1992 has the largest flood control capacity of 357 million m^3. No overflowing through the spillway due to large floods has so far occurred. On the other side, overflows have occurred in several times at both the Sul and Oeste dams in times of the medium-sized flood inflow.

For both the Oeste and Sul dams, reinforcement to increase flood control capacity is contemplated by means of the following measures:

i) Oeste Dam: Heightening of the existing dam body and spillway
ii) Sul Dam: Heightening of the existing spillway

As for the Sul dam of a rock fill type, heightening of the existing spillway is examined because of its technical difficulty to heighten the dam body. By this reinforcement of two dams, flood control effect (reduction of the flood peak discharge) would be expected in Rio do Sul city as well as downstream major cities along the Itajaí River.


Spillway at the Oeste dam


Spillway at the Sul dam

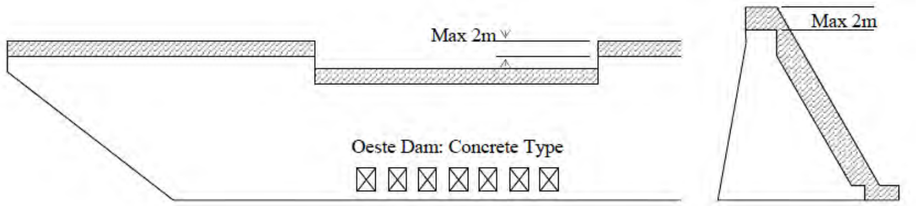
Table 5.3.1 presents the Brazilian Standard about dam top elevations.

Table 5.3.1 Brazilian Standard about Dam Top Elevation

Term	Case	Type	Description
Free Board	Ordinal time	Fill dams	Free board must be more than wind wave height. Wind wave height should be estimated with Saville's method. Minimum free board should be 3.0 m.
		Concrete dams	Minimum free board should be 1.5 m.
	Flood time	Fill Dams	Minimum free board should be 1.0m on design flood water level.
		Concrete dams	Minimum free board should be 0.5m on design flood water level.
Design Flood Discharge	Normal dams	Probable maximum flood	Probable maximum flood is applied as design flood discharge for dams more than 30m in height, or dams which has eternal residences along the downstream river who might suffer from dam collapse.
	Small dams	1000-year probable flood	1000-year probable flood is applied as design flood discharge for dams less than 30m in height, or dams of which total reservoir volume is less than 50 million m^3 and which has no residences along the downstream river.

Source: Criterios De Projeto Civil De Usinas Hidreletricas, Eletrobras, Outubro/2003

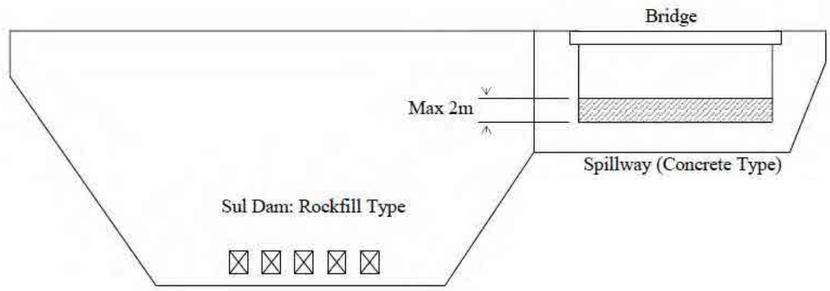
Oeste Dam (Height of the dam: 25m, completed in 1973): Increased height of the dam should be limited to around 2 m (increased reservoir volume: 16.2 million m^3) from topographic and geological aspect.



Source: JICA Survey Team

Figure 5.3.2 Diagram Heightening of Oeste Dam

Sul Dam (Height of the dam: 43.5m, completed in 1976): Increased height of the spillway should be limited to around 2 m (increased reservoir volume: 16.6 million m^3) from the flow capacity for the design flood discharge and the clearance between maximum flood water level and beams of the bridge.



Source: JICA Survey Team

Figure 5.3.3 Diagram Heightening of Sul Dam

Table 5.3.2 Ralation between Increased Reservoir Volumen and Height of Heightening Dams

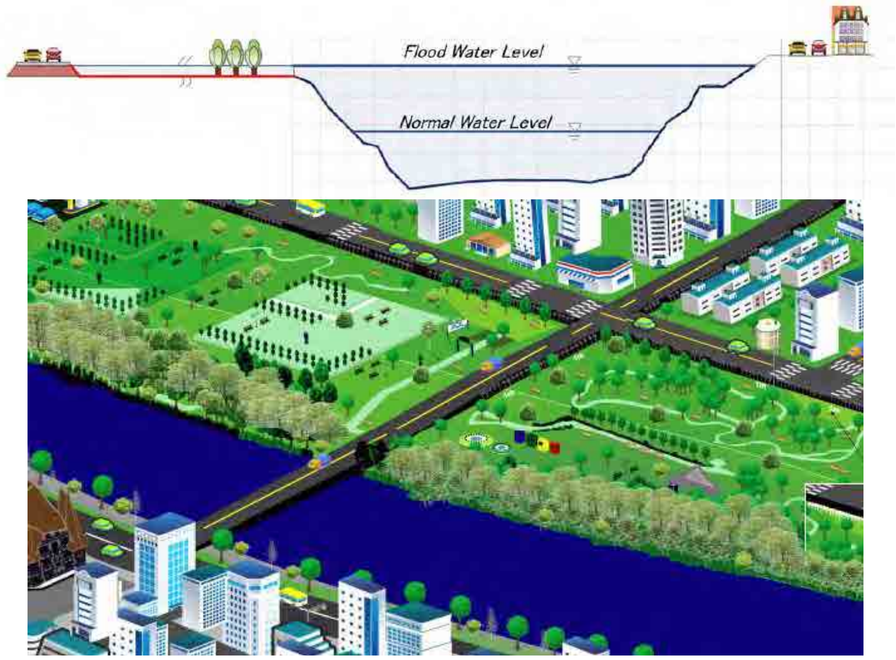
Height of Heightening Dams (m)	Oeste Dam (million m^3)	Sul Dam (million m^3)
0.5	3.9	4.0
1.0	7.9	8.1
1.5	12.0	12.3
2.0	16.2	16.6

Source: JICA Survey Team

(2) Dykes (River Improvement)

In order to increase the current flow capacity of river channel, river widening and riverbed excavation are most commonly applied for flood control projects. In the flood control master plan formulated by JICA in 1988, widening and riverbed excavation of river channel were proposed in the stretches between Blumenau and Gaspal cities in the Itajaí River. However, these measures are not to be applied as much as possible for the Itajaí mainstream under the current Study. Nevertheless, river widening with provision of composite section preserving the existing riparian forest is included in the flood control alternatives, because it is inevitably required to increase the current flow capacity when the higher flood safety level is required.

Figure 5.3.4 illustrates the image of composite section of the Itajaí River. As shown in the figure, when the composite section is applied to river widening, the current riparian forest shall be preserved to be used as a park and open space. Furthermore, the existing road shall be utilized as dyke (including raising of road) or proposed new road to be used as dyke. In this connection, the current river channel forms a low-water channel of the composite section.



Source: JICA Survey Team

Figure 5.3.4 Illustration of Composite Section in Blumenau City

(3) Floodway

The flood control master plan in 1988 proposed a floodway to divert part of the large flood discharge of the Itajai River to the Atrantic Ocean crossing Navegantes city from immediately downstream reaches of the bridge of BR 101, considering that it was very difficult to widen the river channel and provide dykes on the both banks to increase the flow capacity to pass the flood. The floodway is added as the flood control alternative, because it is expected to reduce the depth and duration of flood inundation that is likely to occur widely over the alluvial plain spreading from Gaspar city.

(4) Ring Dyke

Various cities have been developed along the banks of Itajaí River. Obviously, potential of flood damages has become large at major urban areas where the main assets are concentrated. Ring dyke is also added into the flood control alternatives to the urban areas where river widening by composite section might be difficult due to urbanization. This is based on the priority to protect the urban areas from overflowing from river channel in times of flood.

(5) New Flood Control Dam

Only the natural retarding effects in paddy fields and cultivated lands might be limited for controlling the floods safely in the cities of Blumenau and Brusque, when it is required to increase the safety level against the floods. Therefore, a new flood control dam in the upstream river basin is added to the flood control alternatives.

5.3.2 Measures in River Basin

(1) Water Storage in Paddy Field

The area of paddy fields by municipality in the Itajaí River basin is summarized in the table below. Although the total paddy area is 26,295 ha, the paddy area in the Itajaí Mirim River basin is not included because the farmers in the Itajaí Mirim River basin are not the corporation member of CRAVIL. CRAVIL has a plan to build water storage in the existing paddy fields to store rainfall water in the existing paddy fields covering the area of 22,000 ha, which is equivalent to around 80% of the total paddy area. Out of the paddy fields, 20% of the area is irrigated by small tributary rivers, and 80% is the rainfed paddy (including pumping up of river water), which is the target area for water storage project.

Table 5.3.3 Paddy Fields in the Itajai River Basin

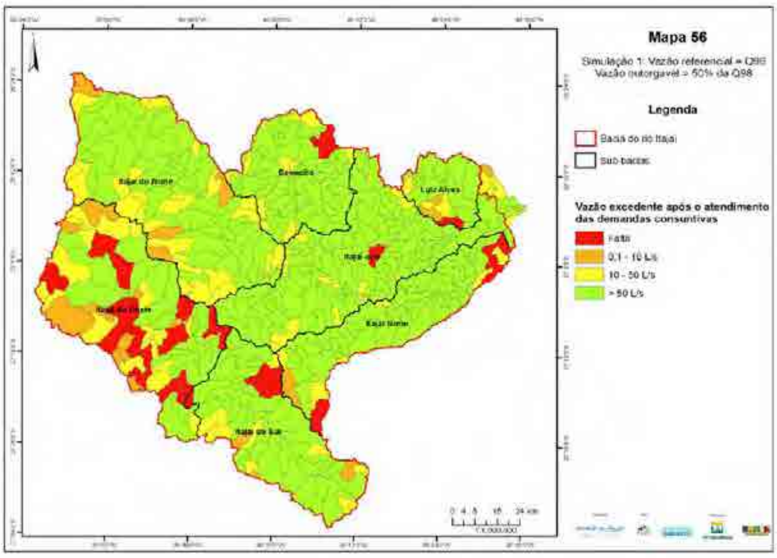
Upper Itajai Valley		Middle and Lower Itajai Valley	
City	**Area (ha)**	**City**	**Area (ha)**
Agronomica	360	Ascurra	567
Agrolandia	260	Brusque	170
Alfredo Wagner	155	Benedito Novo	300
Ibirama	70	Dr. Pedrinho	808
Lontras	100	Gaspar	3,400
Mirim Doce	1,850	Indaial	250
Pouso Redondo	2,045	Ilhota	3,000
Presidente Getuilo	65	Itajai	2,400
Rio do Campo	1,800	Luis Alves	558
Rio do Sul	300	Navegantes	1,200
Rio do Oeste	1,600	Rio dos Cedros	1,100
Salete	100	Rodeio	617
Taio	2,400	Timbo	700
Trombuto Central	80		
Vitor Meirelis	40		
Sub-total	**11,225**	**Sub-total**	**15,070**
Total			**26,295**

Source : CRAVIL

According to the plan, the furrow in paddy field with the average height of 10 cm is to be raised by 20 cm. At the maximum, 66 million m^3 of rainfall is expected to be stored in the water storage.

(2) Basin Storage (Small Dam)

Small dam is planned to be installed on small tributary rivers as basin storage. The stored water is to be utilized for irrigation on the micro basin basis. Selection of small dam sites shall be given high priority to micro basins in the Itajai do Oeste and Sul Rivers as shown below.



Source : Itajai River Basin Committee

Figure 5.3.5 Micro Basin of Water Shortage for Irrigation in the Itajai River Basin

5.4 Flood Control Planning by Flood Protection Level (Safety Level)

5.4.1 Protection for the 5-year Flood

(1) Flood Discharge and Flow Capacity

Figure 5.4.1 shows the distribution of 5-year flood discharge and flow capacity at major cities under the present condition (without flood control measures). As is apparent from the figure, the flow capacity is smaller than the 5-year flood discharge only at Rio do Sul (Itajai River mainstream and Itajai do Oeste River)and Itajai cities (Itajai Mirim River).

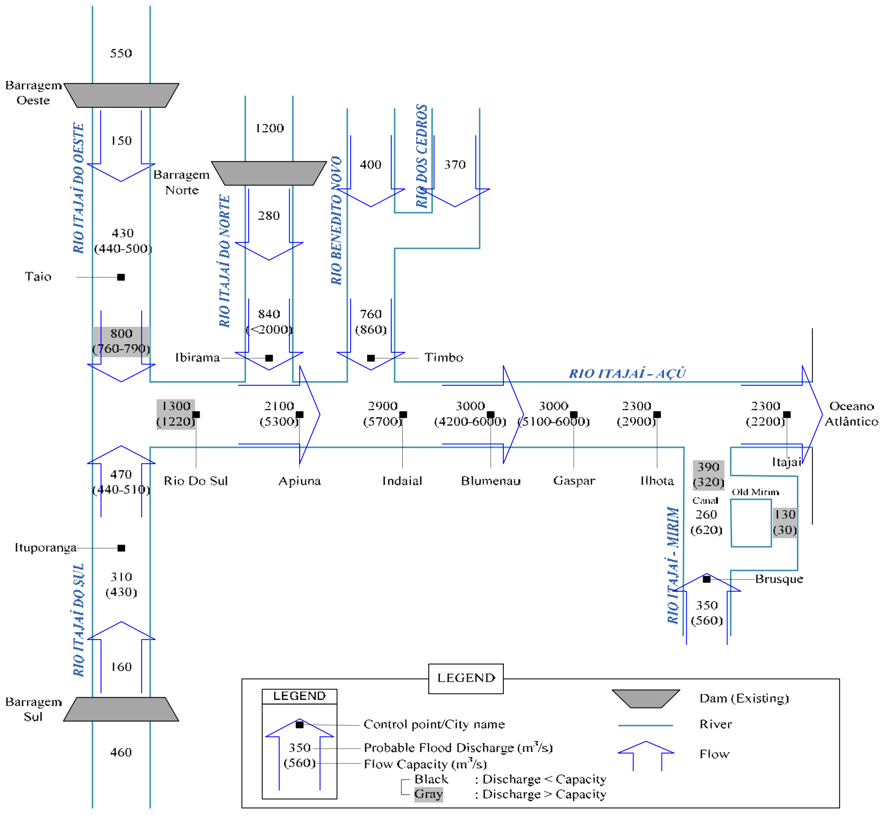
(2) Basic Approach for Planning

Priority is given to the alternative measures in river basin such as water storage in paddy fields and small dam in micro basin, followed by effective utilization of the existing flood control dams. These alternatives are considered small impact on natural and social environments.

(3) Flood Control Planning

a. Water storage in paddy field

The flood control effect of water storage in paddy field is expressed as an initial loss of rainfall. The rainfall volume to be stored is converted the initial rainfall loss by dividing the catchment area of its sub-basin where the paddy field is located (see Figure 3.5.4). Table 5.4.1 shows the calculated initial rainfall loss due to water storage in paddy field for each sub-basin in the flood runoff simulation model. The initial rainfall loss are as small as less than 1 mm in the Itajai do Sul and Itajai do Norte River basins with little paddy fields, as large as 10 to 20 mm for the Itajai do Oeste (Basin 1 in Table 5.4.1) and Itajai River mainstream (Basins 9, 10 and 12).



Source: JICA Survey Team

Figure 5.4.1 Distribution of 5-year Flood Discharge and Flow Capacity by City under Present Condition

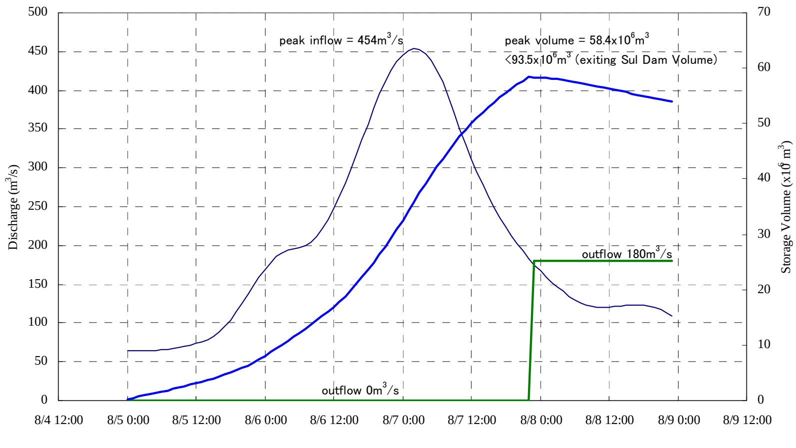
Table 5.4.1 Initial Rainfall Loss due to Water Storage in Paddy Field by Sub-basin

Sub Basin		Catchment Area	Municipality	Paddy Area	Depth	Rate of using	Storage		Initial Loss
		km^2		ha	cm	Rainwater	m^3		mm
Itadai do Oeste	Barragem Oeste	1042	**Rio do Campo**	1,800	20	0.8	2,880,000	2,880,000	2.8
	Basin 1	528	**Mirim Doce**	1,850	20	0.8	2,960,000	6,960,000	13.2
			Taio	2,400	20	0.8	3,840,000		
			Salete	100	20	0.8	160,000		
	Basin 2	1445	**Agrolandia**	260	20	0.8	416,000	7,192,000	5.0
			Pouso Redondo	2,045	20	0.8	3,272,000		
			Agronomica	360	20	0.8	576,000		
			Rio do Oeste	1,600	20	0.8	2,560,000		
			Trombuto Central	80	20	0.8	128,000		
			Rio Do Sul	150	20	0.8	240,000		
Itajai do Sul	Barragem Sul	1273	**Alfredo Wagner**	155	20	0.8	248,000	248,000	0.2
	Basin 4	381	**Rio do Sul**	150	20	0.8	240,000	240,000	0.6
Itajai do Norte	Basin 5	1023	**Ibirama**	70	20	0.8	112,000	280,000	0.3
			Presidente Getuilo	65	20	0.8	104,000		
			Vitor Meirelis	40	20	0.8	64,000		
Benedito	Rio Benedito	831	**Benedito Novo**	300	20	0.8	480,000	2,332,800	2.8
			Dr. Pedrinho	808	20	0.8	1,292,800		
			Timbo	350	20	0.8	560,000		
	Rio dos Cedros	600	**Rio dos Cedros**	1,100	20	0.8	1,760,000	2,320,000	3.9
			Timbo	350	20	0.8	560,000		
Itajai Acu	Basin 6	906	**Lontras**	100	20	0.8	160,000	160,000	0.2
	Basin 7	556	**Ascurra**	567	20	0.8	907,200	2,294,400	4.1
			Indaial	250	20	0.8	400,000		
			Rodeio	617	20	0.8	987,200		
	Basin 9	349	**Gaspar**	3,400	20	0.8	5,440,000	5,440,000	15.6
	Basin 10	227	**Ilhota**	3,000	20	0.8	4,800,000	4,800,000	21.1
	Luiz Alves	580	**Luis Alves**	558	20	0.8	892,800	892,800	1.5
	Basin12	176	**Navegantes**	1,200	20	0.8	1,920,000	3,840,000	21.8
			Itajai	1,200	20	0.8	1,920,000		
Itajai Mirim	Basin11	472	**Itajai**	1,200	20	0.8	1,920,000	1,920,000	4.1
	Itajai Mirim	1207	Brusque	170	0	0.8	0	0	0.0
Sum		11596		26,295				41,800,000	

Source: JICA Survey Team

b. Change of the current dam operation method at the Sul dam

As the Sul dam has a larger storage capacity against the flood inflow compared to the Oeste dam, the inflow of 5-year flood is able to be fully stored in the reservoir with closure of all the gates. As shown in Figure 5.4.2, the stored volume is 58.4 x$10^6$$m^3$, which is within its storage capacity 93.5 x$10^6$$m^3$. According to DEINFRA, almost no overflowing from the spillway has occurred to date except the large floods in 1983 and 1984. As for the 5-year flood, the current dam operation method shall be changed to close all of the gates. In this connection, however, heightening of dam would be required because this change of dam operation method might increase the risk of overflowing through the spillway in times of large floods.



Remark: After the peak of flood, gates are opened in order when the flood inflow decreases to be 180m^3/s, which is sufficiently smaller than the current flow capacity in the downstream river channel.

Source: JICA Survey Team

Figure 5.4.2 Proposed Dam Operation against 5-year Flood at Sul Dam

c. Basin storage (small dam)

The results of flood runoff simulation showed that even if the 5-year flood at the Oeste dam is fully stored in the reservoir with closure of all gates, its effect for decreasing the flood discharge in the downstream stretch of Itajai do Oeste River near Rio do Sul city is small due to its 80 km long river length from the dam to the city and gentle river slope of 1/5,000. Moreover, the effect of water storage in paddy field is also limited, and therefore small dam is examined.

Since the current flow capacity at the stretch of Itajaí do Oeste River is 760m^3/s against the 5-year flood discharge of 800m^3/s, the lack of flow capacity is 40m^3/s. The required storage volume of small dam is estimated to be around 8,140,000m^3 to increase the flow capacity by 40m^3/s in this river stretch. Selection of the candidate location of small dams is necessary for detailed topographic maps with a scale of 1:10,000, mapping of which is under preparation by SDS. The site selection was made based on the available maps of 1:50,000 as shown in Figure 5.4.3 and the storage capacity of small dam are as follows:

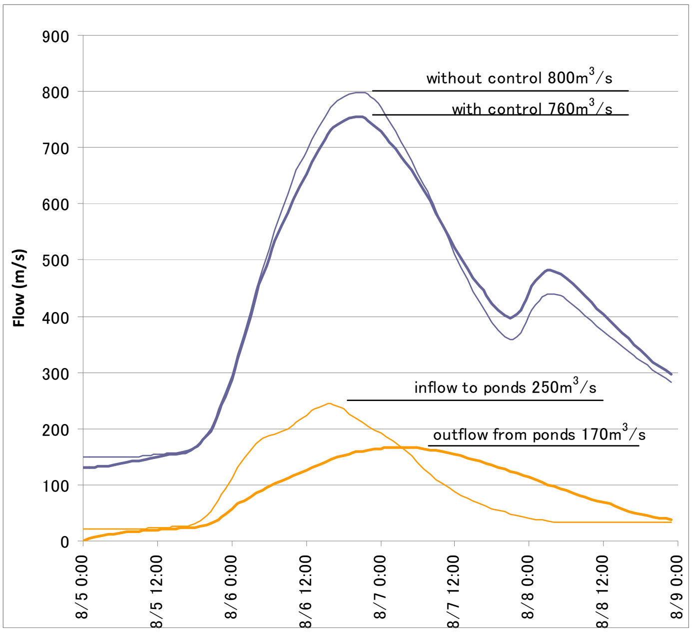
Table 5.4.2 Required Storage Capacity of Small Dams for 5-year Flood

Candidate location	Trombudo River	Braço do Trombudo River
Catchment area	294 km^2	117 km^2
Storage capacity	5,830,000 m^3	2,310,000 m^3

Source: JICA Survey Team

Source: JICA Survey Team

Figure 5.4.3 Location Map of Small Dams (5-year Flood Level)

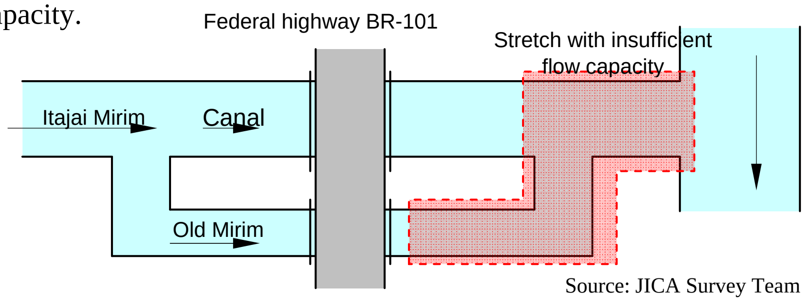


Source: JICA Survey Team

Figure 5.4.4 Flood Control Calculation of Small Dam for Riparian Area along the Itadai do Oeste River in Rio do Sul city (5-year flood)

d. Itajaí Mirim River

The Itajaí Mirim River branches into two rivers; the old Mirim River and the Canal in the upstream area of Itajaí city, and these two rivers joins each other approximately 1 km upstream of the confluence to the Itajaí River as illustrated in Figure 5.4.5. As shown in the figure, river stretches of small flow capacity less than the 5-year flood discharge are from the federal highway BR 101 to the junction with the Canal along the old Mirim River and from the junction to the confluence with the Itajai River along the Canal. Other stretches along the Canal have larger flow capacity.



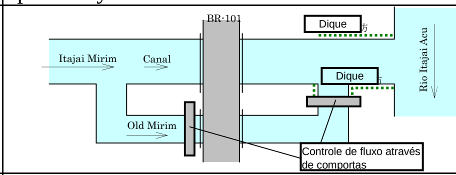
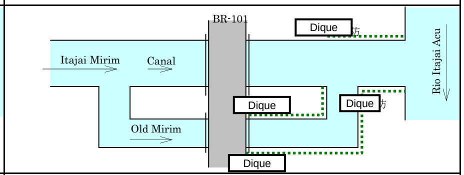
Source: JICA Survey Team

Figure 5.4.5 Stretches of Smaller Flow Capacity than 5-year Flood Discharge along the Itajai Mirim River

As shown in Table 5.4.3, comparative study was carried out for two alternatives for the less flow capacity stretches. They are the “two flood gates with partial dyke” and “full dyke along the stretches”. As a result, the “two flood gates with partial dyke” was selected from the aspects of cost and social impacts to be associated in the populated urban area along the stretches. Two flood gates are planned at locations of both upstream and downstream of the old Mirim River as shown in this table. The upstream flood gate would control the flood inflow into the old Mirim River within its flow capacity in times of flood and the downstream gate would control the influence due to back water of the Itajai River mainstream.

The general features of both flood gates are summarized in Table 5.4.4. (as described in the succeeding sub-sections, the “two flood gates with partial dyke” were proposed for all of the probable floods. Therefore, the height of gates and partial dyke is also indicated in this table).

Table 5.4.3 Comparison of Flood Control Alternatives in the Itajai Mirim River for the 5-year Flood

Aspect	Two Flood Gates with Partial Dyke	Full Dyke
Outline	To protect the populated urban area along the less flow capacity stretches with provision of two flood gates and 1 km long partial dyke as illustrated below.	To protect the populated urban area along the less flow capacity stretches with provision of full dyke system as illustrated below.
Layout		
Project Cost	Apparently predominant due to less land acquisition	Apparently less advantageous due to wide area for land acquisition and replacement of existing seven bridges to be required
Impact to Social Environment	Small social impact due to few residences to be reallocated	Large social impact due to many residences to be reallocated
Impact to Natural Environment	Although no significant impacts might occur, some influence due to temporal inundation during the closure of flood gates shall be noted.	No significant impacts.
Evaluation	Appropriate as a plan to be adopted	Inappropriate as a plan to be adopted due to significant social impacts and disadvantage in cost to be required

Source: JICA Survey Team

Table 5.4.4 General Features of Flood Gates and Dyke per Protection Level

Flood Protection Level		5-year flood	10-year flood	25-year flood	50-year flood
Upstream Flood Gate	No. of Gate	4 nos.			
	Gate Width	10 m			
	Gate Height	4.1 m	4.5 m	4.9 m	5.3 m
	Total width	61 m			
Downstream Flood Gate	No. of Gate	4 nos.			
	Gate Width	10 m			
	Gate Height	3.0 m	3.3 m	3.6 m	4.0 m
	Total width	61 m			
Dyke Height*	Left bank	0.6 m	0.8 m	1.3 m	1.7 m
	Right bank	1.0 m	1.3 m	1.7 m	2.1 m

Remarks: The dyke height is based on the ground elevation at the river section IMa surveyed under the JICA Survey.
Source: JICA Survey Team

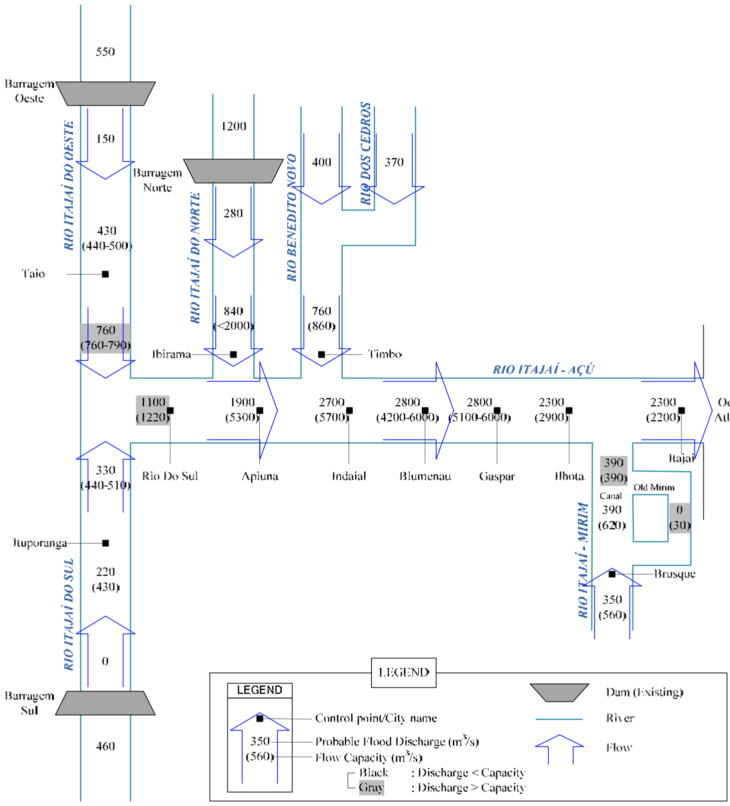
(4) Flood Discharge after the Proposed Plan

Figure 5.4.6 shows the distribution of 5-year flood discharges after implementation of the proposed flood control plan above. It is to be noted that the flood discharges in the figure is based on the conditions that the existing wide flood plain along the Itajai River from Gaspar to Itajai cities is preserved without any development.

5.4.2 Protection for the 10-year Flood

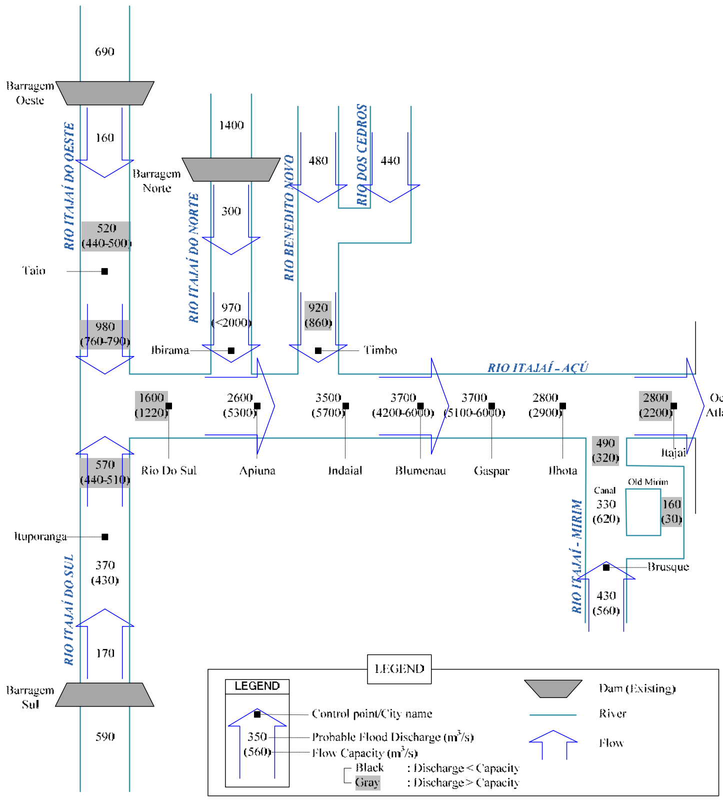
(1) Flood Discharge and Flow Capacity

Figure 5.4.7 shows the distribution of 10-year flood discharge and flow capacity at major cities under the present condition. As indicated in the figure, cities having smaller flow capacity than the 10-year flood discharge are Taio, Rio do Sul (Itajai River mainstream, Itajai do Oeste and Itajai do Sul Rivers) and Itajai cities (Itajai River mainstream and Itajai Mirim River).



Source: JICA Survey Team

Figure 5.4.6 Distribution of 5-year Flood Discharge and Flow Capacity by City for Flood Control Plan



Source: JICA Survey Team

Figure 5.4.7 Distribution of 10-year Flood Discharge and Flow Capacity by City under Present Condition

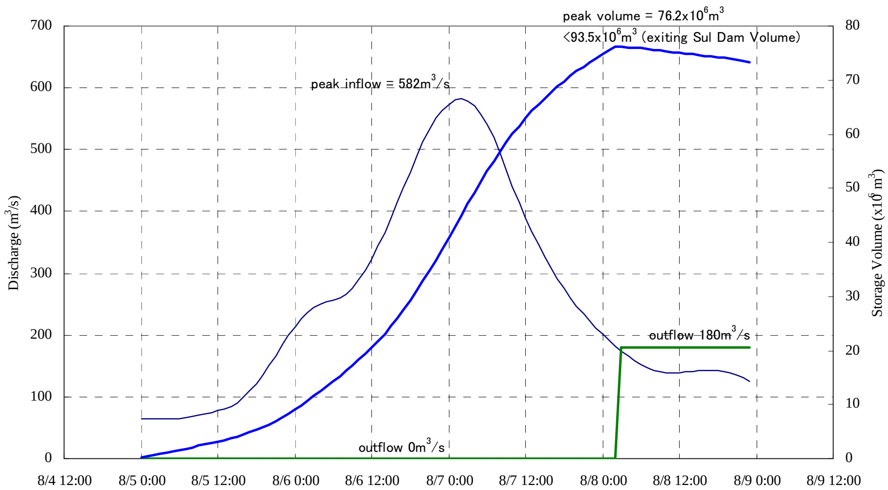
(2) Basic Approach for Planning

Same as the flood control planning for the 5-year flood, priority is given to the alternative measures in river basin such as water storage in paddy fields and basin storage (small dam), followed by effective utilization of the existing flood control dams. As for the Itajai Mirim River and water storage in paddy field, the same measures for the 5-year flood are applied to the 10-year flood.

(3) Flood Control Planning

a. Change of the current dam operation method at the Sul dam

The inflow of 10-year flood is able to be fully stored in the reservoir with closure of all the gates at the Sul dam. As shown in Figure 5.4.8, the stored volume is 76.2 x10^6 m^3, which is within its storage capacity 93.5 x10^6 m^3. As mentioned in preceding sub-section, heightening of dam would be also required because this change of dam operation method might increase the risk of overflowing through the spillway in times of large floods.



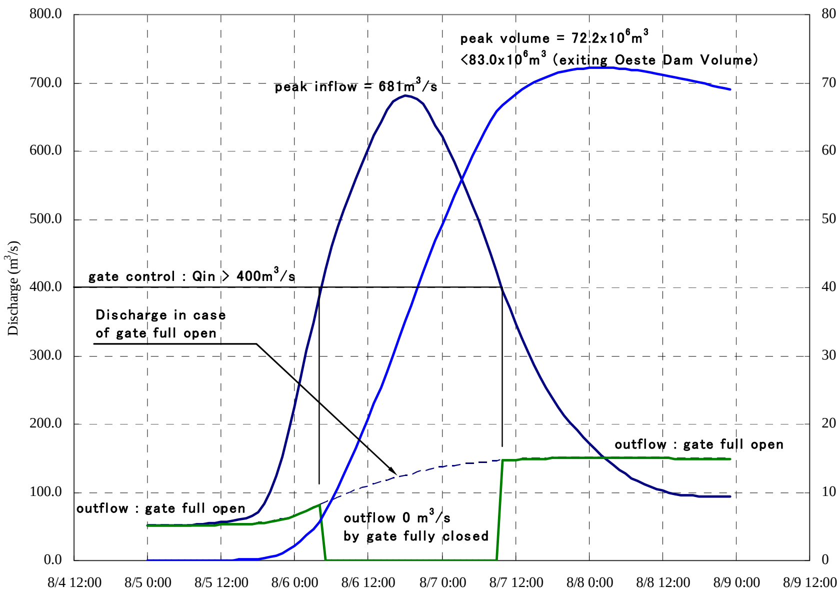
Remark: After the peak of flood, gates are opened in order when the flood inflow decreases to be 180m^3/s, which is sufficiently smaller than the current flow capacity in the downstream river channel.

Source: JICA Survey Team

Figure 5.4.8 Proposed Dam Operation against 10-year Flood at Sul Dam

b. Change of the current dam operation method at the Oeste dam

Overflowing from the spillway has occurred in several times to date at the Oeste dam, as the Oeste dam has a smaller storage capacity compared to the Sul dam. However, the 10-year flood is able to be controlled with full opening of gates when the flood inflow exceeds 400 m^3/sec to avoid inundation in Taio city located immediately downstream of the dam. As shown in Figure 5.4.9, the stored volume is 72.2 x 10^6 m^3, which is within its storage capacity 83.0 x 10^6 m^3. Same as the Sul dam, heightening of dam would be also required to reduce the increased risk of overflowing due to the change of dam operation method.

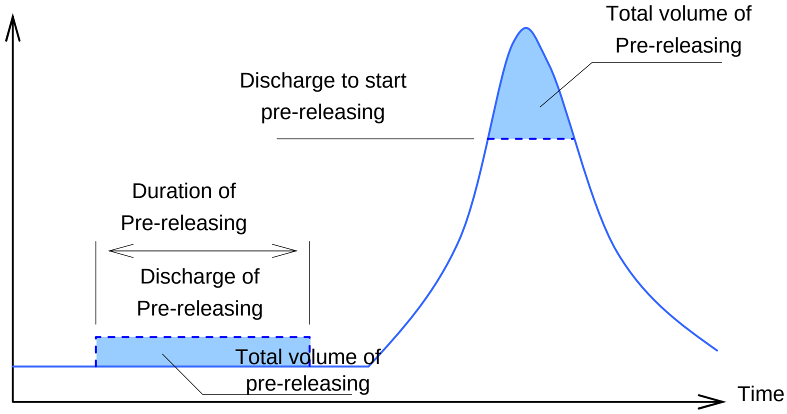


Source: JICA Survey Team

Figure 5.4.9 Proposed Dam Operation against 10-year Flood at Oeste Dam

c. Utilization of the existing hydropower generation dams for flood control

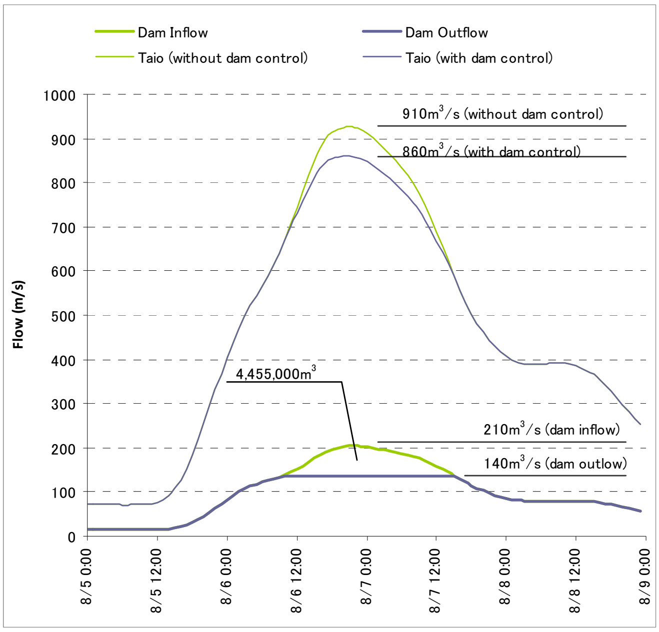
To overcome the lack of flow capacity is 50m^3/s in Timbó city, utilization of the existing two hydropower generation dams for flood control was contemplated, which is belong to CELESC and located in the upstream Rio dos Cedros River. Along this line, pre-releasing of the stored water was studied considering the fact that both municipal governments of Rio dos Cedros and Timbó cities expect to lower the reservoir operation level of two dams[4]. As illustrated in Figure 5.4.10, the pre-releasing discharge, total water volume for pre-releasing, duration of pre-releasing, and discharge for starting the pre-releasing shall be studied and then determined. The study is detailed in the Supporting Report No.3 Flood Mitigation Plan. The study results proposed the operating reservoir water level would be lowered by 80 cm for the Pinhal dam and 70 cm for the Rio Bonito dam.



Source: JICA Survey Team

Figure 5.4.10 Schematic Diagram of Dam Operation through Anticipated Discharge

4 The petition containing the signatures of 1,200 local residents was submitted to the State Government in June 2010, requiring for lowering the reservoir water level by pre-releasing.



Source: JICA Survey Team

Figure 5.4.11 Required Total Volume of Pre-releasing for Flood Control in Timbo City (for 10-year flood)

Table 5.4.5 Required Volume of Pre-releasing (for 10-year flood)

	Catchment Area	Total Volume of Pre-releasing	Discharge to be controlled	Outflow Discharge from Dams
Pinhal Dam	179.9km^2	2,940,000m^3	42m^3/s	84m^3/s
Rio Bonito Dam	119.8km^2	1,960,000m^3	28m^3/s	56m^3/s
Total	**299.7km^2**	**4,900,000m^3**	**70m^3/s**	**140m^3/s**

Source: JICA Survey Team

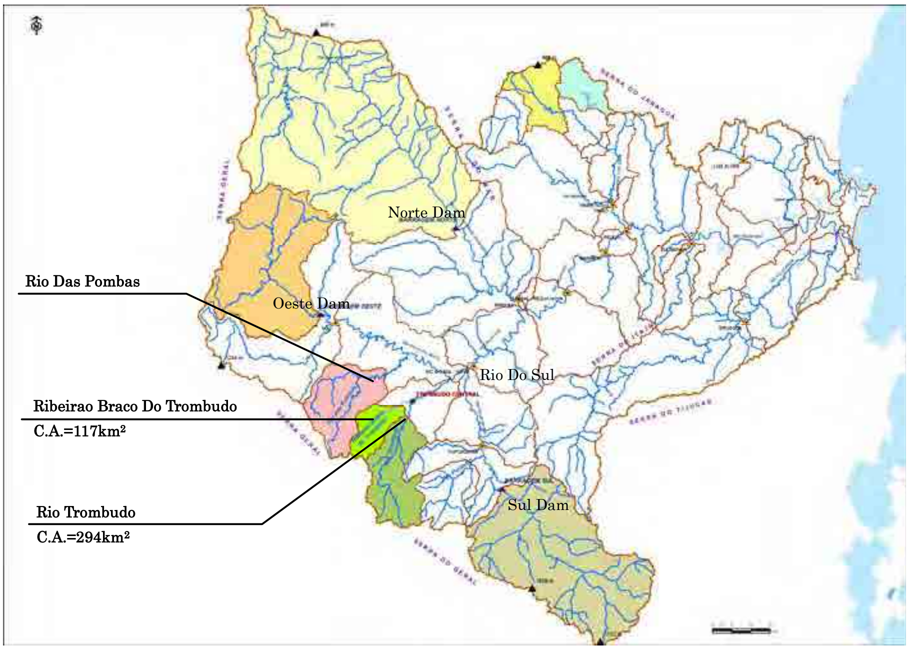
It is estimated that reservoir water levels should be lowered for pre-releasing around 80 cm in Pinhal Dam, 70 cm in Rio Bonito Dam from the relation between wate level and reservoir volume.

d. Comparison study on flood control alternatives for Rio do Sul City

Even if the change of dam operation method at both the Sul and Oeste dams as well as water storage in paddy field are provided, there remains lacks of flow capacity of 180m^3/s in the Itajai River mainstream in Rio do Sul city and 150 m^3/s in the Itajai do Oeste River, requiring further flood control measures. Three alternatives; i) small dam, ii) retarding basin, and iii) river widening of downstream reaches of Rio do Sul city were compared. River widening aims at increasing of the current flow capacity in Rio do Sul city by means of lowering the flood water level in the downstream reaches. The comparison is outlined below.

1) Basin Storage (Small dam)

The required storage volume of small dam is estimated to be around 27,550,000 m^3 to increase the flow capacity in Rio do Sul city. Figure 5.4.10 shows the location map of candidate dam sites and the required storage capacity of small dams are as follows:



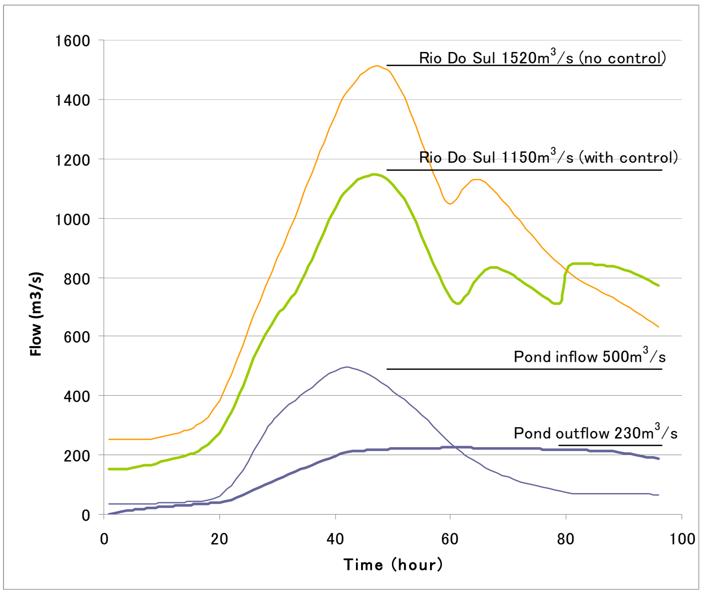
Source: JICA Survey Team

Figure 5.4.12 Location Map of Small Dams（10-year Flood Level）

Table 5.4.6 Required Storage Capacity of Small Dams for 10-year Flood

Candidate Location	**Trombudo River (2 dams)**	**Braco do Trombudo River (1 dam)**	**Rio das PombasRiver (2 dams)**
Catchment area	294 km^2	117 km^2	315 km^2
Storage capacity	11,160,000 m^3	4,420,000 m^3	11,970,000 m^3

Source: JICA Survey Team

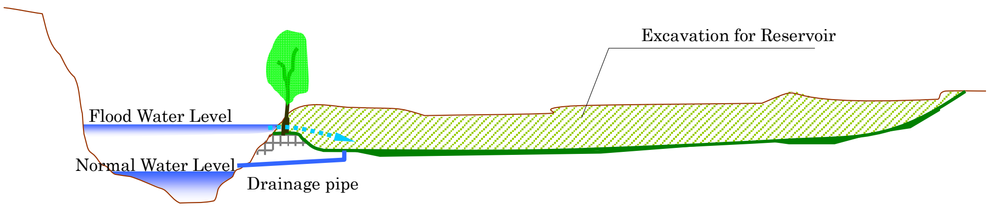


Source: JICA Survey Team

Figure 5.4.13 Flood Control Calculation of Small Dam for Riparian Area in Rio do Sul city (10-year flood)

2) Retarding basin

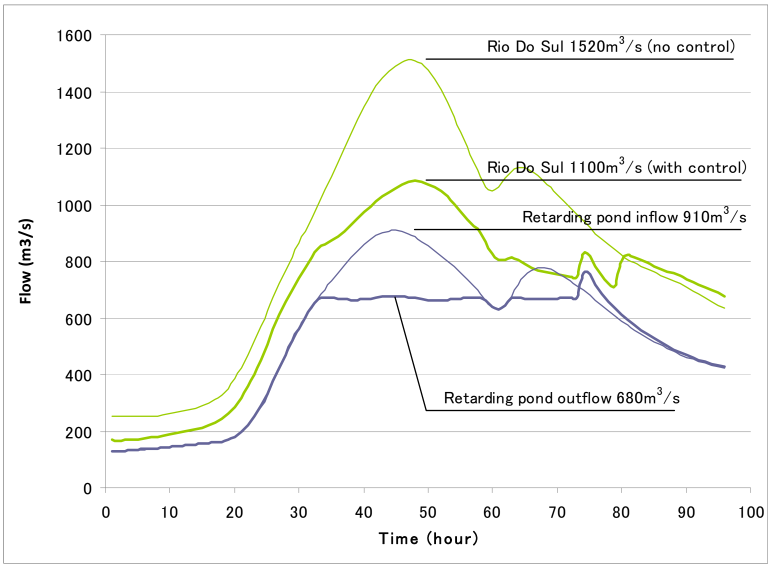
Retarding basin was planned immediately upstream of Rio do Sul city. As illustrated in Figure 8.4.14, retarding basin is constructed by excavation widely on the river bank. A part of flood would be laterally overflowed into the retarding basin.



Source: JICA Survey Team

Figure 5.4.14 Illustration of Retarding Basin on River Bank

From the site inspection, possible wide areas for retarding basin are near Agronômica city along the Trombudo River and stretch between the cities of Laurentino and Rio do Sul along the bItajaí do Oeste River. As the result of runoff calculation, the required storage volume of retarding basin is 15,400,000 m^3. As the bottom elevation of retarding basin shall be set at the higher elevation than the average river water level, the maximum depth of retarding basin is around 3 m. Therefore, it is necessary to acquire widely the lands of at least of 513 ha to ensure the required volume.

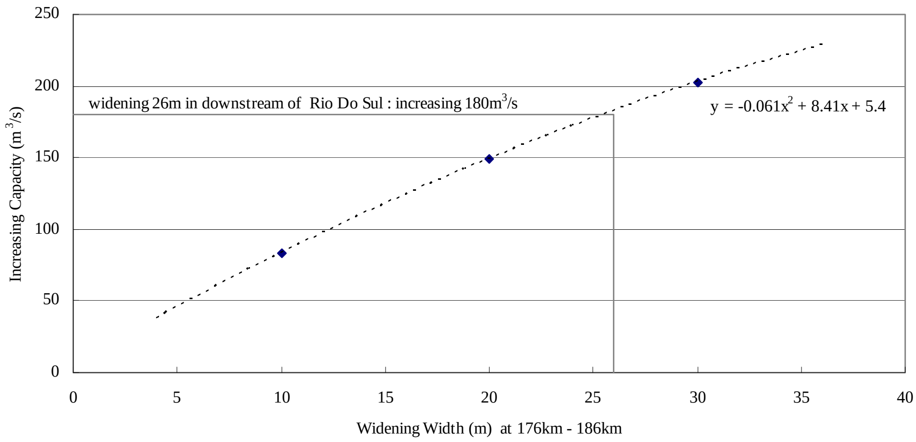


Source: JICA Survey Team

Figure 5.4.15 Flood Control Calculation of Retarding Basin for Riparian Area in Rio do Sul city (10-year flood)

3) River widening of downstream reaches of Rio do Sul city

Due to the gentle riverbed gradient of the Itajai River and the backwater from its downstream reaches, significant effect of lowering the flood water level would not be obtained by widening of the current river channel in Rio do Sul city. Therefore, river widening in the 10 km long downstream reaches from Rio do Sul city is planned to lower the flood water level in the city due to its backwater effect, resulting in an increase of the current flow capacity in the city. Figure 5.4.16 presents the relationship between the width of river widening in the downstream reaches and the expected increase of flow capacity in Rio do Sul city. As indicated in this figure, it is necessary to widen the river channel by 26 m to increase the current flow capacity by 180 m^3/sec, which is equivalent to the lack of flow capacity against the 10-year flood.



Source: JICA Survey Team

Figure 5.4.16 Relationship between Width of River Widening in the Downstream Reaches and Expected Increase of Flow Capacity in Rio do Sul City

4) Comparison result of alternatives

As a result of comparison of three alternatives above, flood control plan by basin storage (small dam) is apparently advantageous from the following factors:

(1) The retarding basin plan needs a large scale of excavation. The required cost of such excavation is extremely high associating the issues of spoil bank areas. Moreover, it might be difficult to acquire the extensive area for retarding basin as large as around 523 ha.

(2) The river widening plan requires huge excavation volume of 2,600,000m^3, resulting in a high construction cost. There is also the problem of spoil bank areas for excavated materials.

(3) The plan of 5 small dams would create the storage volume of approximately 28,000.000m^3 with provision of agricultural use of the stored water, allowing to store a great volume of water with a relatively low cost.

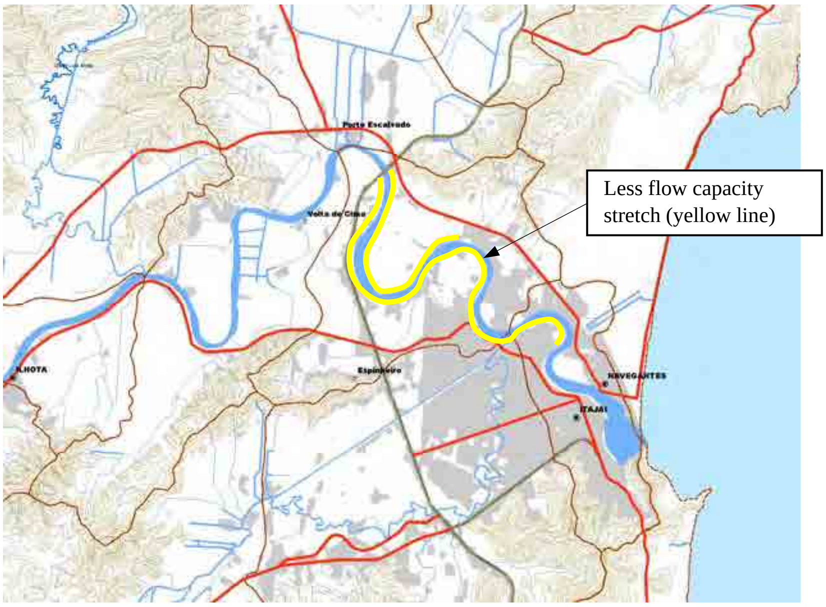
e. Itajai Mirim River and Itajai River mainstream near Itajai city

1) Itajai Mirim River

Same as the plan for the 5-year flood, the two flood gates with partial dyke was proposed. The general features are shown in Table 5.4.4.

2) Itajai River mainstream

Figure 5.4.17 shows the river stretches of less flow capacity against the 10-year flood in the lower reaches of Itajai River. Comparative study was carried out for two alternatives for the less flow capacity stretches; the “lateral dyke (only on the right bank to protect Itajai city)” and a “new floodway”. As indicated in the comparison result of Table 5.4.7, the lateral dyke plan is advantageous in view of the required cost. In case of the lateral dyke, natural retarding effect in the inundation area on the left bank from the federal highway BR-101 to Navegantes city and thus no negative impact to the upstream stretches might occur because no flood water level might increase due to the lateral dyke.



Source: JICA Survey Team

Figure 5.4.17 River Stretche of Less Flow Capacity along the Itajai River for the 10-year Flood

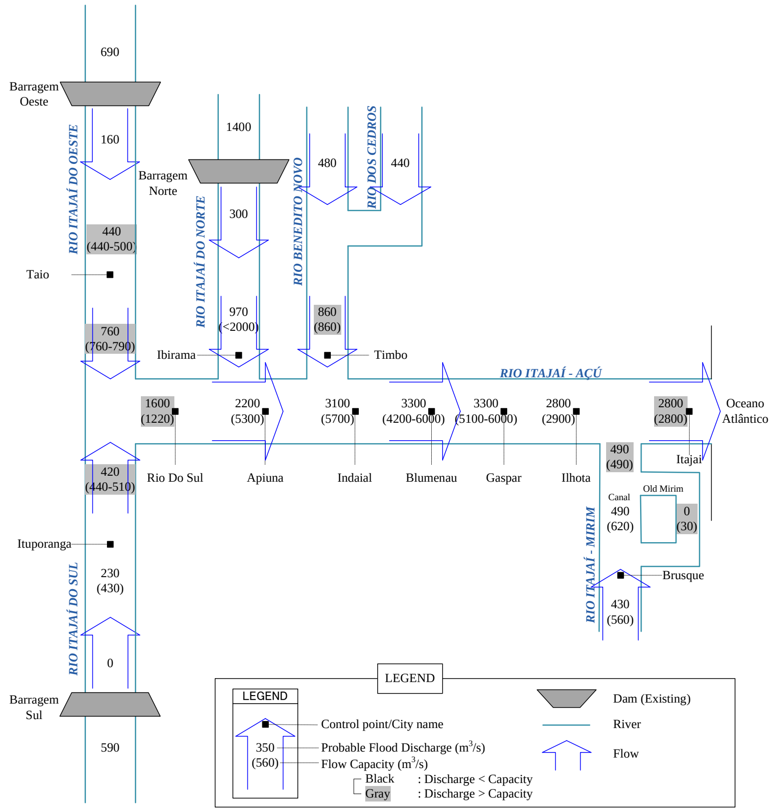
Table 5.4.7 Comparison of Flood Control Alternatives in the Itajai River Mainstream for the 10-year Flood near Itajai City

Aspect	Lateral Dyke	New Floodway
Outline	To install the lateral dyke on the right bank to protect Itajaí city and to preserve the left bank as retarding basin	To install a new floodway immediately downstream of BR-101 to divert the discharge exceeding the flow capacity directly the sea in Navegantes city
Project Cost	Construction cost and land acquisition cost: R$ 171,000,000. The land acquisition cost in the urban area is high, but the project cost is smaller than the floodway.	Construction cost and land acquisition cost: R$ 273,000,000. As a diversion weir is required on the Itajaí river to regulate the discharge in the Itajaí river, the project cost becomes huge.
Impact to Social Environment	Large impact because of relocation of residences in the urban area	Large impact because of separation of Navegantes city by the floodway
Impact to Natural Environment	No significant impact might occur.	Significant impact might occur. Many impacts such as sedimentation at the outlet and the salt water intrusion shall be studied.
Evaluation	Despite large social impact, it is more advantageous than the floodway plan from the cost and natural environment points of view.	It is inferior to the lateral dyke plan from the cost and natural environmental impact points of view.

Source: JICA Survey Team

(4) Flood Discharge after the Proposed Plan

Figure 5.4.18 shows the distribution of 10-year flood discharges after implementation of the proposed flood control plan above. It is to be noted that the flood discharges in the figure is based on the conditions that the existing wide flood plain along the Itajai River from Gaspar to Itajai cities is preserved without any development.



Source: JICA Survey Team

Figure 5.4.18 Distribution of 10-year Flood Discharge and Flow Capacity by City for Flood Control Plan

5.4.3 Protection for the 25-year Flood

(1) Flood Discharge and Flow Capacity

Figure 5.4.19 shows the distribution of 25-year flood discharge and flow capacity at major cities under the present condition. As indicated in the figure, cities having smaller flow capacity than the 25-year flood discharge are Taio, Rio do Sul (Itajai River mainstream, Itajai do Oeste and Itajai do Sul Rivers), Timbó, Blumenau, Ilhota, and Itajai cities (Itajai River mainstream and Itajai Mirim River).

(2) Basic Approach for Planning

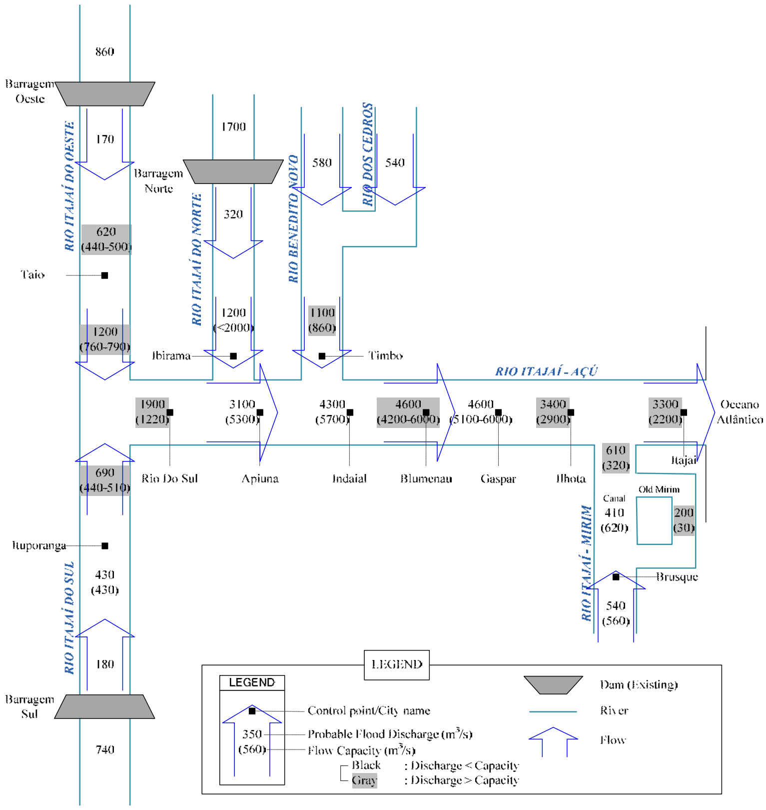
Same as the flood control planning for the 10-year flood, priority is given to the alternative measures in river basin such as water storage in paddy fields and basin storage (small dam), followed by effective utilization of the existing flood control dams.

The flood inflow from remnant river basin other than the drainage area of Oeste dam exceeds the flow capacity in Taió city. Therefore, it becomes necessary to store in remnant basin or to widen the existing river channel in Taió city together with heightening of the Oeste dam. As for Rio do Sul city, addition of small dam and river improvement are considered for the comparative study.

Even though the pre-releasing of two hydropower generation dams is provided, Timbó city would still continue with insufficiency of 240m^3/s in its flow capacity. However, as insufficiency might be in the limited river stretch in the city, partial river improvement is to be conceived.

(3) Flood Control Planning

Same as the proposed plan for the 10-year flood, water storage in paddy field and pre-releasing of two hydropower generation dams are incorporated into the plan for the 25-year flood. Other flood control measures are outlined below. The content of the study is detailed in the Supporting Report on Flood Mitigation Plan.

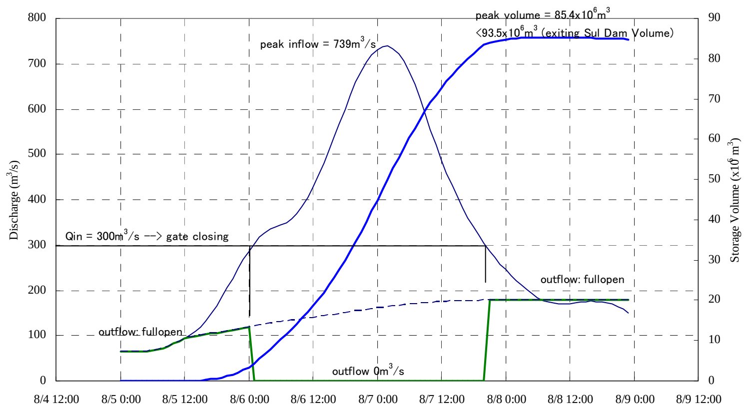


Source: JICA Survey Team

Figure 5.4.19 Distribution of 25-year Flood Discharge and Flow Capacity by City under Present Condition

a. Change of the current dam operation method at the Sul dam

As shown in Figure 5.4.20, the 25-year flood is able to be controlled with full opening of gates when the flood inflow exceeds 300 m^3/sec. No overflowing from the river has occurred in Rio do Sul city when the Sul dam released 300 m^3/sec.

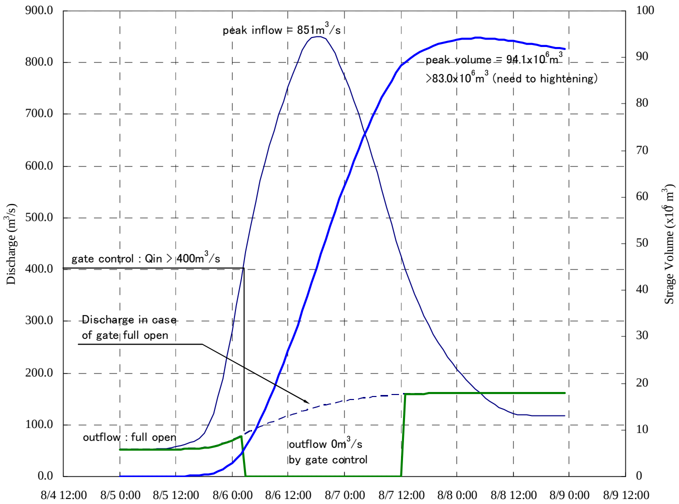


Source: JICA Survey Team

Figure 5.4.20 Proposed Dam Operation against the 25-year Flood at Sul Dam

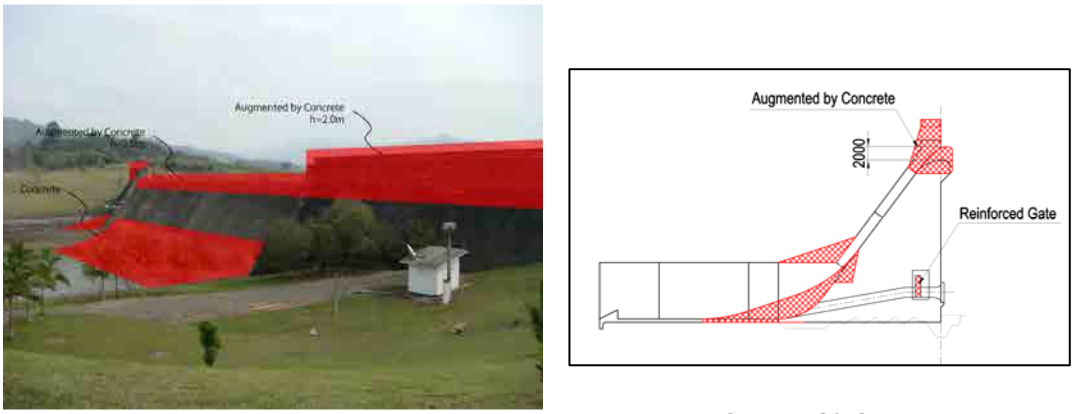
b. Heightening and change of the current dam operation method at the Oeste dam

The Oeste dam is proposed to be heightened by 2 m to increase flood control capacity. The capacity will be increased by approximately 16,200,000m^3. Figure 5.4.21 shows the dam operation against the 25-year flood. When the flood inflow exceeds 400 m^3/sec, all the gates shall be closed in order.



Source: JICA Survey Team

Figure 5.4.21 Proposed Dam Operation against the 25-year Flood at Oeste Dam



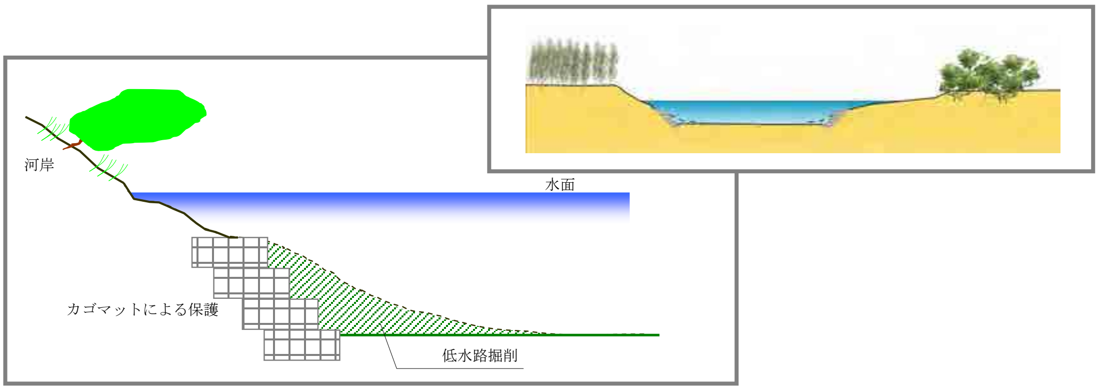
Source: JICA Survey Team

Figure 5.4.22 Diagram of Heightening Oeste Dam

c. River improvement in Taió and Timbó cities

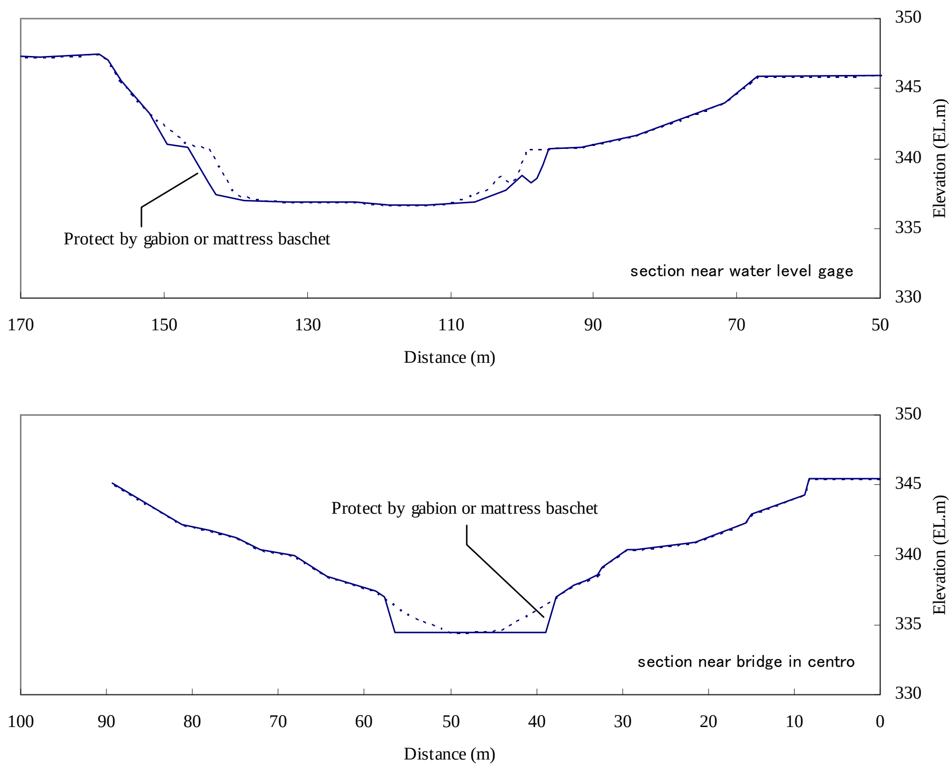
For both cities, river improvement is proposed considering that they are relatively small cities and river improvement might be possible without any relocation of residents. As for Taió city, river widening was proposed because of gentle riverbed slope. The current flow capacity would be increased 490 m^3/s from 440 m^3/s.

The Rio dos Cedros River joins the Benedit River in Timbó city. The current flow capacity downstream of the confluence is 860m^3/s, which is smaller than the 25-year flood discharge of 1200 m^3/s. Beside, the flow capacity of the Rio dos Cedros River in Timbó city is around 450 m^3/s less than the he 25-year flood discharge of 590m^3/s. However, since only partial portions of river stretches have insufficient flow capacity, where the river bank elevation is relatively low, partial river improvement by embankment was planned as illustrated below.



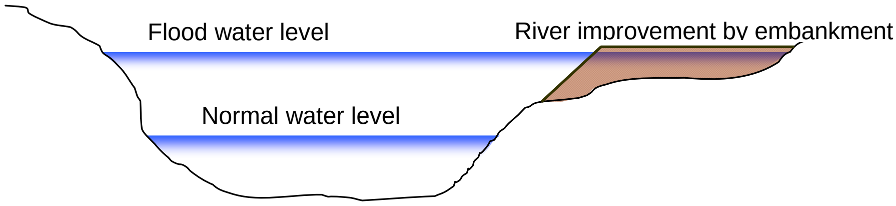
Source: JICA Survey Team

Figure 5.4.23 Diagram of River Improvement in Taio City



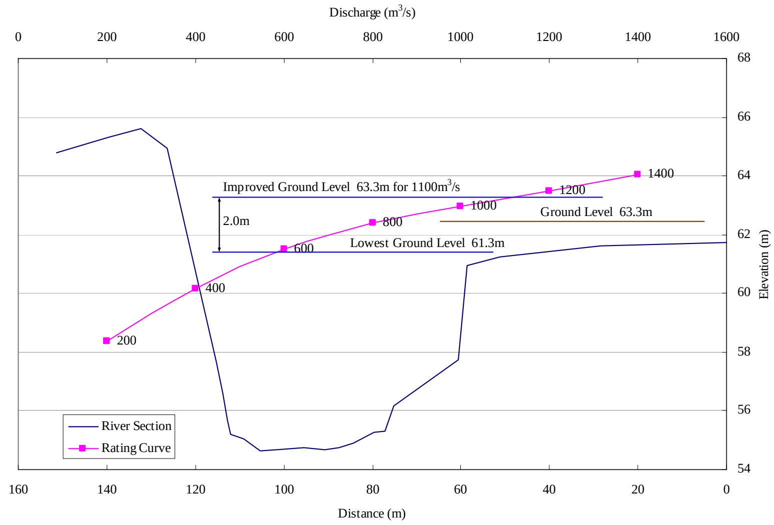
Source: JICA Survey Team

Figure 5.4.24 Diagram of River Improvement in Taio City (for 25-year flood)



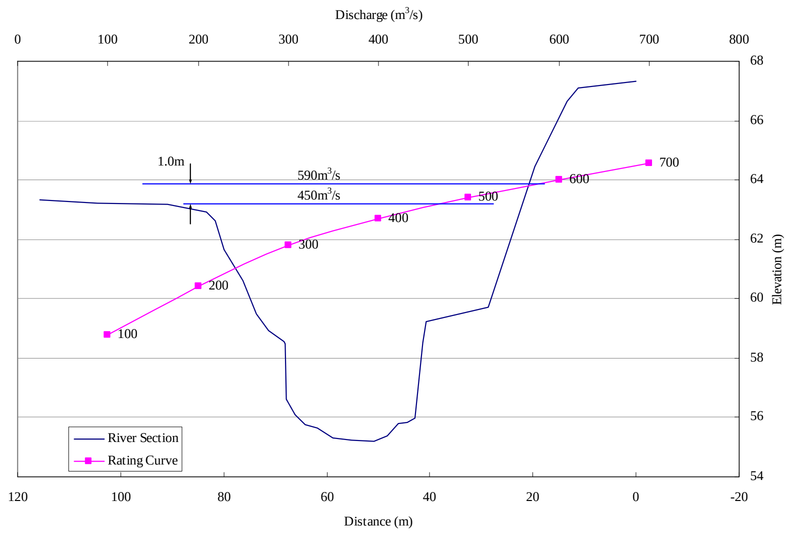
Source : JICA Survey Team

Figure 5.4.25 Image of River Improvement in Timbo City



Source: JICA Survey Team

Figure 5.4.26 Required Ground Elevation at Right Bank of Section BE03

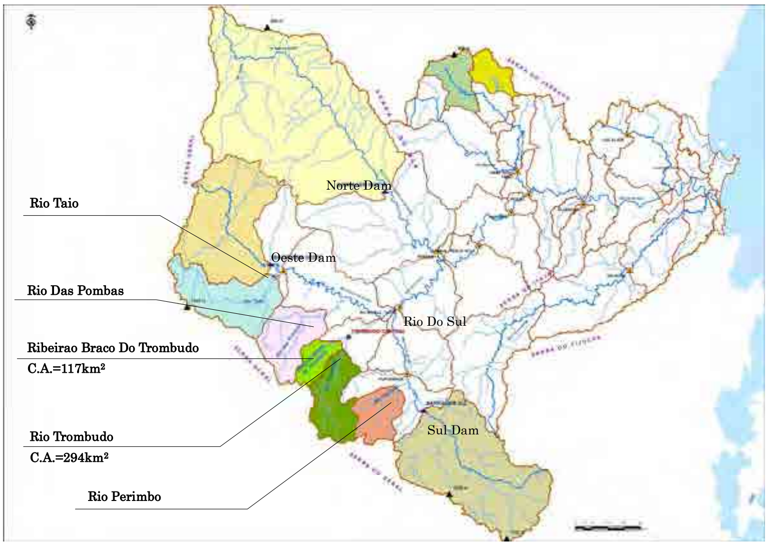


Source: JICA Survey Team

Figure 5.4.27 Required Ground Elevation at Left Bank of Section BE04

d. Flood control measures in Rio do Sul City

The proposed measures for Rio do Sul city is the combination of basin storage (small dams) and river widening. Due to delay of the ongoing topographical mapping, seven small dams are proposed in maximum having a total storage capacity of 41 million m^3. The location map of candidate basins for small dam is shown in Figure 5.4.28. As a result of flood runoff analysis, the 25-year flood discharge becomes 1,300 m^3/s in Rio do Sul city. Therefore, river improvement was studied to increase the current flow capacity of 1,220 m^3/s by 80 m^3/s. Along this line, two alternatives are compared as summarized in Table 5.4.10, which are the same alternatives as for the 10-year flood. As a result, flood control by river widening of the downstream reaches is concluded to be advantageous in view of the required cost and less social impacts.



Source: JICA Survey Team

Figure 5.4.28 Location Map of Small Dams（25-year Flood Level）

Table 5.4.8 Required Volume of Small Dams for Flood Prevention in Rio do Sul (25-year flood)

Basin	River	Required Volume	Location
Itajai do Oeste	Trombudo River	24,900,000 m^3	Trombudo Central、Agrolandia
	Braco do Trombudo River	9,900,000 m^3	Braco do Trombudo
	Rio das Pombas River	34,800,000 m^3	Pouso Redondo
	Taio River	6,000,000 m^3	Taio、Mirim Doce
Itajai do Sul	Perimbo River	7,000,000 m^3	Ituporanga、Petrolandia
Total		82.600,000 m^3	

Source: JICA Survey Team

Table 5.4.9 Proposed Small Dams for Flood Mitigation in Rio do Sul (25-year flood)

Location	Perimbo River (1 site)	Trombudo River (2 site)	Braco do Trombudo River (1 site)	Rio Das Pombas River (2 site)	Taio River (1 site)
Catchment Area	372 km^2	294 km^2	117 km^2	315 km^2	528 km^2
Total Volume	7,035,000 m^3	11,160,000 m^3	4,420,000 m^3	11,970,000 m^3	6,006,000 m^3

Source: JICA Survey Team

Table 5.4.10 Comparison of Flood Control Alternatives in Rio do Sul City for the 25-year Flood

Aspect	River Widening of Downstream Reaches	Dyke
Outline	To enlarge the current river channel by 10 m (see Figure 5.4.12) in the downstream reaches to lower the flood water level in Rio do Sul city.	To install 1.6 m high dykes on both banks to increase the current flow capacity in Rio do Sul city
Layout		
Project Cost	Construction cost and land acquisition cost: R$ 154,000,000. Although the construction cost is high, but the land acquisition cost for unpopulated area and project cost are smaller than the dykes in Rio do Sul city.	Construction cost and land acquisition cost: R$ 169,000,000. Although the construction cost is smaller than the river widening, but the land acquisition cost for the populated urban area and project cost are higher than the river widening.
Social Environmental Impact	Relatively smaller impacts, because the river widening is proposed in agricultural land	Large impacts, because of required relocation of many residences in the populated urban area
Natural Environmental Impact	No significant impacts, but the excavated earth materials shall be properly disposed	No significant impacts.
Influence on the Flood Condition	River widening might increase river velocity in Rio do Sul city and flood discharge in downstream reaches, but from the aspect of basin-wide flood control, flood discharge in the downstream cities is	Flood water level will increase because of the confined dykes in both sides, and it is necessary to be careful not to contribute to flooding in the stretches with sufficient flow capacity.

	substantially decreased by the effect of small dams and change of flood control dam operations.	
Evaluation	It is more advantageous than the dyke plan from the cost and social environmental impact points of view.	It is inferior to the river widening plan from the cost and social environmental impact points of view

Source: JICA Survey Team

e. Flood control measures in Ilhota City

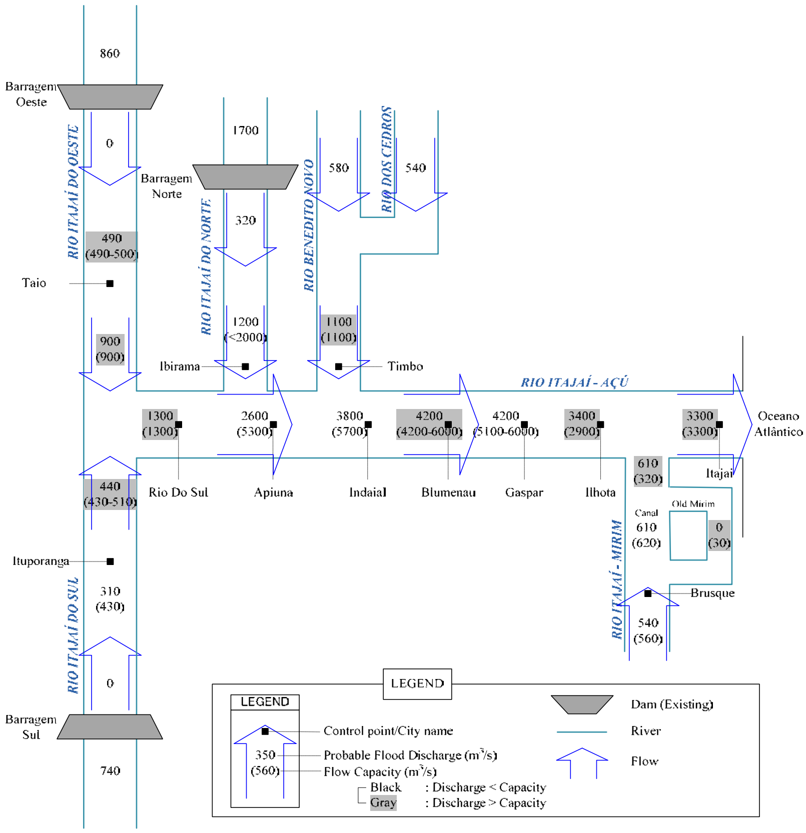
As the flood inundation area spreading from Itajai city (BR 101) to Gaspar city is unprotected as a natural retarding basin, ring dyke is proposed to protect Ilhota city from flood inundation.

f. Itajai Mirim River and Itajai River mainstream near Itajai city

Same as the plan for the 10-year flood, two flood gates with partial dyke was proposed in the Itajai Mirim River. The general features are shown in Table 5.4.4. As for the Itajai River mainstream, the lateral dyke plan is proposed compared to the floodway in view of the required cost and natural environmental impacts.

(4) Flood Discharge after the Proposed Plan

Figure 5.4.29 shows the distribution of 25-year flood discharges after implementation of the proposed flood control plan above.



Source: JICA Survey Team

Figure 5.4.29 Distribution of 25-year Flood Discharge and Flow Capacity by City for Flood Control Plan

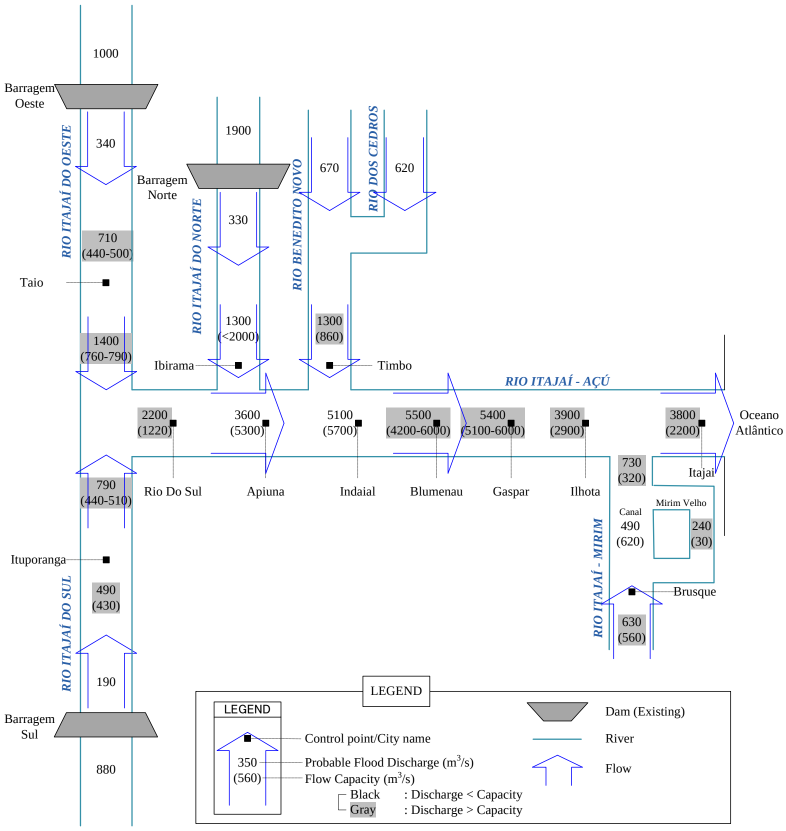
5.4.4 Protection for the 50-year Flood

(1) Flood Discharge and Flow Capacity

Figure 5.4.30 shows the distribution of 25-year flood discharge and flow capacity at major cities under the present condition. As indicated in the figure, t6he current flow capacities in almost all cities along the Itajai River having are smaller than the 50-year flood discharge.

(2) Basic Approach for Planning

Even though river basin measures such as water storage in paddy fields, basin storage (small dam), effective utilization of the existing flood control dams are provided, it is difficult in Rio do Sul, Taió, Timbó Blumenau, and Itajai cities to control the 50-year flood discharges smaller than the current flow capacity. Therefore, river improvement such as river widening, dyke and floodway are added to the alternatives for comparative study. In addition, a new flood control dam is considered to decrease the 50-year flood discharge in Brusque city.



Source: JICA Survey Team

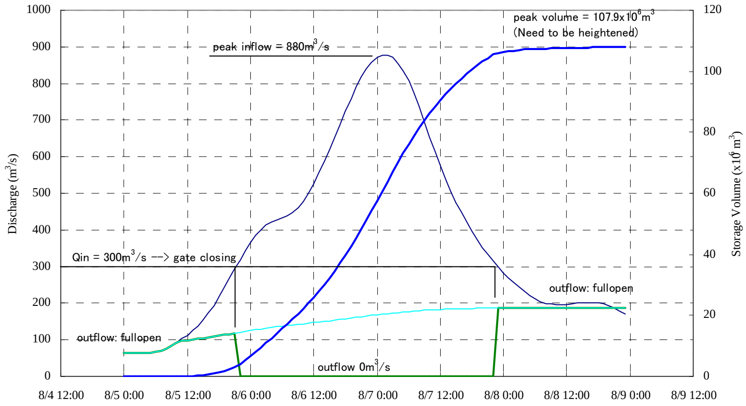
Figure 5.4.30 Distribution of 50-year Flood Discharge and Flow Capacity by City under Present Condition

(3) Flood Control Planning

Same as the proposed plan for the 25-year flood, water storage in paddy field, pre-releasing of two hydropower dams and 7 small dams are incorporated into the plan for the 50-year flood. Other flood control measures are outlined below.

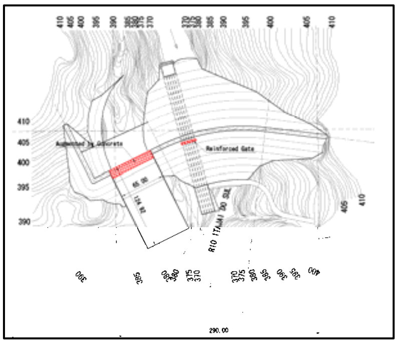
a. Heightening of the Sul dam

The crest of existing spillway is proposed to be heightened by 2 m. Due to the heightening, the storage capacity of the Sul dam would be increased to be 110 million m^3. As shown in Figure 5.4.31, the 50-year flood is able to be controlled with full opening of gates when the flood inflow exceeds 300 m^3/sec. The stored water volume will be 107.9 million m^3.



Source: JICA Survey Team

Figure 5.4.31 Proposed Dam Operation against the 50-year Flood at Sul Dam

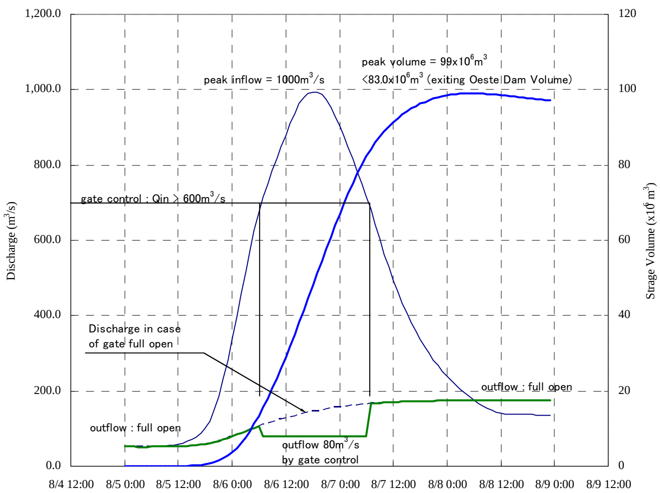


Source: JICA Survey Team

Figure 5.4.32 Diagram of Heightening Spillway of Sul Dam

b. Heightening of the Oeste dam

The Oeste dam is proposed to be heightened by 2 m. Due to the heightening, the storage capacity would be increased to be 99.3 million m^3. As shown in Figure 5.4.33, the 50-year flood is able to be controlled with full opening of gates when the flood inflow exceeds 700 m^3/sec. The stored water volume will be 99.0 million m^3.



Source: JICA Survey Team

Figure 5.4.33 Proposed Dam Operation against the 50-year Flood at Oeste Dam

c. Flood control measures in Rio do Sul, Taió, Timbó cities

Same as the 25-year flood control plan, two alternatives are compared for Rio do Sul, Taió, Timbó cities. Table 5.4.11 shows the comparative study result for Rio do Sul city. It is concluded that flood control by dyke is advantageous in view of the required cost. The same results were obtained for both Taió and Timbó cities.

Table 5.4.11 Comparison of Flood Control Alternatives in Rio do Sul City for the 50-year Flood

Aspect	River Widening of Downstream Reaches	Dyke
Outline	To enlarge the current river channel by 40 m (see Figure 5.4.12) in the downstream reaches to lower the flood water level in Rio do Sul city.	To install 2.2 m high dykes on both banks to increase the current flow capacity in Rio do Sul city
Project Cost	Construction cost and land acquisition cost: R$ 616,000,000. Due to huge excavation volume, the project cost will significantly increase compared to the dyke plan.	Construction cost and land acquisition cost: R$ 246,000,000. Although land condemnation in the urban area is necessary, the project cost will be far smaller than the river widening plan due to small work volume for embankment.
Evaluation	It is inferior to the dyke construction plan from the aspect of required cost.	It is more advantageous than the river widening plan from the aspect of required cost.

Source: JICA Survey Team

d. Flood control measures in Blumenau city

The 50-year discharge in Gaspar city will be reduced to be 4,900m^3/s with provision of the basin measures such as water storage in paddy fields, small dam, effective utilization of the existing flood control dams, and heightening of two flood control dams, which is smaller than the current flow capacity. Therefore, no measures might be necessary in Gaspar city.

On the other hand, although the 50-year discharge in Blumenau city will be reduced to be 4,790m^3/s with provision of the same basin measures above, the current flow capacity is still insufficient in around 600 m^3/s. Two alternatives; i) river improvement with provision of composite river section and ii) a new flood control dam in the Benedit River were compared. As summarized in Table 5.4.12, composite river section was proposed in Blumenau city.

Table 5.4.12 Comparison of Flood Control Alternatives in Blumenau City for the 50-year Flood

Aspect	Composite River Section	New Flood Control Dam
Outline	To widen the river channel with provision of composite section and adopt APP to high water channel (see Figure 5.3.2). The existing road on the left bank is heightened by approximately 1.0 m used as dyke.	To construct two new flood control dams; one is a 46 m high dam in the upstream Benedito River and the other is a 34 m high dam in the upstream Rio dos Cedros River
Project Cost	Construction cost and land acquisition cost: R$ 163,000,000. Although heightening cost of the existing road is very small, land condemnation cost in the urban area is high. However the project cost will be smaller than the dam construction plan.	Construction cost and land acquisition cost: R$ 205,000,000. The project cost is very high, including land acquisition cost.
Social Environmental Impact	Large impacts, because of the required relocation of many residences on the left bank in the urban area of Blumenau city.	Relatively small impacts with reallocation of several residences in the Rio dos Cedros River
Natural Environmental Impact	No significant impacts.	Because of the construction of new dam in two locations, there will be natural environmental impacts to the reservoir area to be inundated.
Flood Control Effect	The current flow capacity can be increased to the design discharge for the 50-year	Despite construction of two dams, the design discharge will be decreased to be 4400m^3/s,

	flood.	exceeding the flow capacity. Therefore, it is not completely solving the problem (it becomes necessary to combine with river improvement, requiring additionally more cost).
Evaluation	It is more advantageous than the new flood control dam plan in terms of the cost and the expected flood control effect.	It is inferior in relation to the cost. It is not capable to fully control the 50-year flood only by flood control dams.

Source: JICA Survey Team

e. Flood control measures in Ilohota city

Same as the 25-year flood control plan, ring dyke is proposed.

f. Itjai River mainstream (Itajai city)

Although the lateral dyke plan on the right bank is proposed for both the 10-year and 25-year flood protection levels, it becomes necessary to provide further the dyke in the urban area on the left bank in Nevegantes city, increasing the cost and associating significant impacts on the social environments. For the 50-year flood protection level, the plan of dyke on the both banks was compared to the plan of a new floodway as summarized in Table 5.4.13. As shown in this table, the floodway plan to the contrary was concluded advantageous because of less land acquisition cost in the urban area. Therefore, the floodway plan was proposed for the 50-year flood to protect Itajai city. The layout plan is shown in Figure 5.4.34.

Table 5.4.13 Comparison of Flood Control Alternatives in the Itajai River Mainstream for the 50-year Flood near Itajai City

Aspect	Dyke	Floodway
Outline	To install dykes both on the left bank (Itajaí city) and right bank (Navegantes city) along the main course of Itajaí River.	To install a new floodway immediately downstream of BR-101 to divert the discharge exceeding the flow capacity directly the sea in Navegantes city.
Project Cost	Construction cost: R$ 23,000,000 Land acquisition cost: R$ 449,000,000 Total cost: R$ 472,000,000 Due to huge land acquisition cost in the urban area, the project cost becomes more expensive than the floodway plan.	Construction cost: R$ 25,000,000 Land acquisition cost: R$ 425,000,000 Total cost: R$ 450,000,000 Although the construction cost is high, the land acquisition cost is smaller. Due to this, the floodway plan is more advantageous than the dyke plan.
Social Environmental Impact	Significant impacts, because of the required relocation of many residences on both banks in the urban areas of two cities.	Significant impacts, because of separation of Navegantes city by the floodway.
Natural Environmental Impact	No significant impacts.	Environmental impacts shall be subject to assessment on sediment deposition at the floodway outlet, changes of coastal line, and see water intrusion along the floodway.
Evaluation	It is inferior to the floodway plan from the cost and social environmental impacts point of view.	It is advantageous from the cost and social environmental impacts point of view. However, it is necessary to assess various natural environmental impacts in detail.

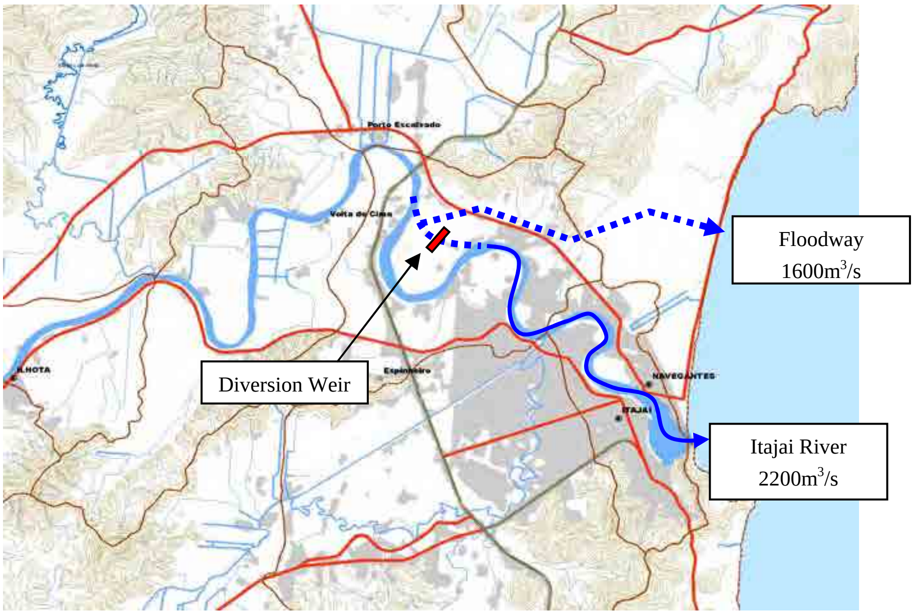
Source: JICA Survey Team

Table 5.4.14 Outline of Floodway for 50-year flood

Facilities	Item	Specification	Remarks
Floodway	Extention of channel	9.0 km	Except jetty (1.0 km)
	Gradient of river bed	1/6000	
	Width of river bed	50.0 m	
	Design depth	11.5 m	

	Slope of river bank	1:2.0	
Weir (with gates)	Total Length	250 m	
	Height of Weir	27 m	Except gate control house
	Gate number	8gates	
	Gate size	W20m x H9m	
New Itajai River	Extention of channel	1.7km	
	Width of river bed	150m～190m	
Bridge	Bridge number	6 bridges	Crossings of existing roads

Source: JICA Survey Team

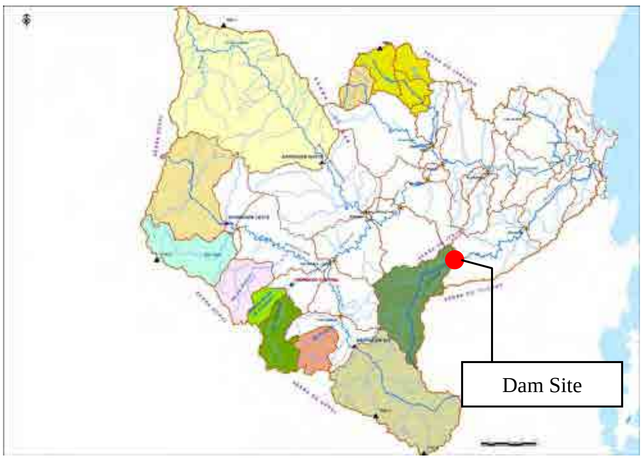


Source: JICA Survey Team

Figure 5.4.34 Layout Plan of Floodway and Design Flood Discharge

f. Itajai Mirim River and Itajai River mainstream near Itajai city

Same as the 25-year flood level, two flood gates with partial dyke was proposed in the Itajai Mirim River. The general features are shown in Table 5.4.4. However, the 50-year flood discharge might overflow the Canal due to the concentration of flood water by the closure of flood gates. Further, the current flow capacity in Brusque city is insufficient to pass the 50-year flood. To solve these problems simultaneously, a flood control dam is planned in the upstream Itajaí Mirim River (mountainous area in Botuverá city) to decrease the 50-year discharges in Brusque city and in the Canal in Itajaí city.



Source: JICA Survey Team

Figure 5.4.35 Proposed Site of New Flood Control Dam in Upper Itajai Mirim River

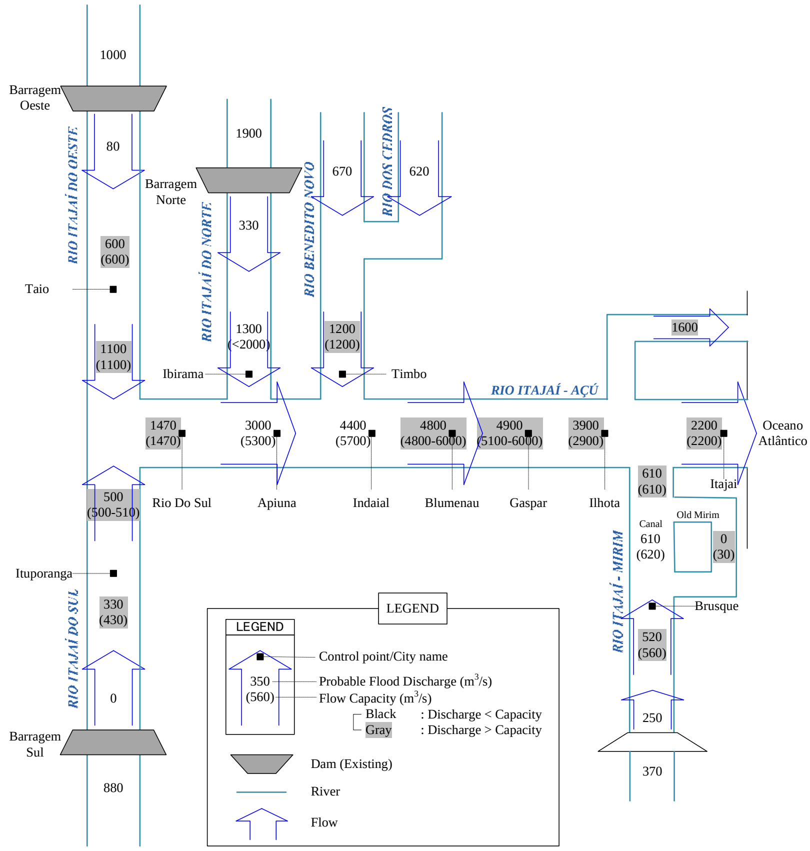
Table 5.4.15 General Features of New Flood Control Dam in the Itajaí Mirim River for 50-year Flood

Plan Item	Feature	Remarks
Catchment area	630 km^2	Upstream river of Botuvera city
Maximum inflow discharge	370 m^3/s	
Maximum outflow discharge	250 m^3/s	Regulating discharge: 120m^3/s
Flood control volume	15,700,000m^3	
Dam height	34.2 m	

Source: JICA Survey Team

(4) Flood Discharge after the Proposed Plan

Figure 5.4.36 shows the distribution of 50-year flood discharges after implementation of the proposed flood control plan above.



Source: JICA Survey Team

Figure 5.4.36 Distribution of 50-year Flood Discharge and Flow Capacity by City for Flood Control Plan

5.4.5 Flood Control Measures in Urban Rivers (Garcia and Velha Rivers)

(1) Flood Discharge and Flow Capacity

The Garcia and Velha Rivers flow down in the urban area of Blumenau city and join the Itajaí River. These rivers are small tributary rivers having drainage areas of 163.3 km^2 for the Garcia River and 52.9 km^2 for the Velha River. Riverbed slope of these rivers is steep compared to that of Itajai River (approximately 1/200 to 1/600 in the Garcia River). In recent years, the “flush flood” has been highlighted in such urban rivers. The flush flood is sudden and violent rising of river water level and runoff caused by localized torrential rainfall, of which mud flow containing some sediments and debris flow are included.

According to various interviews in cities as Blumenau, the flush flood caused in the November 2008 flood brought about huge damages including much sediments caused by slope collapses and landslides, which were triggered by localized heavy rainfall over the fully saturated ground with the antecedent rainfalls. It is generally said that such debris and sediment flows are very difficult to be controlled by means of conventional structural measures. In this respect, introduction of flush flood alert system is desirable giving top priority to human lives. This system is proposed in the succeeding Supporting Report C.

As many residences have been built near the banks of Garcia and Velha Rivers, the cross section of river channel are small with insufficient flow capacity, causing frequent flooding by normal flood (however, a sharp flood because of narrow watershed and steep river gradient). In this section, conventional river channel improvement plan was studied based on the evaluation of various water levels by probable floods.

(2) Probable Flood Discharges

Although the duration of design rainfall was set at 4 days for flood runoff analysis to estimate probable flood discharges along the mainstream of Itajai River and its main tributaries considering the characteristics of rainfall of past flood events, probable flood discharges for both the Garcia and Velha Rivers were estimated through flood runoff analysis based on the results of frequency analysis on 1-day rainfall in Blumenau city, where localized heavy rainfall with short duration is predominant for urban rivers as mentioned above. Table 5.4.16 summarizes the estimated probable flood discharges together with probable 1-day rainfalls.

Table 5.4.16 Probable Rainfalls and Discharges in Garcia and Velha Rivers

Flood Level	5-year	10-year	25-year	50-year
Probable 1-day Rainfall	113 mm	135 mm	168 mm	190 mm
Garcia River	320 m^3/s	390 m^3/s	490 m^3/s	550 m^3/s
Velha River	140 m^3/s	170 m^3/s	210 m^3/s	240 m^3/s

Source: JICA Survey Team

(3) Proposed Flood Control Measures

As for the flood control measures for both rivers, water storage in reservoirs is almost impossible because of many residential houses along the rivers and existence of the National Park therein. Besides, absence of flat lands makes it difficult to provide retarding basins. Moreover, due to the backwater from the Itajai River, it might be difficult to increase the current flow capacity by widening of the Garcia River near the confluence with the Itajai River. Therefore, embankment in the river stretches with insufficient bank elevation is proposed to increase the flow capacity.

On the other hand, embankment is not appropriate in the middle reaches of both rivers, where both rivers flow down in hilly area with relatively steep gradient and meanderings, considering the existence of some flow velocity and water colliding portions of the river channel. Therefore, expansion of the river area is proposed by adopting APP in such river stretches, forming the high water channel by slightly lowering the bank elevation by means of excavation. Table 5.4.17 presents the proposed measures by flood protection level. The study details are described in the Supporting Report on Flood Mitigation Plan.

Table 5.4.17 List of Flood Controls for Garcia and Velha Rivers

River	River Section	Method	Bank Elevation (EL. m)	Dyke Height/APP Width (m)			
				5-year	10-year	25-year	50-year
Garcia River	GA01	Dyke	-	-	-	-	1.0 – 1.5
	GA02	Dyke	-	-	-	1.5 – 2.0	2.5 – 3.0

River	**River Section**	**Method**	**Bank Elevation (EL. m)**	**Dyke Height/APP Width (m)**			
				5-year	**10-year**	**25-year**	**50-year**
	GA03	Dyke	-	-	-	1.0 – 1.5	2.0 – 2.5
	GA06	APP	29.0		15	20	25
	GA07	APP	60.0	20	30	45	55
Velha River	VE04	APP	13.5	5	10	20	35
	VE05	APP	15.0	5	25	30	30

Source: JICA Survey Team

Table 5.4.18 Calculated Water Level in Garcia River

Section	Distance (km)	Ground Elevation (m)			Water Elevation (m)			
		Riverbed	Leftbank	Rightbank	5-year	10-year	25-year	50-year
GA01	0.00	-0.17	12.48	11.14	8.03	9.04	10.58	11.57
GA02	0.55	0.89	13.57	9.70	8.27	9.26	10.78	11.76
GA03	1.25	1.87	10.20	10.33	8.38	9.33	10.87	11.80
GA04	1.51	2.06	16.81	12.44	8.51	9.42	10.95	11.84
GA05	2.66	4.07	13.34	15.27	9.96	10.64	11.69	12.50
GA06	9.35	27.32	31.29	31.29	31.12	31.61	31.93	32.12
GA07	14.61	58.83	61.95	66.09	62.54	62.77	63.10	63.26

Remark: highlighted water levels are higher than riverbank elevation
Source: JICA Survey Team

Table 5.4.19 Calculated Water Level in Velha River

Section	Distance (km)	Ground Elevation (m)			Water Elevation (m)			
		Riverbed	Leftbank	Rightbank	5-year	10-year	25-year	50-year
VE01	0.00	0.35	20.53	15.10	8.32	9.32	10.74	11.84
VE02	0.44	2.12	9.80	11.08	8.36	9.35	10.77	11.86
VE03	1.74	4.07	22.76	11.83	8.97	9.76	10.92	11.94
VE04	5.04	11.33	15.43	15.54	15.86	15.96	16.09	16.22
VE05	5.53	13.07	16.91	19.64	17.31	17.49	17.69	17.77

Remark: highlighted water levels are higher than riverbank elevation
Source: JICA Survey Team

CHAPTER 6 SELECTION OF PRIORITY PROJECTS FOR THE FEASIBILITY STUDY

6.1 Selection of Priority Projects for Flood Mitigation Measures

6.1.1 Background for Selection of Flood Safety Level

The first phase of the current Preparatory Survey ended on 18th December 2010, with the creation of the Disaster Mitigation Master Plan and submission of the Interim Report. On the 10th and 13th December 2010, presentations were made to the Santa Catarina State Government and the priority projects were discussed with the financing possibilities by the JICA.

The flood safety level, which is the focus of the Master Plan for prevention and mitigation measures for flood disasters, is generally represented in terms of the occurrence probability and return period by years for floods. The flood safety level in Brazil is not established according to the importance of the river and the management of water resources, including flood control. It would be established by the committees of each basin, in accordance with law No. 9,433 (January 8, 1997). In the objective of the current Survey, it is mentioned that the team will create three protection levels of flood plans. In other words, measures for a flood to be occurred once in 5, 10 and 25 years (hereinafter call the “25-year flood). However, the 50-year flood study has also been solicited as a part of the flood plan study.

After an exchange of opinions and interviews with various government institutions, universities and the Itajai River Basin Committee, the regions for flood prevention were selected and the Master Plan was formulated with the goal for each flood plan: 5, 10, 25 and 50-year flood.

Between the 16th and 18th of November 2010, the State Government held a public audience (Itajaí, Blumenau and Rio do Sul). On the 29th November 2010, the counterpart meeting was held for the commission of government representatives to plan the execution of the 50-year flood plan as the final goal in the Itajaí River basin.

6.1.2 Summary of the Flood Mitigation Plan for 50-year Safety Level

(1) Resolution No. 40 of Itajaí River Basin Committee

Basic strategy for formulating a flood mitigation master plan (described in Section 4.3) and the selected regions for protection against flooding (described in Section 5.2) were explained to the Itajaí River Basin Committee on July 28th 2010, as well as to the Technical Chamber for Disaster Prevention on August 11th. And finally, it was the subject of discussion at the Itajaí River Basin Committee general assembly on September 23rd. It was approved in Resolution No. 40 on October 7th 2010.

(2) Flood mitigation plan for the 50-year flood

Under the 50-year flood level, main cities on the margins of the Itajaí River and the Itajaí Mirim River would be inundated. They are Taío, Rio do Sul, Ituporanga, Timbó Blumenau, Gaspar, Ilhota, Itajaí and Brusque cities. The proposed main measures of 50-year flood mitigation plan are as follows:

i) As the basin storage measures, water storage in paddy fields (total of 22,000 ha) and basin storage (small dams) in micro-basin along the upper and middle reaches of the Itajai River (total of 41 million m^3), heightening the Sul and Oeste dams (2 meters each) and the pre-releasing of water in reservoir at the CELESC hydroelectric dams (4.9 million m^3) shall be implemented.

ii) As there is limitation of the basin storage measures for flood mitigation, it is necessary to provide dykes to increase the current flow capacity in Rio do Sul, Taió and Timbó cities. As well as in Blumenau city, it is necessary to utilize the permanent preservation areas (APP) on the river margins as the flood water channel. This margin can be utilized as park in usual time. The road along the river can work as dyke when flood comes.

iii) In the city of Itajaí, identical measures will be adopted through installation of flood gates and dykes on the Itajaí Mirim River. However, on the Itajaí River a floodway will be built (from the downstream side of the BR-101 to Navegantes beach) which is economically advantageous compared to the construction of dykes.

iv) On the Itajaí Mirim River, including Brusque city, the flow capacity is insufficient. It will be necessary to build new flood control dam on the upstream of Brusque city to solve these problems (flood control volume of 15.7 million m^3).

v) In the regions of Garcia and Velha streams which flow into the city of Blumenau, widening of river channel by excavation was proposed in the APP. At the confluence with the Itajaí River, dykes will be provided to avoid back water effect from the Itajaí River.

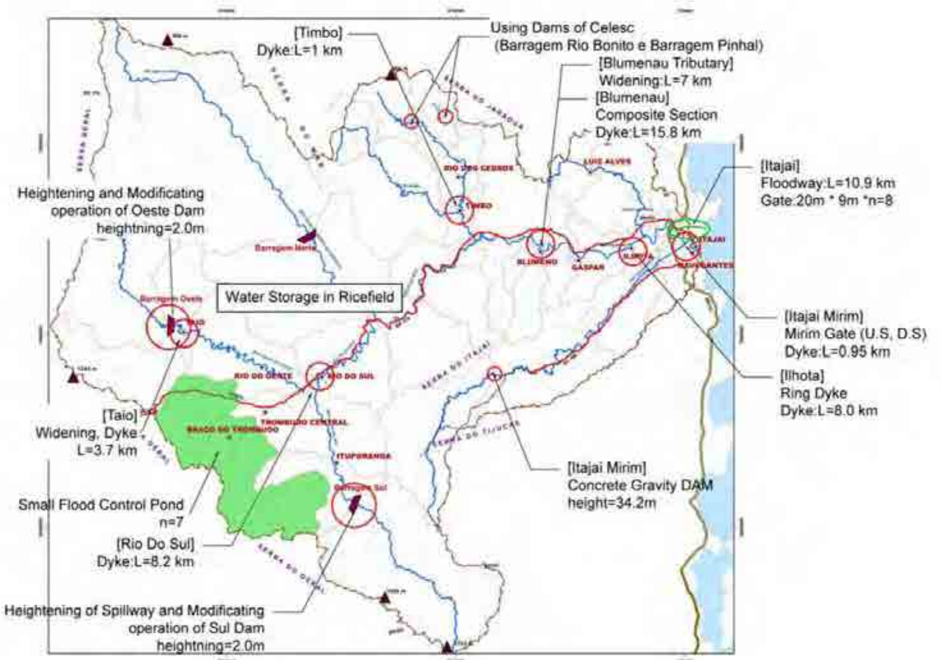
vi) However, with a flush flood that includes landslides is difficult to adopt conventional flood control measures. So, an early warning system for landslides and flush flood will be introduced, giving priority to saving human life.

Below, the project costs are demonstrated and a location map of the flood mitigation plan for 50-year flood is outlined.

Table 6.1.1 Project Cost for the 50-year Flood Mitigation Plan

Plan for Measures	Cost ($R\$10^3$)	Land Acquisition & Relocation ($R\$10^3$)
Rain water containment in rice fields (22,000 ha)	33,000	-
Heightening of dams (Oeste and Sul dam)	33,000	-
Basin Storage (Small dams) (7 places)	211,000	112,100 (53%)
Flood gates in the old Itajaí Mirim canal (2 places) [1]	44,000	-
Floodway in Itajai and Navegantes cities: 10.9 km	593,000	29,400 (5%)
New flood control dam in Itajaí Mirim river (1 dam)	95,000	15,900 (17%)
Improvement of river channel in Taió: 3.7 km	114,000	54,000 (47%)
Improvement of river channel in Rio do Sul: 8.2 km	268,000	205,200 (77%)
Improvement of river channel in Timbó: 1.0 km	22,000	13,400 (61%)
Improvement of Itajaí River channel in Blumenau: 15.8 km	267,000	231,000 (88%)
Improvement of tributary channels in Blumenau: 7.0 km	196,000	171,500 (88%)
Ring dyke in Ilhota: 8 km	70,000	61,500 (88%)
Improvement of old Itajaí Mirim River channel: 0.95 km	50,000	32,200 (64%)
Total	**1,996,000**	**926,500 (46%)**

Source: JICA Survey Team



Source: JICA Survey Team

Figure 6.1.1 Location Map of the Mitigation Plan for 50-year Flood

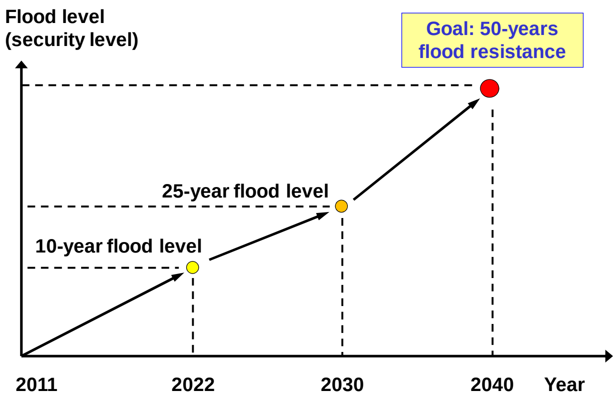
(3) Summary of the plan for flood forecasting warning system (FFWS)

Currently the FFWS is operated by FURB/CEOPS and its observation network is composed of 15 stations with rainfall and water level gauges and 2 more stations with only rainfall gauges. With the intention to improve the accuracy of flood forecast, 13 more stations with rainfall and water level gauges as well as closed circuit cameras (CCTV) in Rio do Sul, Blumenau and Itajaí cities are proposed to strengthen the current FFWS. The implementation cost was estimated at around R$ 4 million.

6.1.3 Step-wise Implementation of Mitigation Measures for 50-year Flood

(1) Implementation strategy with the establishment of the priority level

To achieve the safety level for 50-year flood in the Itajaí River basin, a lot of resources such as around R$ 2 billion and long period of implementation will be necessary. However, it is important to implement step-wise gradually increasing safety level according to priority level in combination with the non-structural measures (improvement of the existing FFWS)



Source: JICA Survey Team

Figure 6.1.2 Image of Stage-wise Implementation of Flood Mitigation Plan

(2) Selection of priority projects for the first phase

The target flood safety level for the first phase highly depends on the budget to be allocated by the State Government. However, it is possible to adopt the flood plan with a safety level for around the 10-year flood level as illustrated in Figure 6.1.2.

Tables 6.1.2 and 6.1.3 summarize the components and general features of the plans for respective flood safety levels. It is important to note that respective plans were formulated independently. Especially, for both the 10 and 25-year flood plans, dyke construction on the right margin of the Itajaí River was proposed. However, for the 50-year flood plan a floodway was proposed instead of dykes. The construction of dykes on the right bank will not be implemented to avoid future conflict in the stage-wise implementation of the project. On the other hand, from the viewpoint of flood control, the floodway that is being proposed for the 50-year flood plan also effects the 5, 10 and 25-year plans and the construction of the dyke becomes unnecessary. In conclusion, the floodway is proposed in the 2nd phase of implementation.

As presented in Table 6.1.3, components of each plan are divided into two large categories of measures as basin storage and river improvement to better understanding for the Itajaí River Basin Committee and communities in the basin. The “basin storage” is water storage measures in the micro-basin and the “river improvement” is measures to increase the flow capacity by improvement of river channel.

Table 6.1.2 Flood Mitigation Plans by Safety Level

Measures	Projects	5-years	10-years	25-years	50-years
Basin Storage Measures	Water storage in paddy fields	✓	✓	✓	✓
	Basin Storage (Small dams)	✓	✓	✓	✓
	Heightening of the dam (Oeste dam)			✓	✓
	Heightening of the spillway (Sul dam)				✓
	New flood control dam (Itajaí Mirim River)				✓
	Improve operation of Oeste and Sul dams	✓	✓	✓	✓
	Preventive discharge at the hydro-electric generation dams (2 dams)		✓	✓	✓
River Improvement Measures	Itajaí River, Rio do Sul city stretch			✓	✓
	Itajaí do Oeste River, Taió city stretch			✓	✓
	Benedito River, Timbó city stretch			✓	✓
	Itajaí River, Blumenau city stretch				✓
	Ilhota city, ring dyke			✓	✓
	Garcia and Velha Rivers, in Blumenau city	✓	✓	✓	✓
	Itajaí River improvement, in Itajaí city		✓	✓	
	Floodway in Itajaí and Navegantes cities				✓
	Floodgates and river improvements for the Itajaí Mirim River in Itajaí city	✓	✓	✓	✓

Source: JICA Survey Team

Table 6.1.3 Components of Flood Mitigation Plans by Safety Level

Measures	Projects	5 years	10 years	25 years	50 years
Basin Storage Measures	Containment of water in rice fields	22,000 ha	22,000 ha	22,000 ha	22,000 ha
	Basin Storage (Small dams)	2 units	5 units	7 units	7 units
	Heightening of the dam (Oeste dam)			2 m	2 m
	Heightening of the spillway (Sul dam)				2 m
	New flood control dam (Itajaí Mirim river)				1 unit
	Improve operation and functioning of dams (2 dams)	2 dams	2 dams	2 dams	2 dams
	Preventive discharge at the hydro-electric generation dams (2 dams)		2 dams	2 dams	2 dams
River Improvement Measures	Itajaí river, Rio do Sul city stretch			Excavation 10.3 km	Dykes 8.1 km
	Itajaí de Oeste river, Taió city stretch			Excavation 3.7 km	Dykes 3.7 km
	Benedito river, Timbó city stretch			Excavation 1 km	Dykes 1 km
	Itajaí river, Blumenau city stretch				Dykes 15.8 km
	Ilhota city, ring dykes			8 m	8 km
	Garcia and Velha streams, in Blumenau city	Excavation /Dyke 7.0 km	Excavation /Dyke 7.0 km	Excavation /Dyke 7.0 km	Excavation /Dyke 7.0 km
	Itajaí river in the Itajaí city		Dykes 12.8 km	Dykes 12.8 km	
	Floodway in Itajaí/Navegantes cities				10.9km
	Floodgates and flow improvements for the Itajaí Mirim river in Itajaí city	2 floodgates and 0.95 km dykes	2 floodgates and 0.95 km dykes	2 floodgates and 0.95 km dykes	2 floodgates and 0.95 km dykes

Source: JICA Survey Team

For choosing the priority projects for the first phase, the following should be considered:

i) It is important for making consensus for implementation to incorporate mind of Itajai River Basin Committee, which is responsible to suggest for water resources development plans and the water resources management in the Itajai River. As the development of water storage in paddy fields and basin storage (small dams) in micro-basin is proposed in the Water Resource Management Master Plan, this agrees with the intention of Itajai River Basin Committee. Therefore, basin storage measures have high priority.

ii) The goal of flood safety level is for the 50-year flood and thus the first phase of implementation is of provisional to the goal. It takes long time to realize the target safety level, and therefore the flood protection level is forced to be low until realization of the master plan for the 50-year flood. In this sense, strengthening of the existing flood forecasting and warning system (FFWS) is given high priority to alleviate flood damages and to avoid human losses by floods.

iii) The cities where the flood protection measure is urgently necessary are: Rio do Sul, Blumenau along two urban streams (Garcia and Velha Rivers) and Itajaí.

iv) Heightening of the existing flood control dams will become necessary for the 25-year flood mitigation plan. Both dams are able to control smaller with full closure of the gates. However, this gate operation increases the risk of overflowing of the spillway. Heightening of the dams will be necessary to reduce risk of overflowing in the first phase of implementation.

v) The floodway will solve flooding problems in Itajaí city drastically. However, it is necessary to evaluate the diverse problems such as sedimentation within the floodway channel and on the Navegantes beach and environmental degradation caused by salt intrusion. The urgency level is high, although, more time is necessary to analyze the solutions from environmental aspect. And it is necessary to consider the usage of the floodway in usual condition.

vi) In the old Itajaí Mirim River, the current flow capacity is insufficent. Even with smaller floods than the 5-year flood, flooding occurs frequently. So, the urgency level for adoption of flood mitigation measure is high.

vii) The Garcia and Velha Rivers in Blumenau city are typical urban rivers with high residential concentrations on their margins. The cost of land acquisition and relocation of the existing population represents 97% of the total river improvement costs for the 5 year flood mitigation plan and 89% of the costs for the 10-year flood mitigation plan. Although the urgency level is high, there is a need for time to negotiate and make a consensus with the residence for removal as well as to find a proper location for relocation.

viii) As for the basin storage (small dam), dam sites were roughly identified based on the available topographical maps with a scale of 1:50,000 (contour interval is 20 m), because the on-going topographical mapping of 1: 10,000 scale by the State Government has been seriously delayed. Although 1:10,000 scale topographical maps are necessary for feasibility design, it might be impossible to use these maps in the second phase for feasibility study due to serious delay of mapping. Therefore, small-scale dam will not be included in the second phase of the current Preparatory Survey.

Based on the above in view, the priority projects for the second phase for feasibility study are recommended as follows:

- Water storage in paddy fields
- Change of the current dam operation method and heightening of the dam (2 dams)
- Utilization of the existing hydropower generation dams for flood control (2 dams)
- Strengthening the existing flood forecasting and warning system (FFWS)
- Installation of floodgates and improving Itajaí Mirim River in Itajaí city

The basin storage (small dams) development which was proposed in the Water Resource Management Master Plan as watershed management project is recommended to be implemented under the responsibility of Itajai River Basin Committee as separate project in parallel with the proposed first phase project of flood mitigation plan (in a meeting on December 7th 2010, the Committee agreed upon these terms). In case the Committee's project is delayed, it is recommended that the small-scale dam development shall be in the second phase of implementation.

6.1.4 Evaluation of the Proposed Flood Mitigation Plan from the Aspects on Environmental and Social Considerations

The evaluation has been made in aspect of implementation cost, social urgent level (which means the inundation frequency of the object area in each measure), environmental and social impacts, negative effect for downstream of the object area, technical difficulty, the time to take positive effect and difficulty for making consensus. The evaluation criteria are as follows; A: easy or negligible negative impact, B: a little difficult or a little negative impact and C: quite difficult or big negative impact. The comprehensive evaluation has done after the first evaluation with score as follows; AA the highest priority or only with small negative impact, A: higher priority or with small negative impact and B: suppose to implement in second phase after solving existing difficulties.

The evaluation and comprehensive evaluation table are as below.

Table-16.1.4 Evaluation of protection measures（1/2）

Evaluation Components	Rain water containing in rice fields	Improvement of operation and heightening dams	Small-scale dams	Flood gate in old Itajai Mirim river	Floodway in Itajai/Navegantes	New flood control dam in Itajai Mirim river
Implementation cost (R$)	33,000 (A)	33,000 (A)	211,000 (B)	44,000 (A)	593,000 (C)	95,000 (B)
Security level of flood	5-year	10-year	5-year	5-year	5-year (without dykes)	50-year
Social urgent level by flood security level	(A) It should be implement earlier although its effect is less than others.	(A) The inundation frequency in Rio do Sul is high and the risk of inundation in Taio is high because of deficiency of dam capacity. The priority of this measure is quite high.	(A) The inundation frequency in Rio do Sul is high, it is urgent to increasing security level. Its water can also be used for irrigation.	(A) The inundation frequency along the old Itajai Mirim canal is quite high, it is urgent measure.	(A) This is the most effective way to protect Itajai city which is the most economically important in the basin. Its necessity and urgent level is quite high.	(C) The urgent level is low because it is not necessary to make until 25-year flood.
Social impacts	(A) It affects to agricultural land, when only flood comes.	(A) There are only few impacts for people who lives near to the dams accompanied by dam heightening.	(B) It would be necessary only a few resettlement when the dam uses as agricultural water.	(A) The impact is negligible.	(C) The social impacts are very big because of massive land acquisition, resettlement, dividing social community and construction of new bridge.	(C) This measure is necessary some land acquisitions and resettlements because this is the new installing dam.
Natural environmental impacts	(A) The impact is negligible.	(A) Same as left one.	(B) There is little impact of ecosystem because of damming.	(A) The impact is negligible because this measure is for old canal only.	(B) There are many problems which have to do preliminary study about balance of sedimentation, salination, etc.	(B) It can be minimize negative impacts of ecosystem and landscape because the purpose of this dam is only for flood control.
Negative impacts for downstream	(A) Negative impacts will not appear because it is basin storage measure.	(A) Same as left one.	(A) Same as left one.	(A) The impact is negligible because this is the measure for Itajai city, there is no more downstream.	(A) Same as left one.	(A) Negative impacts will not appear because it is basin storage measure.
Technical difficulty	(A) There is no difficulty in implementation.	(A) Same as left one.	(A) Same as left one.	(A) Same as left one.	(B) There are many problems which have to do preliminary study about balance of sedimentation, salination, etc.	(A) There is no difficulty in implementation.
Time to take positive effect	(A) The effectiveness comes according to implementing area although the target area is vast.	(A) The construction period is not so long, but there is no effect before complete the construction.	(A) It takes time to find an appropriate site to fulfill agricultural needs.	(A) The construction period is not so long, but there is no effect before complete the construction.	(B) It takes for a long time to take environmental license, and the construction period will be for 5, 6 years. The effect of this measure will not appear before completion.	(B) It can take a long time to environmental license and construction period is 3-4 years. The effect of this measure will not appear before completion.
Difficulty for making consensus	(A) The demand by relative organization high because this measure comes from CRAVIL's proposal.	(A) There are few contrary opinion and negative effect is small.	(B) This is the dam although its scale is small, it takes time to make consensus.	(A) There are few contrary opinion and negative effect is small.	(B) There are a lot of unclear points of environment impact, it is necessary to have time to study its precise impact.	(C) It can take a long time to make consensus because Itajai committee is opposed for every intersect construction in river.
Priority for F/S 1st phase (Comprehensive evaluation)	(AA) The priority for 1st phase is very high, once it is necessary to analyze investment effect.	(AA) The priority for 1st phase is very high resulted by comprehensive consideration.	(A) It was impossible to find the site for lack of precise map, and it takes time to make consensus for land acquisition and resettlement after the site would be fixed.	(AA) The priority for 1st phase is very high resulted by comprehensive consideration.	(B) The effect for reducing inundation is clear, on the other hand, it takes long time to make consensus and take environmental license. Therefore, this measure should be implement in 2nd phase.	(B) The urgent level is low and it takes time to ready for construction, therefore, this measure should be in 2nd phase.

Legend: A: No negative impact / easy
B: A few negative impact / difficult to some extent
C: Big negative impact / very difficult

Comprehensive evaluation: AA: The most priority measure with less negative impact
A: The priority level is high although with a few negative impact
B: It would be implemented after the difficulties solved

Source: JICA Study Team

Table-16.1.4 Evaluation of protection measures（2/2）

Evaluation Components	Improvement of river channel in Taió	Improvement of river channel in Rio do Sul	Improvement of river channel in Timbó	Improvement of Itajaí-açu river channel in Blumenau	Ring dykes in Ilhota	Improvement of old Itajaí Mirim river channel	Improvement of stream channels in Blumenau
Implementation cost (R$)	114,000 (B)	268,000 (B)	22,000 (A)	267,000 (B)	70,000 (A)	50,000 (A)	169,000 (B)
Security level of flood	25-year	25-year	25-year	50-year	25-year	5-year	5-year
Social urgent level by flood security level	(B) This measure is not urgent because Taio is small city and it is not necessary until 10-year flood.	(B) It is not urgent because this measure is not necessary until 10-year flood.	(B) This measure is not urgent because Taio is small city and it is not necessary until 10-year flood.	(C) This measure is not necessary until 25-year flood. The urgent level is to some extent because Blumenau is big city.	(B) It is not urgent because this measure is not necessary until 10-year flood.	(A) The inundation of Itajai city is happen less than 5-year flood's rain, therefore, this measure is urgent.	(A) Upper stream area of these rivers is more critical from 10-year floods. In 25-year flood, the rest of basin would be inundated. The urgent level is high.
Social impacts	(B) This measure includes a few resettlement.	(C) This measure is widening river channel, it would need many land acquisition, resettlement and rebuilding of bridge.	(C) This measure includes some land acquisition and resettlement although it is small city.	(C) The most important improvement site is the center of the city, the impact is not only land acquisition and resettlement but also relocate hotels and shops.	(B) There are impacts of dividing society and land acquisition, in total impact is small.	(A) There is no impact for house although the project area is in residential area.	(C) The impact is quite big because this measure is widening river in residential area, it has many land acquisitions and resettlements.
Natural environmental impacts	(B) There are a negative impact of turbid water only in construction phase.	(A) This measure is not included excavation but widening river and constructing dyke. Negative environment impact is just a few.	(A) This measure is not included excavation but widening river and constructing dyke. Negative environment impact is just a few.	(B) The environment impact is quite big because the construction would be in the center of the city.	(A) There are only impacts by construction.	(A) The impact is small because this is in the old canal.	(B) In the construction phase, construction of dyke would be temporarily with noises in residential area.
Negative impacts for downstream	(C) This measure can make water flow increasing. The storage measure and measures in downstream have to do prior to this measure.	(C) Same as left one.	(C) Same as left one.	(C) Same as left one.	(A) Floodplain would be conserved with ring dyke, therefore, there is no impacts in downstream.	(A) The impact is negligible because this is the measure for Itajai city, there is no more downstream. There is big time difference of peak time with Itajai-açu river.	(A) The flow amount to Itajai-açu river would be increased, but only the small impact would appear because here is difference of peak time.
Technical difficulty	(A) There is no difficulty in implementation.	(A) Same as left one.	(A) Same as left one.	(A) Same as left one.	(A) Same as left one.	(A) Same as left one.	(A) Same as left one.
Time to take positive effect	(B) The effect would be appear according to complete construction, although it takes time to take environmental license.	(B) Same as left one.	(B) Same as left one.	(B) Same as left one.	(B) Same as left one.	(A) The construction period is not so long, but there is no effect before complete the construction.	(B) The effect would be appear according to complete construction, although it takes time to take environmental license.
Difficulty for making consensus	(C) Itajai committee and residents both have strong feeling of resistance to excavation and dyke.	(C) Same as left one.	(C) Same as left one.	(C) Itajai committee is positive for this measure, however, it is necessary and takes time to make consensus with residents.	(B) It is necessary to explain well to residents and make consensus.	(A) There are few contrary opinion and negative effect is small.	(C) Itajai committee is positive for this measure, however, it is necessary and takes time to make consensus with residents.
Priority for F/S 1st phase (Comprehensive evaluation)	(B) This measure is less priority than basin storage and river improvement in downstream because there is bottleneck in Itajai. It can take time to make consensus, therefore, this measure should be in 2nd phase.	(B) It is not urgent and it can take time to make consensus, therefore, this measure should be in 2nd phase.	(B) Same as left one.	(B) The urgent level is not high and basin storage and the measures of downstream should be done earlier.	(B) There is no problem except making consensus, but the urgent level is low.	(AA) The priority for 1st phase is very high resulted by comprehensive consideration.	(B) It can take time to make consensus with residents, therefore, it should be in 2nd phase although it is urgent measure.

Legend: A: No negative impact / easy
B: A few negative impact / difficult to some extent
C: Big negative impact / very difficult

Comprehensive evaluation: AA: The most priority measure with less negative impact
A: The priority level is high although with a few negative impact
B: It would be implemented after the difficulties solved

Source: JICA Study Team

6.2 Selection of Priority Projects for Sediment Disaster Prevention

6.2.1 Structural Measures for Sediment Disaster Prevention

Totally, 67 locations were selected for stabilization measures on roadside slopes. The stabilization measures on the slopes were planned to prevent blocking the roadways during a rain storm like the one in November 2008 (60-year rainfall). The total project cost for implementation of these measures for roadside slope stabilization was estimated at R$ 54 million and was classified into two large groups in terms of the risk level (annual potential loss) as demonstrated in the table below.

Table 6.2.1 Project Costs for Selected Structural Measures for Sediment Disaster Prevention

Classified by Risk Level	Number of Locations	Project Cost in R$ (x10^3)
Risk Level: Large Annual potential loss > R$ 500,000	13	18,650
Risk Level: Medium Annual potential loss between: R$ 50,000 and R$ 500,000	54	35,374
Total	**67**	**54,024**

Source: JICA Survey Team

The measures with a high priority level for the first implementation phase were estimated to be 13 locations with high risk level as shown above. In case of the proposed sediment disaster prevention measures, all measures are stabilization of roadside slopes, because no costs will be incurred for the acquisition of land due to the fact that all projects will be executed within the existing road area

6.2.2 Early Warning System for Sediment Disaster and Flush Flood

In the master plan, an installation of totally 53 stations on the municipal government building was proposed in each city. EPAGRI/CIRAM will be responsible for the data storage management and the sequential analysis of the observed data and will calculate the rainfall reference index sequentially based on the predicted rainfall estimated by the WRF model (Weather Research and Forecasting) and when the predicted rainfall exceeds the predetermined reference index for warning, warning will be announced to the public. The estimated costs are R$ 4 million.

6.3 Cost for Priority Projects (First Phase)

The amount subject to ODA Loan by the State Government of Santa Catarina was planed around R$ 100 to 150 million. Priority projects were selected below as being the project for the first phase of implementation with a target safety level of the 50-year flood. The costs for land acquisition and relocation of residents will not be the object of ODA loan but will be included in the State budget.

Table 6.3.1 Estimated Cost for the First Phase of Project Implementation

Project Component	Cost (R$ 10^3)	Cost excluding Land Acquisition and Relocation (R$ 10^3) (for Loan)
Water storage in paddy fields (22,000 ha)	33,000	33,000
Heightening of dams (2 dams)	33,000	33,000
Floodgates in Itajaí Mirim River (2 locations)	44,000	44,000
River improvement Itajaí Mirim River 0.95 km	50,000	17,800
Strengthening of the existing FFWS	4,000	4,000
Road landslide prevention measures (13 locations)	18,650	18,650
Early warning system for sediment disaster and flush flood	4,000	4,000
Total	**186,650**	**154,450**

Source: JICA Survey Team

In the first implementation phase of the project, change of the current dam operation method at the two flood control dams (Oeste and Sul dams), as well as utilization of the existing hydropower generation dams for flood control (Pinhal and Rio Bonito dams of CELESC) will be implemented as proposed in the master plan. Therefore, in the second phase of Preparatory Survey for feasibility study, concrete dam operation at these dams will be studied.

Table below shows the expected flood control effects of the first phase implementation by city.

Current situation:

Municipality	5-year	10-year	25-year	50-year
Rio do Sul				
Blumenau				
Blumenau, tributary				
Gaspar				
Ilhota				
Timbo				
Taio				
Itajai				
Itajai, Mirim				
Brusque				

After the 1st phase of implementation:

Municipality	5-year	10-year	25-year	50-year
Rio do Sul				
Blumenau				
Blumenau, tributary				
Gaspar				
Ilhota				
Timbo				
Taio				
Itajai				
Itajai, Mirim				
Brusque				

Inundation

1st phase of implementation:

<Source of funding>

JICA 's loan	Rain water containment in rice fields (22,000ha)
	Heightening of dams (Oeste and Sul dam)
	Flood gates in the old Itajai Mirim canal (2 units)
	River improvement in the old Itajai Mirim canal、0.95km
	Strengthening flood forecasting warning system
	Improve operation of Oeste and Sul dams
	Preventive discharge at the hydro-electric generation dams (2 dams)
SC State government	River improvement of tributary in Blumenau (2 streams)
	Small-scale dams

With the construction of the floodway, it will be unnecessary to build dykes which was proposed in the 50-year flood plan, but the floodway by itself can solve the 10 and 25-year flood damage.

Source: JICA Survey Team

Figure 6.3.1 Flood Control Effects of First Phase Implementation by City

CHAPTER 7 FEASIBILITY STUDY FOR HEIGHTENING OF EXISTING FLOOD CNTROL DAMS AND MODIFICATION OF DAM OPERATION

7.1 Current Condition and Basic Policy for Heightening of Dams

7.1.1 Necessity of Heightening Dams

There are three existing dams for flood control in the Itajai River basin, named the Norte Dam, the Oeste Dam, Sul Dam. Norte Dam has enough volume for flood control. On the other hand, as the reservoir volume of the Oeste Dam and Sul Dam is relatively small, floods have often overflowed from the spillway and brought some damage to the downstream area.

The M/P proposed the heightening of the Oeste Dam and Sul Dam and modification of their operations. The Oeste Dam and the spillway of Sul Dam are proposed to be heightened by 2 m. As the Sul Dam is of rockfill type, the dam body is difficult to be heightened.

7.1.2 Existing Flood Control Dams

(1) General Features

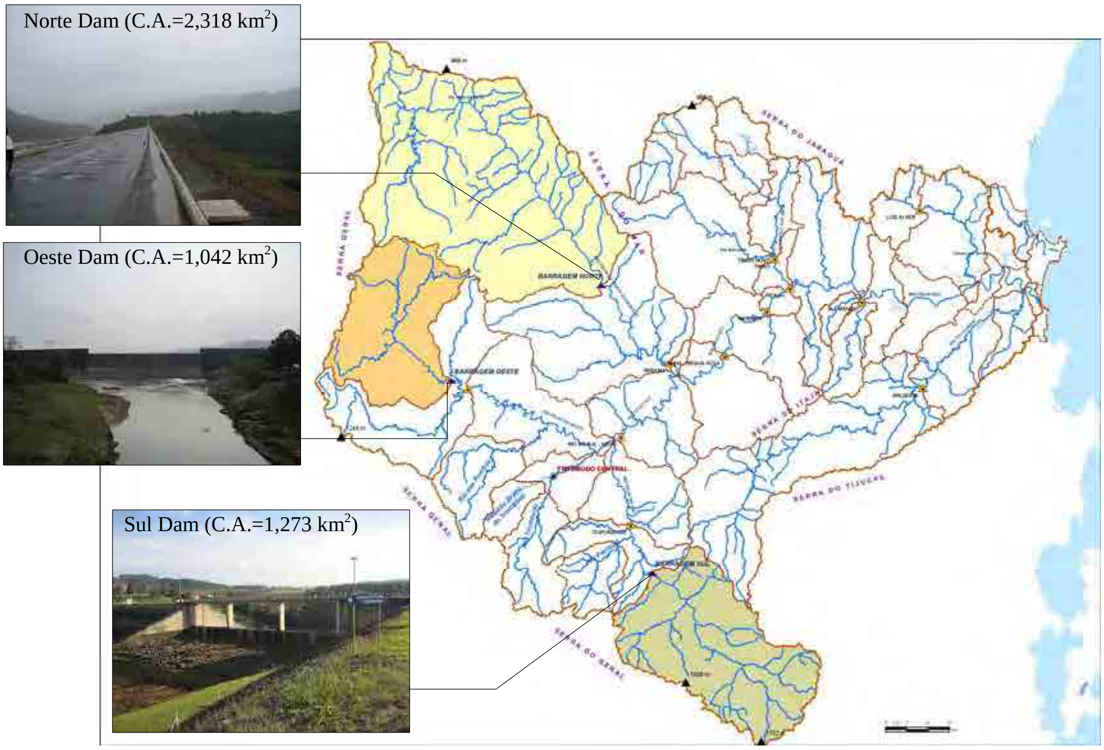
Both of the Oeste and Sul Dams were constructed for the flood control purpose. These dams should be operated in empty condition in reservoir.

Figure 7.1.1 shows the location of dams. The general features of those dams are shown in Table 7.1.1. The Oeste Dam is of concrete gravity type. The Sul Dam is of Rockfill type, so the spillway is independent of the dam body.

Table 7.1.1 General Features of the Oeste and Sul Dams

		Oeste Dam	Sul Dam
Reservoir	Catchment area	1,042 km^2	1,273 km^2
	Reservoir area	950 ha	840 ha
	Total reservoir capacity	83,000,000 m^3	93,500,000 m^3
	Minimum water level	EL.340.0 m	EL.372.9 m
	Maximum water level	EL.362.5 m	EL.408.0 m
Dam body	Year of completion	1973	1976
	Type of dam	Concrete gravity	Rock-fill
	Height of dam	25.0 m	43.5 m
	Crest length of dam	422 m	390 m
	Crest elevation of dam	363.0 m	410.0 m
Conduit	Number of conduits	7	5
	Type of flood control	Gate control	Gate control
	Diameter at gate	1500 mm	1500 mm
	Elevation of pipe center	340.05 m	Around 368 m
	Discharge capacity (crest elevation of spillway)	163 m^3/s (at WL.360 m)	194 m^3/s (at WL.399 m)
Spillway	Width	Around 100m	65m
	Crest elevation of spillway	360.0m	399.0m
	Discharge capacity (at maximum water level)	Conduit 175 m^3/s Spillway 1,125 m^3/s Total 1,300 m^3/s	Conduit 217 m^3/s Spillway 3,053 m^3/s Total 3,270 m^3/s

Source: Hatching: web site of DEINFR http://www.deinfra.sc.gov.br/barragens/sobre-as-barragens/
Discharge capacity : see Supporting Report A, Table 7.4.6
Others: Drawing not authorized, or hearing from the department of the SC State



Source: JICA Survey Team

Figure 7.1.1 Location of existing flood control dams in Itajai River Basin

(2) Existing Operation Manual

The operation manual of those dams was prepared by DEINFRA/DENOH in April of 2007, named "Manual De Procedimentos Para Operacao Das Barragens do Alto Vale do Itajai". The gates are operated based on the river water level in the downstream cities. This operation manual summarized as Table 7.1.2.

Table 7.1.2 Summary of the Operation Manual of Oeste Dam and Sul Dam

Dam	Operation Manual
Oeste Dam	When the river water level in the city reaches the emergency level mentioned below, the gates begin to be closed. The number of gates to be initially closed depends on the amount of rainfall which continues to fall over the city, and the first dam to be operated will depends on the distribution of rainfall, i.e., smaller rainfall intensity in its drainage area. - The river water level forecasted in Blumenau is reaching over 8.50 m. - The river water level is reaching to 6.50 m in Rio do Sul – start to close gates together with Sul Dam. - When the river water level reaches 7.10 m in Taio – start to close first gate; when the river water level reaches 7.50 m - the seven gates shall be closed. - When the river water level reaches 8.00 m in Rio do Oeste – start to close first gate; when the river water level reaches 9.00 m, the seven gates will be closed.
Sul Dam	When the river water level in the city reaches the emergency level mentioned below, the gates begin to be closed. The number of gates to be initially closed depends on the amount of rainfall which continues to fall over the city, and the first dam to be operated will depends on the distribution of rainfall, i.e., smaller rainfall intensity in its drainage area. - The river water level forecasted in Blumenau is reaching over 8.50 m. - The river water level is reaching to 6.50 m in Rio do Sul – start to close gates together with Sul Dam. - When the river water level reaches 3.80 m in Ituporanga, or the flood over the spillway reaches to Ituporanga with water depth over 2.00 m.
Remarks	- Since the gates are closed, each reservoir should start to be monitored more carefully, to avoid that the storage exceeds the reservoir capacity and starts to spill out. The operator shall record water elevation and percentage of storage on the worksheet by relation between the water level and the storage. - The operation of the gates is executed through the command panel with buttons. At first, turn on the electric energy panel (located beside the command panel), turn on the hydraulic pump, then push the button "open" and/or "close" of each gate. Movement of each gate shall terminate automatically. The operation of plural gates at the same time is not advisable, should be done in sequence.

Source: Manual De Procedimentos Para Operacao Das Barragens do Alto Vale do Itajai, DEINFRA/DEOH, 4-2007

7.1.3 Heightening of Dams and Increase of the Volume

(1) Brazilian Criteria about Height of Dam Crest

Table 7.1.3 presents the criteria on the height of dam in Brazil.

Table 7.1.3 Criteria about the Height of Dams in Brazil

Terms	Cases	Types	Criterias
Freeboard	For Normal Water Level	Fill Dam	Free board should be installed more than wave height by wind. The wave height should be estimated with Saville Equation. Minimum free board is 3.0 m.
		Concrete Dam	Minimum free board is 1.5 m.
	For Maximum Water Level	Fill Dam	Minimum free board is 1.0 m.
		Concrete Dam	Minimum free board is 0.5 m.
Design discharge of Spillway	General Dams	Probable Maximum Flood Discharge	It should be applied to dams higher than 30 m in height, and also applied to dams with residents in its downstream area, who is considered to suffer from collapse of the dams
	Small Dams	1,000-year Probable Flood	It should be applied to dams less than 30 m in height, or applied to dams with reservoir volume less than 50 x 10^6 m^3 and without residents in its downstream area.

Source: Criterios De projeto Civil De Usinas Hidreletricas, Eletrobras, Outubro/2003

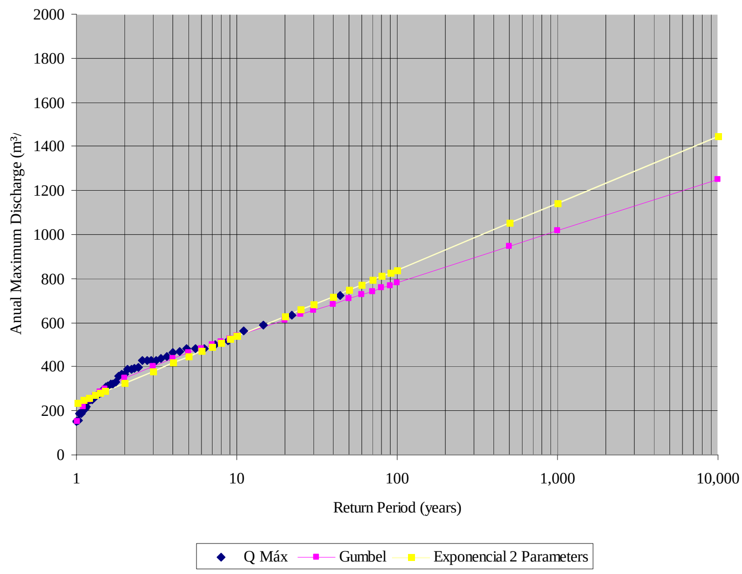
(2) Possibility of the Dam Heightening

1) Oeste Dam

As the height of the Oeste Dam is less than 30 m, the 1,000-year flood would be applied as the design discharge of spillway. The 1,000-year discharge of daily mean in Taio city (1,570 km^2) was estimated 1,143 m^3/s as shown in Figure 7.1.2. Therefore, the instantaneous peak 1,000-year discharge at Oeste Dam was estimated 1,010 m^3/s from the rate of catchment area between Taio and the Oeste Dam and by the Fuller Equation as follows.

- Daily mean 1,000-year discharge in Taio city 1,570 m^3/s (see Figure 7.1.2)
- Daily mean 1,000-year discharge at the Oeste Dam 1,143 m^3/s x 1,042/1,570 km^2 = 759 m^3/s
- Instantaneous peak 1,000-year discharge at the Oeste Dam

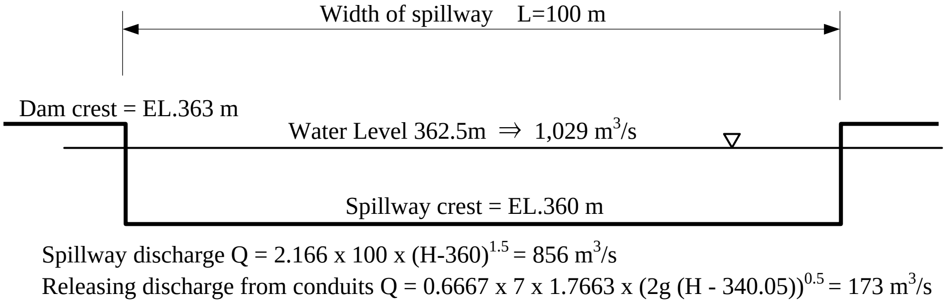
$$759 \times (1 + 2.66/1{,}042^{0.3}) = 1{,}010\ m^3/s$$



Source: JICA Survey Team

Figure 7.1.2 Frequency Analysis of Daily Mean Discharge in Taio City

The present crest elevations of the dam and spillway top are 363 m and 360 m relatively. As the maximum water level under the 1000-year flood is EL.362.5 m. The freeboard is thus 0.5 m as illustrate in Figure 7.1.3. This satisfies minimum freeboard as required in Table 7.1.3. Therefore, both crests of the dam and spillway could be raised by 2 m.



Source: JICA Survey Team

Figure 7.1.3 Maximum Water Level by the 1,000-year flood at the Oeste Dam

The possible maximum height by heightening of Oeste Dam is considered to be 2.0 m, from the view of the topographic condition at the abutments of the dam. Therefore, Oeste Dam would be planned to be heightened by 2.0 m for both crests of the dam and spillway.

2) Sul Dam

As the Sul Dam is a rockfill dam higher than 30 m, the required free board should be 1.0m as shown in Table 7.1.3. The design discharge of the spillway (see Table 7.1.3) should be the “Probable Maximum Flood”, but, since the spillways of the Brazilian greatests dams for hydroelectric power (Itaipu in Paraná river, Itá and Machadinho in Uruguai river, Salto Santiago, Salto Osório and Segredo in Iguaçu river and many others over all Brazil) are usually designed for the 10,000-year flood, this discharge was considered in the present study. Also, it was not available, at the present time, meteorological data for the estimation of the PMP (Probable Maximum Precipitation), needed for its transformation in PMF (Probable Maximum Flood).

The 10,000-year flood discharge of daily mean in Ituporanga city (1,645 km^2) is 2,530 m^3/s as shown in Figure 7.1.4. Therefore, the instantaneous peak discharge of the 10,000-year flood at the Sul Dam would be estimated 2,567 m^3/s from the rate of catchment areas between Ituporanga and the Sul Dam and Fuller Equation as follows.

- Daily mean 10,000-year discharge in Ituporanga city 2,530 m^3/s (see Figure 7.1.4)

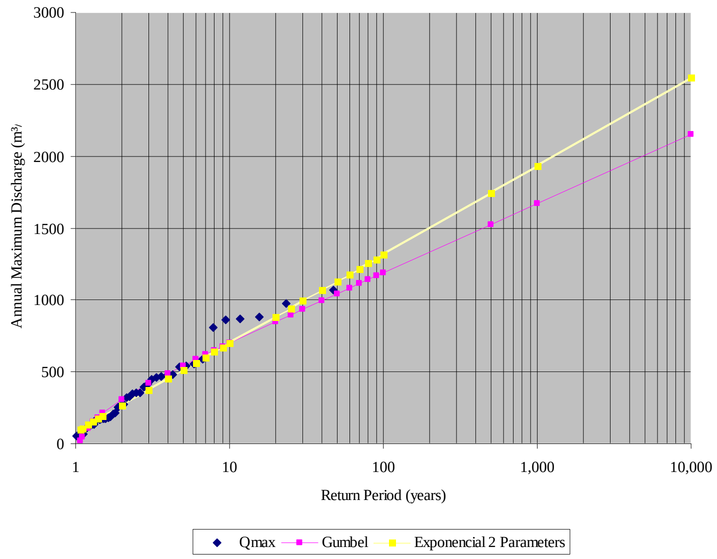
- Daily mean 10,000-year discharge at the Sul Dam 2,530 m^3/s x 1,273/1,645km^2 = 1,958 m^3/s

- Instantaneous peak 10,000-year discharge at the Sul Dam

$$1{,}958 \times (1 + 2.66/1{,}273^{0.3}) = 2{,}567 \text{ m}^3/\text{s}$$

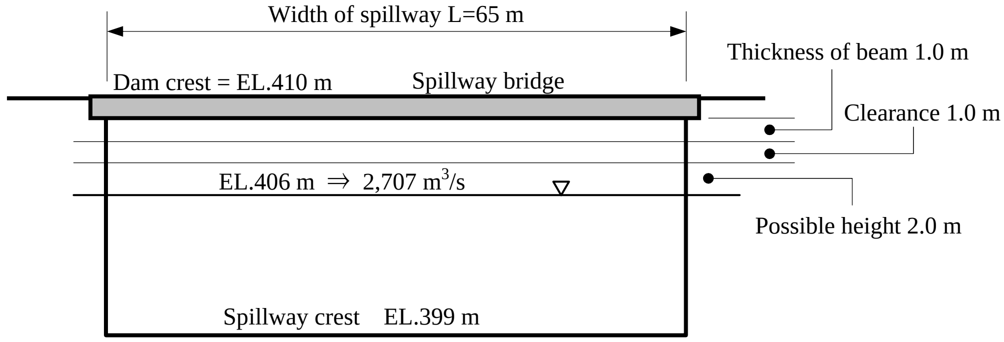
The total discharge from the existing spillway and conduits of the Sul Dam is estimated 2,706 m^3/s at the water level of EL.406 m. This is higher than 10,000-year flood discharge. Therefore, the dam crest (EL.410 m) has a enough freeboard of 4.0 m from the maximum water level of the 10,000-year flood.

The spillway could be heightened by utilizing this surplus of freeboard. The possible heightening of the spillway would be 2.0 m considering freeboard and clearance between water surface and the beam of the bridge.



Source: JICA Survey Team

Figure 7.1.4 Frequency Analysis Daily Mean Discharge in Ituporanga City



Spillway $Q = 2.07 \times 65 \times (H - 399)^{1.5} = 2492\ m^3/s$

Conduits $Q = 0.89 \times 5 \times 1.7663 \times (2g\ (H - 368))^{0.5} = 215\ m^3/s$

Source: JICA Survey Team

Figure 7.1.5 Maximum Water Level by 10,000-year flood at the Sul Dam

(3) Increased Reservoir Capacity by Dam Heightening

The Relation of dam heightening of dams and expected increase of the reservoir capacity are summerized in Table 7.1.4. The expected reservoir capacities to be increased are 16.2 x 10^6 m^3 for the Oeste Dam, 16.6 x 10^6 m^3 for the Sul Dam.

Table 7.1.4 Relation between Heightening of Dams and Increase of Reservoir Capacity

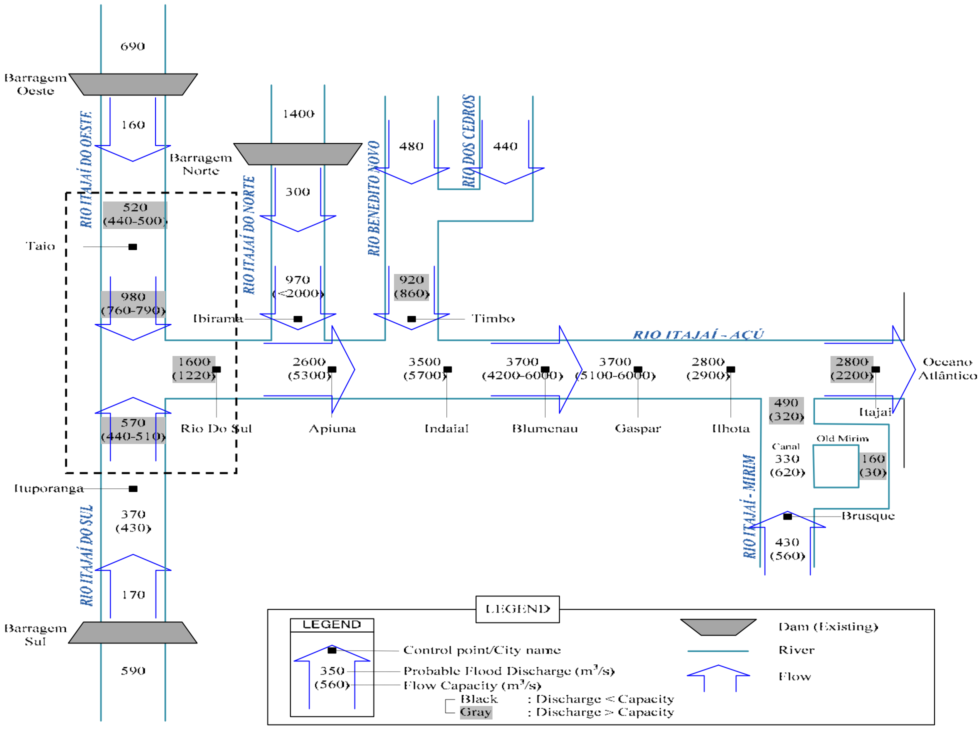
Oeste Dam				Sul Dam			
Crest Elevation of Spillway	Dam Heigtening	Total Reservoir Capacity	Increment of Capacity	Crest Elevation of Spillway	Dam Heigtening	Total Reservoir Capacity	Increment of Capacity
EL.m	m	x 10^3 m^3	x 10^3 m^3	EL.m	m	x 10^3 m^3	x 10^3 m^3
360.0		83,100		399.0		93,600	
360.5	0.5	87,000	3,900	399.5	0.5	97,600	4,000
361.0	1.0	91,000	7,900	400.0	1.0	101,700	8,100
361.5	1.5	95,100	12,000	400.5	1.5	105,900	12,300
362.0	2.0	99,300	16,200	401.0	2.0	110,200	16,600

Source: JICA Survey Team

7.1.4 Flood Control Plan and Hydrograph

(1) Flood Control Plan

The present flow capacities and the design discharges of the 10-year flood at major cities along the Itajai River are shown in Figure 7.1.6. The flow capacities in Rio do Sul and Taio cities are less than design discharges of 10-year flood. Especially in Rio do Sul city, all of three rivers (Itajai do Oeste, Itajai do Sul and Itajai Rivers) do not have enough flow capacities. The heightening of dams and modification of operation aim at decreasing the design discharges of 10-year flood to the flow capacities.



Source: JICA Survey Team

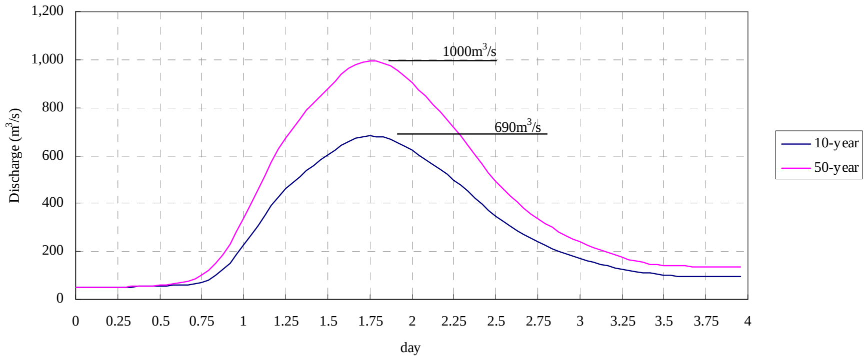
Figure 7.1.6 Design Discharge Distribution of 10-year Flood when the Present Condition and Flow Capacity at Major Cities

It should be noted that the heightening of dams would be planned as the possible maximum height duly considering topography or criteria in Brazil. It means that the height of the dam is not determined from required flood control capacity.

The lack of flood control function should be supplemented by other measures like the water storage in paddy field and the basin storage (small dams).

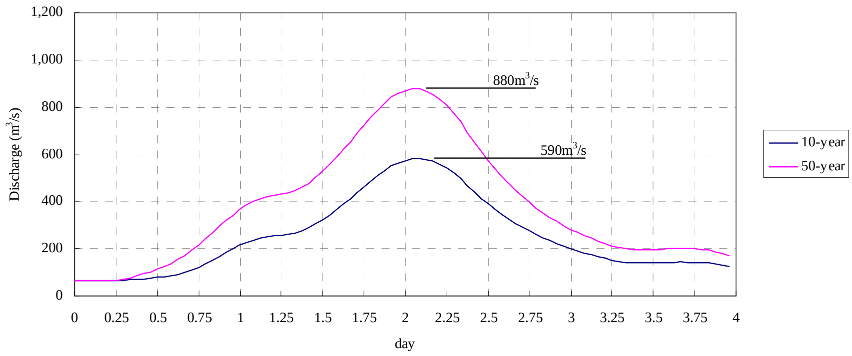
(2) Flood Hydrographs at the two Dams

Figures 7.1.7 and 7.1.8 show the flood inflow hydrographs of the 10-year flood and 50-year flood at the Oeste Dam and Sul Dam, which are estimated by runoff analysis using the hyetographs type of the 1984 flood.



Source: JICA Survey Team

Figure 7.1.7 Flood Hydrograph at the Oeste Dam



Source: JICA Survey Team

Figure 7.1.8 Flood Hydrograph at the Sul Dam

7.2 Feasibility Design for Dams

The shapes of heightening of the Oeste Dam and the spillway of the Sul Dam and the necessity of reinforcement of metal structure of the gates are studied in Supporting Report Annex F.

The shapes of the dams and the situation of foundation rock were investigated by geometric surveys and boring surveys. The shapes of dam heightening were designed with satisfying stable conditions of the criteria of Brazil, based on the information from these surveys above.

The metal structure of the conduit gates were also investigated in field surveys, and confirmed that they need not to be reinforced.

7.3 Modification of the Operation

7.3.1 Operation Method for Flood Control

(1) Reference Point for Operation of Dams

1) Oeste Dam

As mentioned in the Section 7.1, the Oeste Dam is proposed to be heightened by 2 m. The Oeste Dam might be effective for flood control in Taio and Rio do Sul cities along the Itajai do Oeste River. The flood mitigation measures along the Itajai do Oeste River in the M/P are shown in Table 7.3.1.

The present safety level of Taio city is less than the 10-year flood. The heightening of Oeste dam and modification of the operation can cope with the 10-year flood in Taio city. And the basin storage (small dams) and river improvement are also needed against the floods bigger than the 25-year flood.

On the other hand, the safety level of Rio do Sul city along the Itajai do Oeste River is less than the 5-year flood. As the heightening of the Oeste Dam can not achieve the 5-year safety in Rio do Sul city, basin storage (small dams) in the Trombudo River would be inevitably necessary. The heightening of Oeste Dam, basin storage (small dams) and river improvement would cope with the 25 and 50-year floods.

Considering the above, Taio city should be selected as the reference point to modify the operation manual of Oeste Dam.

Table 7.3.1 Flood Mitigation Measures in Taio and Rio do Sul Cities

City	Safty level of flood control	Heightening of dams, Modification of operation	Basin storage (small dam)	River improvement (Dyke)
Taio	5-year food	-	-	-
	10-year food	○	-	-
	25-year food	○	-	○
	50-year food	○	-	○
Rio do Sul （along Itajai do Oeste River）	5-year flood	-	○	-
	10-year food	○	○	-
	25-year food	○	○	-
	50-year food	○	○	○

Source: JICA Survey Team

2) Sul Dam

As mentioned in the Section 7.1, the Sul Dam is proposed to be heightened by 2 m. The Sul Dam might be effective for Ituporanga city and Rio do Sul city along the Itajai do Sul River. The flood mitigation measures along the Itajai do Sul River in the M/P are shown in Table 7.3.2.

The present safety level of Rio do Sul city along the Rio Itajai do Sul is less than 10-year flood. The heightening of Sul Dam and modification of its operation can cope with only the 10-year flood. And the basin storage (small dams) and river improvement are also needed against floods bigger than the 25 and 50-year flood.

On the other hand, Ituporanga city has the safety level of the 25-year flood, and safety level of the 50-year flood shall be achieved with the heightening of the spillway of Sul Dam and modification of the operation.

Considering the above, Rio do Sul city along the Itajai do Sul River should be selected as the reference point to modify the operation manual of Sul Dam.

Table 7.3.2 Flood Mitigation Measures in Ituporanga and Rio do Sul Cities

City	Safty level of flood control	Heightening of dams, Modification of operation	Basin storage (small dam)	River improvement (Dyke)
Ituporanga	5-year flood	-	-	-
	10-year flood	-	-	-
	25-year flood	-	-	-
	50-year flood	○	-	-
Rio do Sul （along Itajai do Sul River）	5-year flood	-	-	-
	10-year flood	○	-	-
	25-year flood	○	○	-
	50-year flood	○	○	○

Source: JICA Survey Team

(2) Target Flood Protection Level

Dams are generally constructed and also operated for the target protection level of M/P (i.e. protection level against the 50-year flood). But if the safety of the downstream river does not achieve the target protection level, the dams should be operated considering the safety level of the downstream cities.

In the M/P, heightening of the dams is planned for the 50-year flood. But the safety of the downstream river shall be provisionally achieved for the 10-year flood by the projects of first stage. Therefore, the operation manual should be prepared provisionally for the 10-year flood.

Floods have spilled out from both Oeste and Sul dams once in several years (once in around 5 years in average according to the interview surveys from dam operators). Therefore, even if the operation manuals are prepared for the 10-year flood, probability of the spilling out shall not increase from present situation.

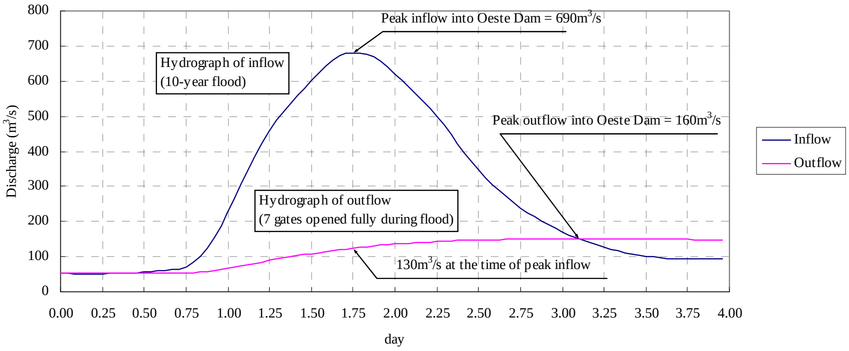
(3) Method of Flood Control

1) Oeste Dam

As shown in Figure 7.3.1, the 10-year flood at the Oeste Dam is estimated 690 m^3/s from the runoff analysis using hyetograph of the 1984 flood. If all the gates are fully opened during the flood, the maximum outflow from the gates is estimated 160 m^3/s, and the outflow at the time of maximum flood inflow is estimated 130 m^3/s.

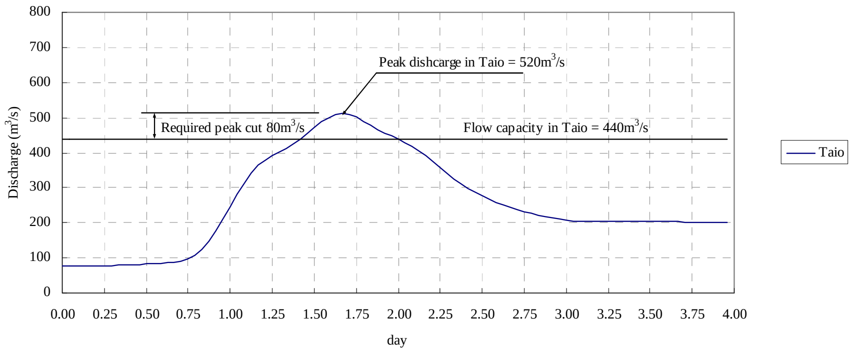
As shown in Figure 7.3.2, if all the gates are fully opened during the flood as mentioned above, maximum flood discharge in Taio city is estimated 520 m^3/s. This discharge exceeds the current flow capacity of 440 m^3/s in Taio city.

Therefore, the gates operation should be carried out so as not to exceed the current flow capacity of 440 m^3/s



Source: JICA Survey Team

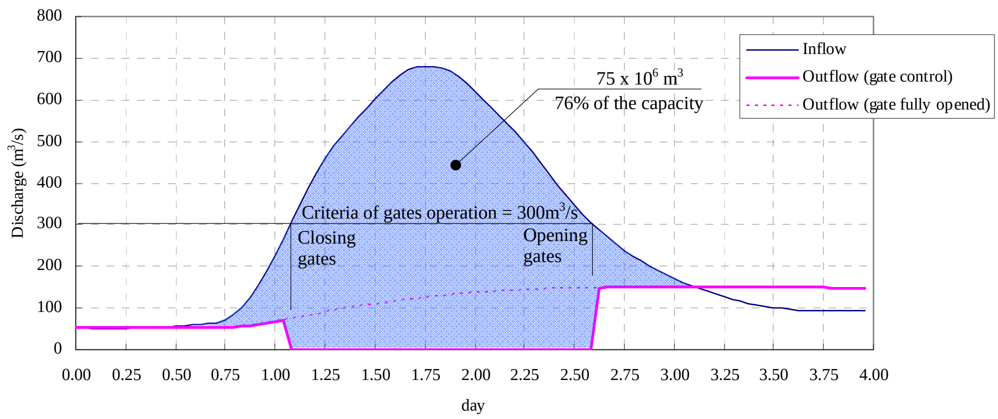
Figure 7.3.1 Inflow and Outflow Hydrographs of 10-year flood at Oeste Dam



Source: JICA Survey Team

Figure 7.3.2 Hydrograph of 10-year flood in Taio City

Though the required peak cut for the 10-year flood at the Oeste Dam is estimated 80 m^3/s, it is desirable to close fully the gates during the flood for as long as possible, expecting effect in Rio do Sul city and simplification of the operation. The criteria of opening and closing gates would be set at 300 m^3/s of the flood inflow into the reservoir, considering more than 20% of the storage capacity as a margin capacity in view of uncertainty of variety of the rainfall distribution and the occurrence of extraordinary floods.



Source: JICA Survey Team

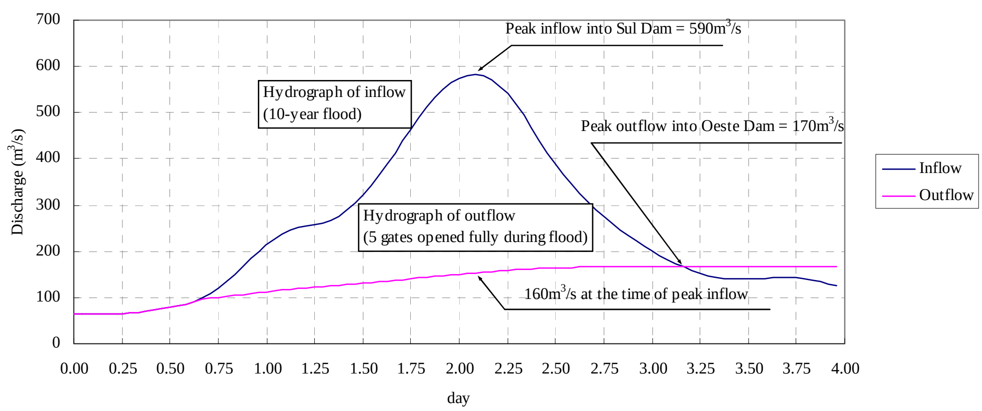
Figure 7.3.3 Method of Flood Control at Oeste Dam

2) Sul Dam

As shown in Figure 7.3.4, the 10-year flood at the Sul Dam is estimated 590 m^3/s. If the all the gates are fully opened during the flood, the maximum outflow from the gates is estimated 170 m^3/s, and the outflow at the time of maximum flood inflow is estimated 160 m^3/s.

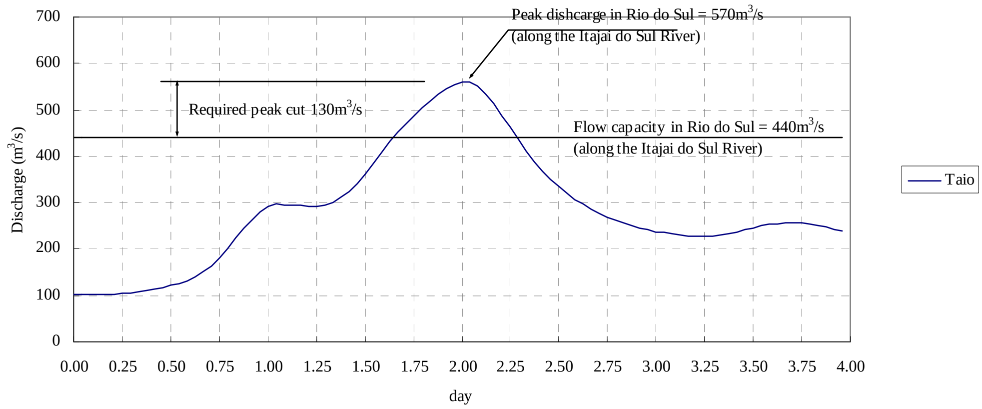
As shown in Figure 7.3.2, if all the gates are fully opened during the flood as mentioned above, maximum flood discharge in Rio do Sul city in the Itajai do Sul River is estimated 570 m^3/s. This discharge exceeds the current flow capacity of 440 m^3/s in Rio do Sul city.

Therefore, the gates operation should be carried out so as not to exceed the current flow capacity of 440 m^3/s.



Source: JICA Survey Team

Figure 7.3.4 Inflow and Outflow Hydrographs of 10-year flood at Sul Dam

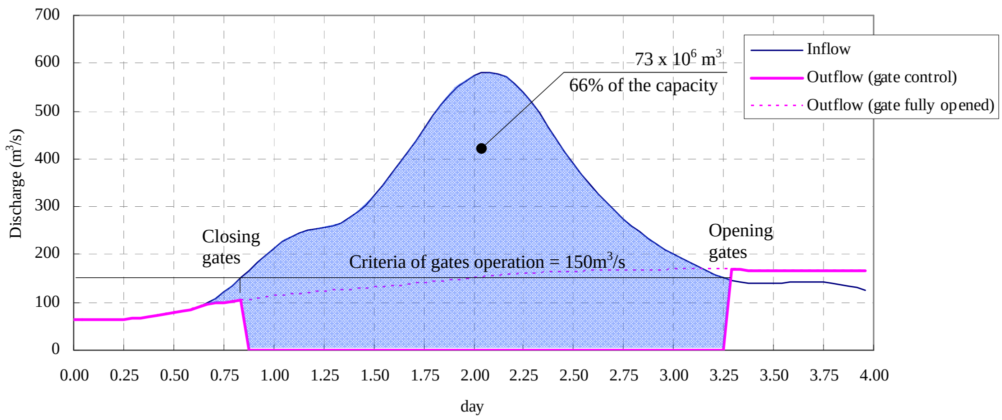


Source: JICA Survey Team

Figure 7.3.5 Hydrograph of 10-year flood in Rio do Sul City in the Itajai do Sul River

Though the required peak cut for the 10-year flood at the Sul Dam is estimated 130 m^3/s, the gates would be closed fully during the flood for as long as possible like the Oeste Dam.

The criteria of opening and closing gates would be set at 150 m^3/s of the flood inflow into the reservoir. As storage volume for 10-year flood shall be 73 x 10^6 m^3, the margin capacity shall be 34% of storage capacity in view of uncertainty of variety of the rainfall distribution and the occurrence of extraordinary floods.



Source: JICA Survey Team

Figure 7.3.6 Method of Flood Control at the Sul Dam

(4) Method of Gate Operation

As mentioned in the previous sub-section, the criteria of gate operation in the Oeste and Sul Dams shall be started when the flood inflow exceeds 300 m^3/s in the Oeste Dam and 150 m^3/s for the Sul Dam, respectively. The method of gate operation would be simple, but gate operator need to know the inflow. The inflow discharge shall be estimated by the following equation.

$$Q_{in} = \frac{\Delta V}{\Delta t} + \overline{Q}_{out}$$

where, Q_{in} : inflow into the dam (m^3/s)

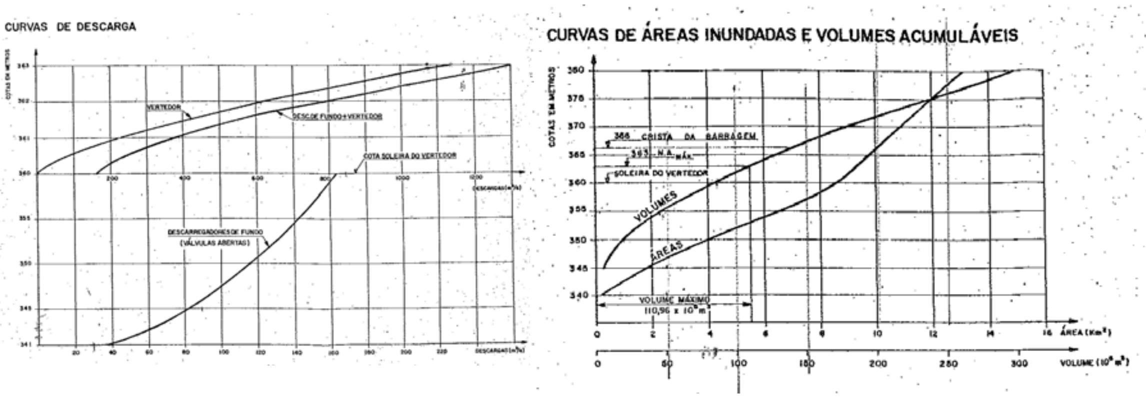
ΔV : increasing volume of reservoir storage during Δt (m^3)

$\overline{Q}_{out}$: average outflow during Δt (m^3/s)

Therefore, the gate operator should obtain the accurate data of reservoir water level and outflow through the conduits every 30 minutes or 1 hour to operate the gates properly. In this connection, the gate operators should also prepare the rating curve showing relationship between reservoir water level and storage volume, and the rating curve among reservoir water level, gates opening and outflow rate.

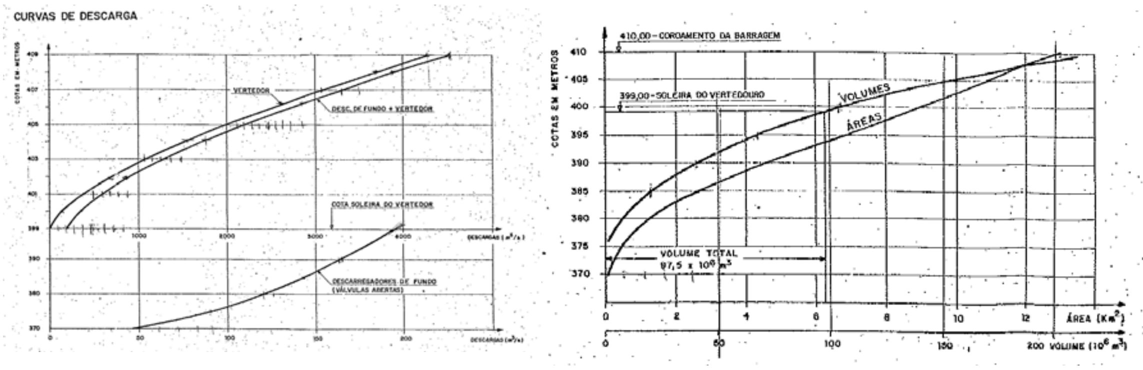
Figures 7.3.7 and 7.3.8 show those rating curves of the Oeste and Sul Dams. But these drawings have not been considered gates opening, and might be fairly old and subject to confirmation from as-built drawings from the manufacture or the completion documents. Therefore, these rating curves should be reviewed at the project of the dams heightening.

Figures 7.3.7 and 7.3.8 also present the relationships between water levels and accumulated reservoir volumes. But these relationships have not been updated to reflect the influence of sedimentaion in the reservoirs, though these relationships are also important to grasp inflow discharge into reservoirs. The dam management department (DEINFRA) should confirm the relationship regularly by periodic topographic survey of reservoirs.



Source: Drawings (Obras Existentes de Conrole de Cheias, Barragem Oeste), CAEEB MME/DNAEE

Figure 7.3.7 Rating Curves between Water Level and Storage volume, Outflow of Oeste Dam



Source: Drawings (Obras Existentes de Conrole de Cheias, Barragem Sul), CAEEB MME/DNAEE

Figure 7.3.8 Rating Curves between Water Level and Storage volume, Outflow of Sul Dam

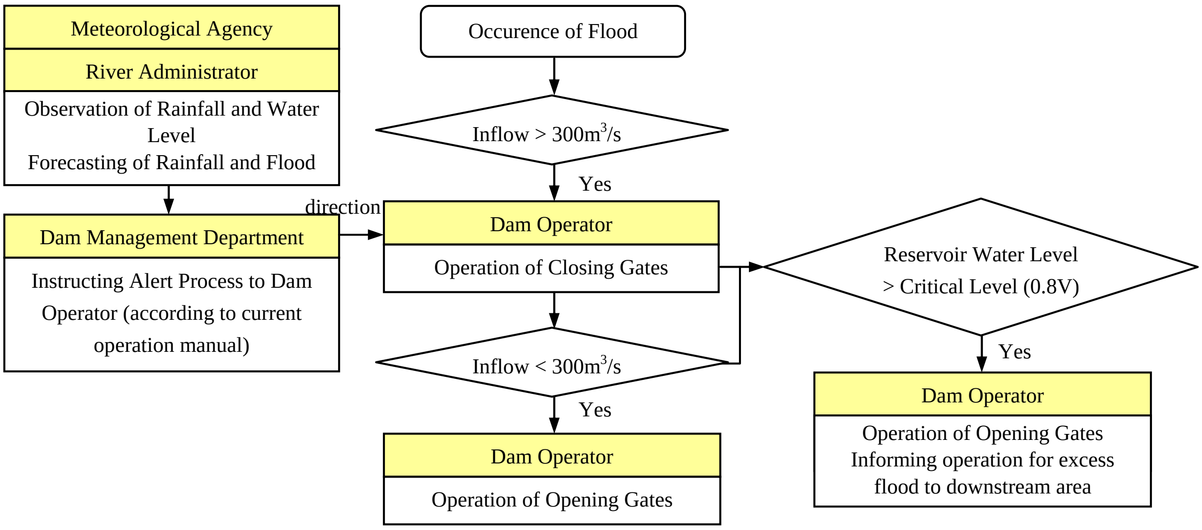
DEINFRA would be considered to be responsible for the existing flood control dams heightening projects and management after the projects implementation. In current operations of these dams, one person in charge of the dam operation is living next to dam body, and is engaged in ordinal dam management and gates operation for flood control. In flood time, a manager of DEINFRA in charge of dam management comes from Florianopolis to support and instruct the operator for gates operation of flood control. When floods come, the operator has to watch scales in the reservoir to understand reservoir water level. Therefore, it is appropriate that the operator and the manager check the reservoir water level, outflow discharge, situation of downstream river in the interval of a hour to calculate accumulated reservoir volume, inflow dishcarge and to operate the gates.

7.3.2 Operation against Extraordinary Floods

If extraordinary floods exceeding the design flood (hereinafter called "excess flood") attack the dam during the operation of flood control, the operator should stop the normal operation of flood control. The excess flood may cause overflowing from spillway and rapid rising of the water level in the downstream river. The operator should make effort to mitigate the rising rate of the water level and reduce damages in the downstream area, as summarized below.

i) All of the gates should be slowly opened in order, when reservoir water level reaches the critical level. The water level considering 80% of the reservoir capacity is generally adopted as the critical level. This operation may, though slightly, mitigate the rising rate of water level in the downstream area, when the stored water is spilled out from the spillway.

ii) The operator should inform the operation of gates opening and possibility of overflowing in advance with the warning sirens to the people who lives along the downstream river from Taio to Rio do Sul (the warning sirens shall be mentioned in Supporting Report D).



Source: JICA Survey Team

Figure 7.3.9 Flowchart of Gates Operation (in case of Oeste Dam)

7.4 Increasing of Discharge Capacity in Sul and Oeste Dams

A huge flood attacked the Itajai River basin from 6th to 9th in September 2011, after the Feasibility Study carried out from February to July. As some problems such as insufficient discharge capacity of the outlets in Sul and Oeste Dams were revealed during the flood, the study team proposed increasing of the dicharge capacities in these dams as follows, at the time when study team submitted the draft final reports in September.

Defesa Civil of the SC State reported that there was a lot of raifall of around 200 mm over the Itajai River basin in average for 4 days during the flood. In this study, basin mean probable 4 days rainfall are estimated to be 188 mm for 25-year, 209 mm for 50-year. Therefore, if the report is accurate, the probability of the flood may be estimated to be 30 to 40-year. This estimation seems correct because maximum water level in Blumenau during the flood was reported to be 12.9 or 13.0 m, while the water levels of memorial floods in Blumenau were recorded to be 15.8 m in 1983 flood (around 70-year flood), 15.5 m in 1984 (around 70-year), 10.6 m in 1992 (around 30-year), and 11.0 m in 2001 (7-year).

On the other hand, the record by the operator in Sul Dam shows that the rainfall from 6th to 9th in September reached 220 mm, and DEINFRA of the SC State reported that around 300 mm rainfall was recorded at some gauging stations in the catchment area of the Sul Dam. It is inferred that a huge storm attacked this area. During this flood, flood discharge overflowed both Oeste and Sul Dams.

Overflow of Oeste Dam

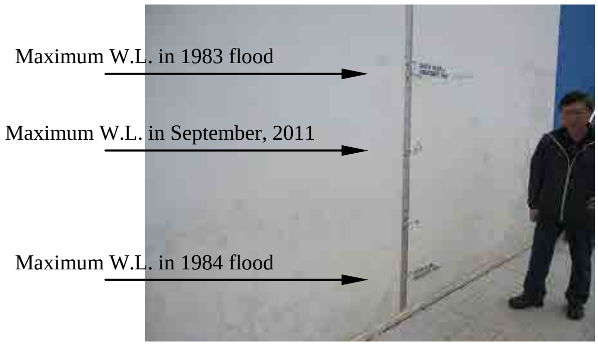
Source: DEINFRA

Inundation in Taio City

Damage in Rio do Sul City

Source: JICA Survey Team

Damage in Rio do Sul City



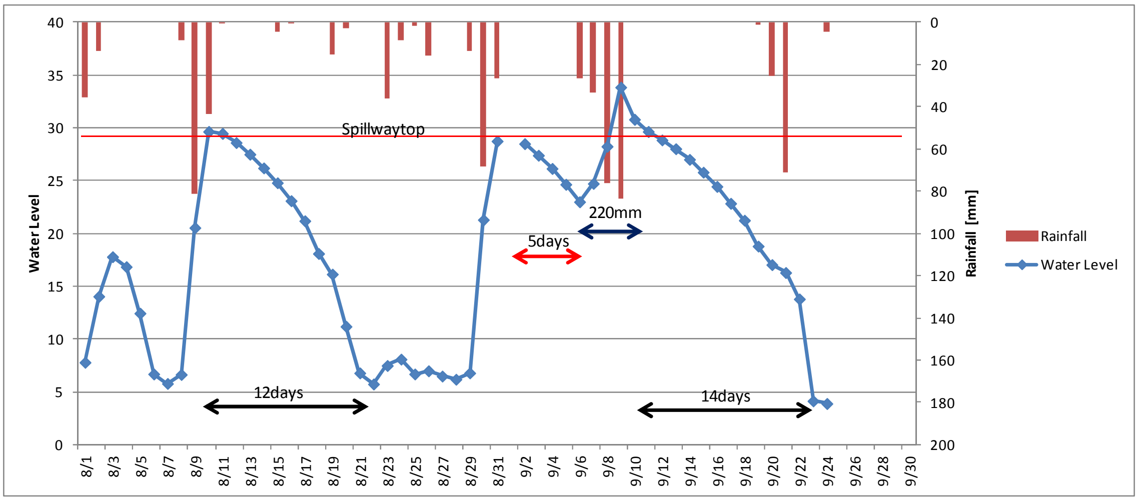
Source: JICA Survey Team

Flood Mark in front of the City Hall of Rio do Sul

Table 3.6.1 shows the variation of daily rainfall and water level at the Sul Dam from August to September in 2011.

- Large rainfall occurred on 10th and 30th in August, 6th to 9th in September.
- Reservoir water level in Sul Dam reached to the spillway top. Lowering of the maximum reservoir water level to normal level required 12 days and 14 days in the case of the floods on 10th in August and 6th in September.
- The floods of 6th in September attacked 5 days after the previous flood. The reservoir water level remained high at the time of the flood attack
- During the food from 6th in September, maximum water level at the Sul Dam was spillway top +5.0 m. The maximum outflow discharge from the spillway and conduit of the Sul Dam was estimated to be around 1,600m^3/s.

The overflows from both dams might be considered to be unavoidable. However, the discharge capacity of the conduits in both dams, 190 m^3/s for Sul Dam and 160 m^3/s for Oeste Dam, should be evaluated to be relatively insufficient against the catchment area of both dams (1,042km^2 for Oeste Dam, 1,273 km^2 for Sul Dam).



Source: JICA Survey Team

Figure7.4.1 Variation of Daily Rainfall and Water Level at Sul Dam from August to September in 2011

Additionally, this flood destroyed the gate operation house at the downstream of the Sul Dam, washed away the panel for gate control, and made the gallery under the dam body impassable. Fortunately, the operator of the Sul Dam repaired the gallery, and made the gate operation possible. However, such the trouble is considered to be a serious problem, because any damages of the structure under the dam body would directly cause collapse of the dam.

According to the hearing from the operator of the Sul Dam, the causes of the trouble are considered as follows,

- Flood water overtopping from the spillway flowed backward, and destroyed the downstream wall of the operation house. Spillway. Moreover, the flood water destroyed upstream slide door and reached the dam body.
- Outflow from the reservoir through the conduit gate under the dam body crashed the upper wall of the concrete channel, and the uplift or negativer pressure destroyed the upper wall concrete.

Source: JICA Survey Team

Damage of the Gate Operation House at Downstream of Sul Dam

Considering the problem mentioned above, increasing of the flow capacity of the conduits of the Sul and Oeste Dams by additional conduits was proposed and agreed at the Counter Part Meeting in September, 2011, in order to improve safety and flood control function of the dams.

As for the Sul Dam, an additional conduit will be installed under ground of the right bank of the Sul Dam as tunnel type, and as for the Oeste Dam will be installed in new block of the dam which will be consructed on the left abutment of the dam.

The capacity of the additional conduits should be same as existing conduits, that is why,

i) Velocity for lowering water level of the reservoirs will be doubled by both existing and additional conduits.

ii) Additional conduits will work as substitutes of the existing conduits.

The general features of the additional conduits are as follows,

i) **OesteDam:** the additional conduit and control gate will be installed in the new dam block on the left abutment, and the conduit will be connected to the enegy dissipator of the dam by new open channel;

- Design discharge: 180m^3/s
- Control gate: width 5.0m x height 4.4m
- Bottomo elevation of the gate: EL.350.4m
- Connecting open channel: channel width 5.0m x length 180m

ii) **Sul Dam:** the additional conduit will be installed under ground of the right bank of the dam as tunnel type, flood control gate will be installed at the entrance of the tunnel, flood water will be dicharged to the downstream river through the tunnel by gravity.

- Design discharge: 200m^3/s
- Control gate: 3.9m×3.9m
- Bottomo elevation of the gate: EL.380m
- Tunnel type channel: length 430m, diameter 6.0m, gradient 1/60

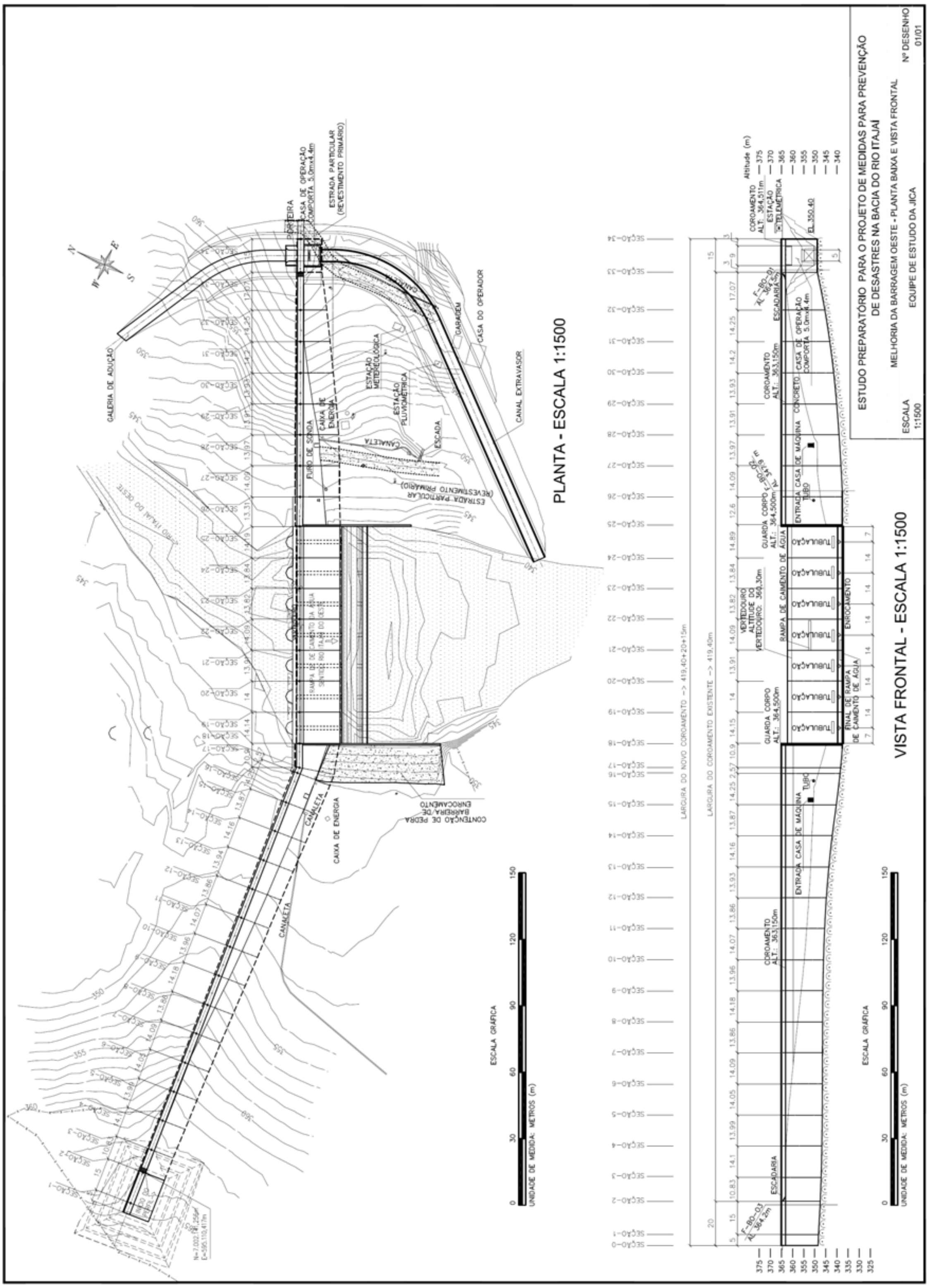


Figure 7.4.2 Heigtening of the Oeste Dam and Additional Conduit (1/2)

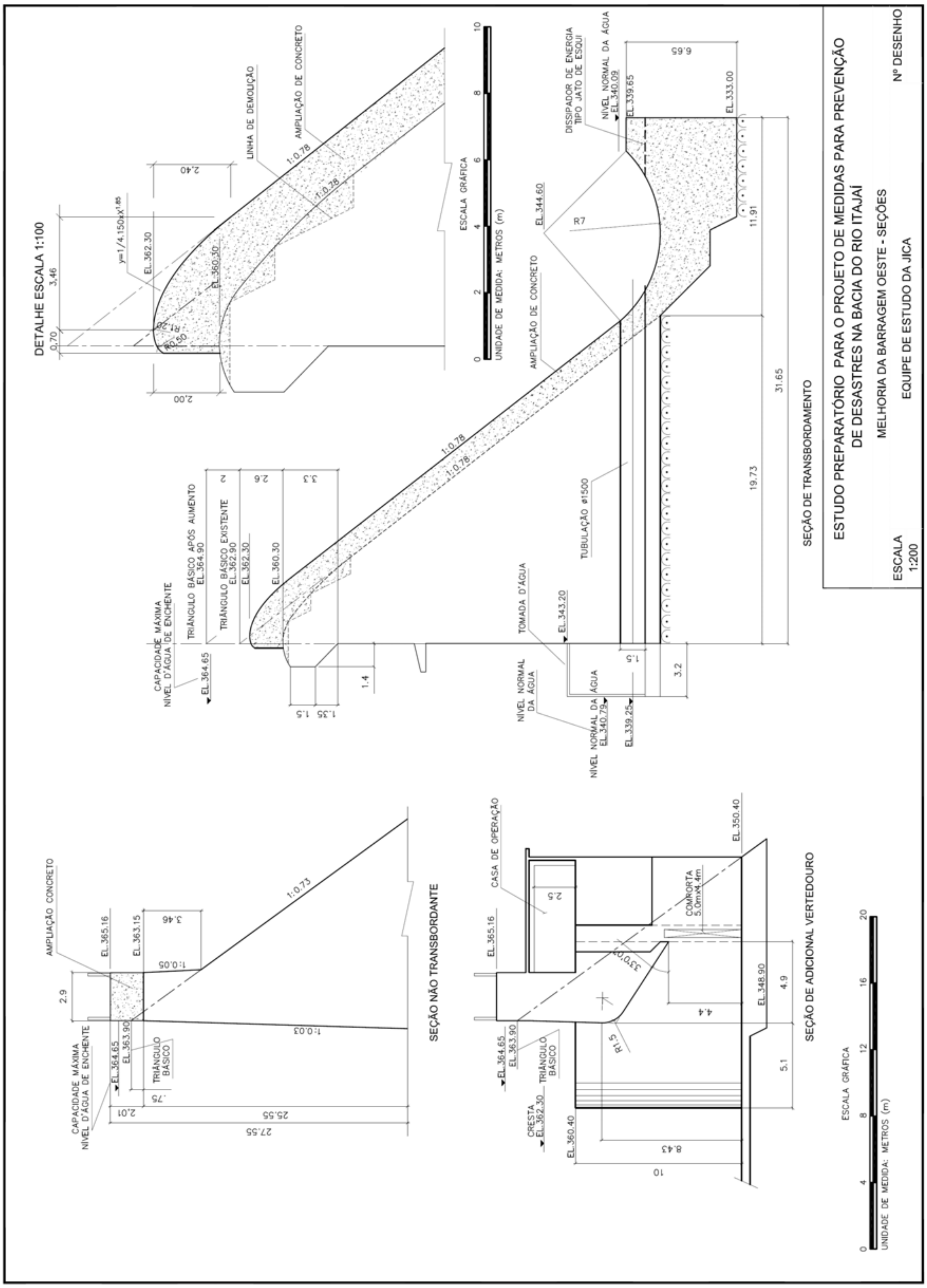


Figure 7.4.3 Heigtening of the Oeste Dam and Additional Conduit (2/2)

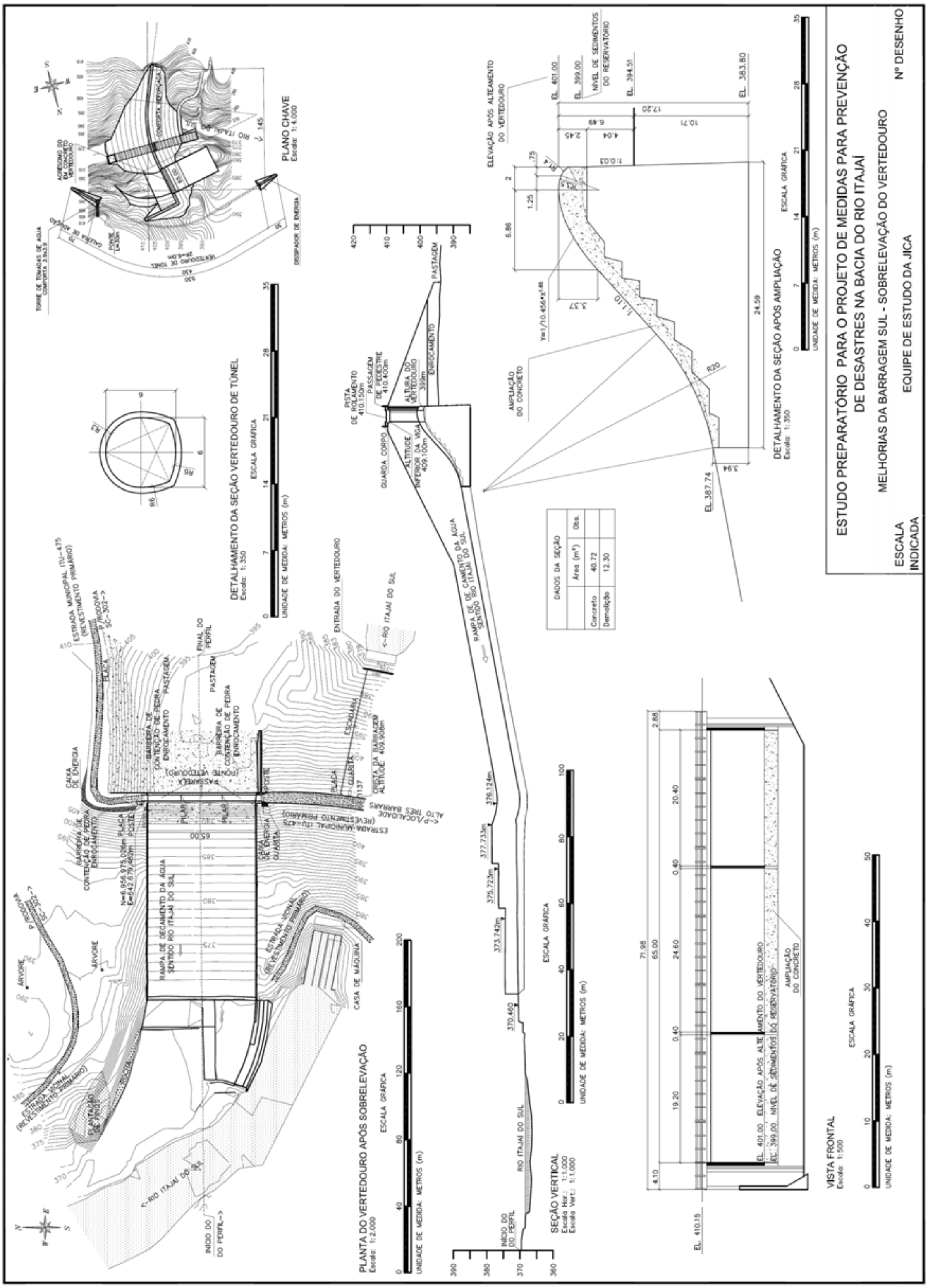


Figure 7.4.4 Heigtening of the Sul Dam and Additional Conduit

CHAPTER 8 FEASIBILITY STUDY FOR MODIFICATION OF EXISTING HYDROPOWER DAM

8.1 Flood Control Plan and Existing Facilities

8.1.1 Flood Control Plan

The existing two dams of CELESC in the Benedito River, named the Rio Bonito Dam and the Pinhal Dam, are now used for hydropower generation. In the M/P, these dams are proposed to be used also for flood control by means of pre-releasing.

The present flow capacity of the Benedito River in Timbo city is around 860 m^3/s, and the 10-year flood discharge is around 920 m^3/s. Therefore, the flow capacity is not enough for the 10-year flood.

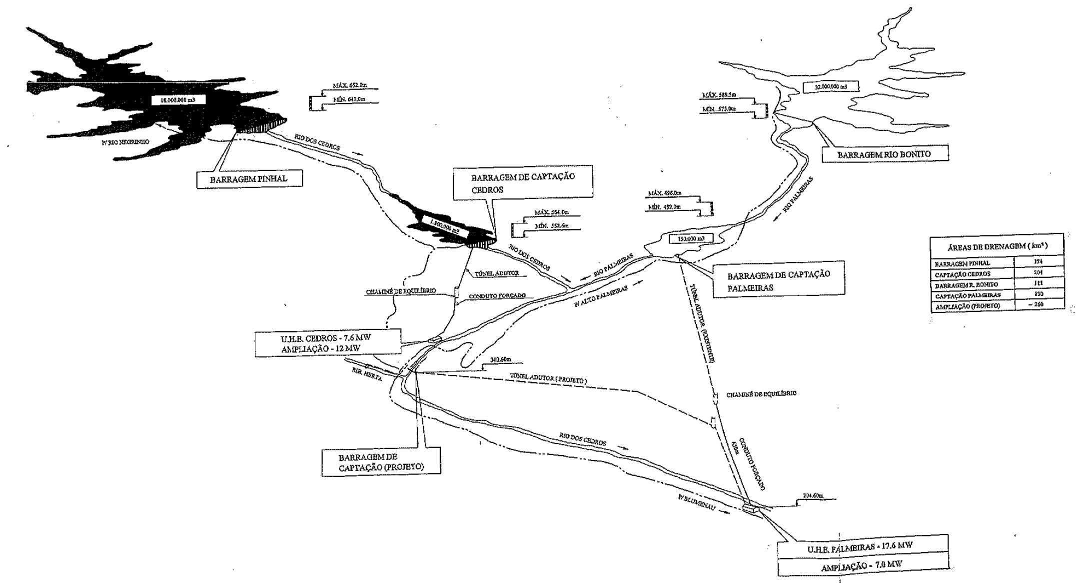
The total inflow into these two dams of the 10-year flood is 210 m^3/s. The total outflow from these dams should be reduced by 140 m^3/s so as not to exceed the current flow capacity in Timbo city.

8.1.2 Existing Facilities

(1) Gneral Features of Two Dams

Both the Rio Bonito and Pinhal Dams are of type of rock fill dam, and the catchment areas are 120 km^2 for the Rio Bonito Dam and 180 km^2 for the Pinhal Dam.

Figure 8.1.1 shows the current hydropower generation system by CELESC in the Rio dos Cedros River. As shown in the figure, the system comprised two water storage reservoirs (Rio Bonito and Pinhal Dams), two intake dams (Palmeiras and Cedros Dams), and two hydropower stations.



Source: CELESC

Figure 8.1.1 General Features of Two Dams

Tables 8.1.1 and 8.1.2 show the general features of both dams. Both of dams have spillways with gates and intakes. Water from intakes of these accumulation dams is released directly to downstream river.

Table 8.1.1 General Features of Rio Bonito Dam

		Features	Remarks
Dam	Dam type	Rock fill	
	Year of completion	1963	
	Height of dam	19.0 m	
	Crest elevation of dam	About EL.592 m (uncertain)	Visual estimation
Reservoir	Catchment area	119.8 km^2	
	Total volume	32,000,000 m^3	
	Maximum water level	EL.589.5 m	Not based on the IBGE system
	Minimum water level	EL.583.5 m	Not based on the IBGE system
Intake	Elevation of bottom	EL.573.7 m	Not based on the IBGE system
	Gate size	Height 3.0 m x Width 2.6 m	
	Gate type	Sluice gate (hoist type)	
	Gate control	Gate can be controlled to any opening position by local control with electric power	
Spillway	Crest elevation	EL.587.3 m	Not based on the IBGE system
	Gate type	Flap gate (hoist type)	
	Gate size	Height 2.2 m x Width 9.0 m x 2 gates	Crest of Gate : EL.589.5 m
	Gate control	Gates can be controlled to any opening position by local control with electric power	

Source: CELESC (from existing materials and interview)


Spillway Gate (left) and Intake Tower (right) of Rio Bonito Dam

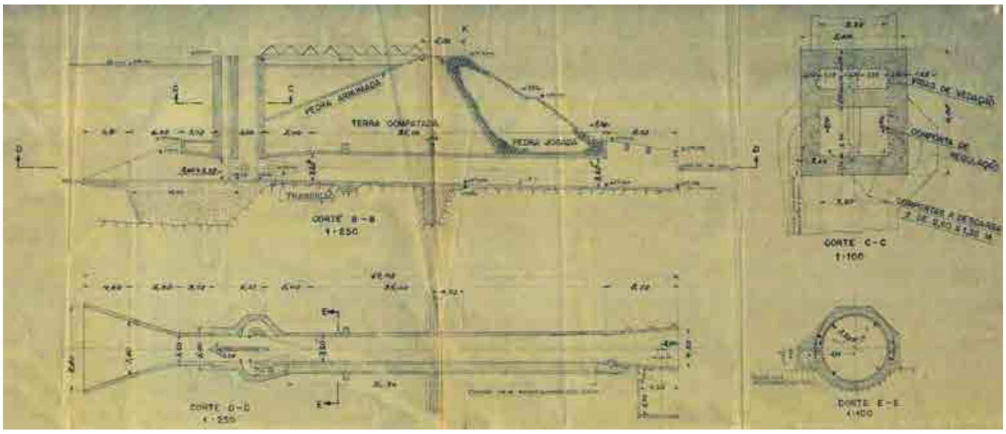
Table 8.1.2 General Features of Pinhal Dam

		Features	Remarks
Dam	Dam type	Earth and rock fill type	
	Year of completion	1949	
	Height of dam	19.0 m	
	Elevation of dam top	About EL.654 m (uncertain)	Visual estimation
Reservoir	Catchment area	179.9 km^2	
	Total volume	18,000,000 m^3	
	Maximum water level	EL.652.0 m	Not based on the IBGE system
	Minimum water level	EL.641.0 m	Not based on the IBGE system
Intake	Elevation of bottom	EL.638.2 m	Not based on the IBGE system
	Gate size	Height 2.6 m x Width 1.35 m x 2gates	
	Gate type	Sluice gate (rack type)	
	Gate control	Gates can be controlled to any opening position by local control with electric power	
Spillway (with gate)	Crest elevation	EL.651.0 m	Not based on the IBGE system
	Gate type	Sluice (rack type)	
	Gate size	Height 1.0 m x Width 4.0 m x 2gates	Crest of Gate : EL.652.0m
	Gate control	Gates can be controlled to any opening position by local control with electric power	
Spillway (without gate)	Crest elevation	EL.652.0 m	Not based on the IBGE system
	Crest length	53 m	

Source: CELESC (from existing materials and interview)

Spillway (left) and Iintake Tower (right) of Pinhal Dam

Figure 8.1.2 is a drawing of conduit and river outlet of Pinhal Dam. The river outlet has circle cross section with 3.2m diameter. On the other hand, no drawing of the intake facilities of Rio Bonito Dam is available at CELESC.



Source: CELESC

Figure 8.1.2 Drawing of Intake Channel of Pinhal Dam

(2) Relation of Reservoir Water Level – Storage Volume and Outflow Discharge

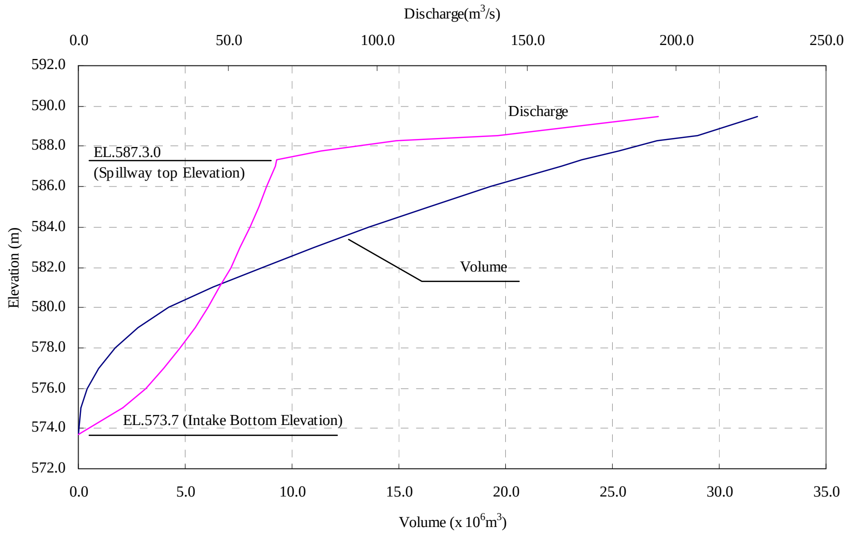
Table 8.1.3 shows the relation between reservoir water level and storage volume (hereinafter called H-V curve), and the relation between reservoir water level and outflow discharge (hereinafter called the H-Q curve) at both dams. The outflow discharge is the total discharge to be released from the conduits and spillways when the gates are fully opened.

Table 8.1.3 H-V and H-Q Curve

Rio Bonito Dam			Pinhal Dam		
Elevation (EL.m)	Volume (x 10^6 m^3)	Discharge (m^3/s)	Elevation (EL.m)	Volume (x 10^6 m^3)	Discharge (m^3/s)
573.7	0.0	0.0	638.2	0.2	0.0
575.0	0.1	15.0	643.0	1.1	34.9
576.0	0.4	22.5	644.0	2.0	39.6
577.0	1.0	28.5	645.0	3.1	43.7
578.0	1.7	34.0	646.0	4.4	47.5
579.0	2.8	39.0	647.0	6.0	51.1
580.0	4.2	43.2	648.0	7.9	54.4
581.0	6.3	47.2	649.0	9.9	57.5
582.0	8.6	50.9	650.0	12.4	60.4
583.0	11.0	54.1	651.0	15.2	63.2
584.0	13.6	57.3	651.2	15.7	65.0
585.0	16.4	60.3	651.4	16.4	67.8
586.0	19.3	63.0	651.6	17.0	71.2
587.0	22.6	65.9	651.8	17.7	75.1
587.3	23.6	66.5	652.0	18.4	79.5
587.8	25.3	81.1	652.2	19.1	92.4
588.3	27.1	106.3	652.4	19.9	112.2
588.5	29.0	140.1			
589.5	31.8	193.7			

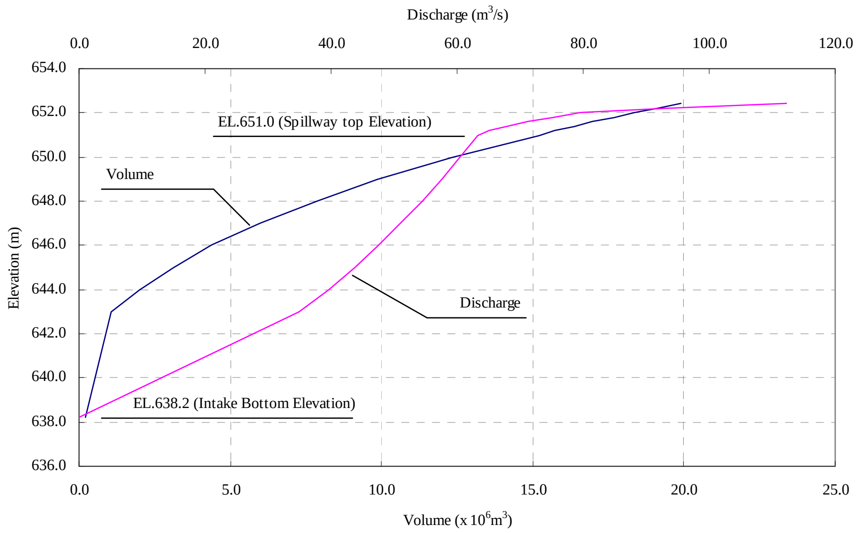
Source: CELESC

Figures 8.1.4 and 8.1.5 shows the H-V and H-Q curves at both dams.



Source: CELESC

Figure 8.1.3 H-V and H-Q Curve of Rio Bonito Dam



Source: CELESC

Figure 8.1.4 H-V and H-Q Curve of Pinhal Dam

(3) Current Operation for Floods

Dam operators of the hydropower plant are usually on standby in the office at the Palmeiras power station, and two operators visit each dam once or twice a day for the gates operation and inspection of the facilities. When flood will occur, the one operator stands by at the dam throughout the flood for gate operation.

In the past time, CELESC always kept the reservoir water level of both dams at 1 m lower than maximum water level in order to avoid the overflowing from the spillways.

But persently, when a flood is forecasted to occur in the catchment area of these dams, CIRAM informs the forecasted information to CELESC, and CELESC decides to release the stored water to lower the reservoir water level by 50 cm from maximum water level according to their own judgment. CELESC tries to keep this water level during the flood to avoid the overflowing from the spillways.

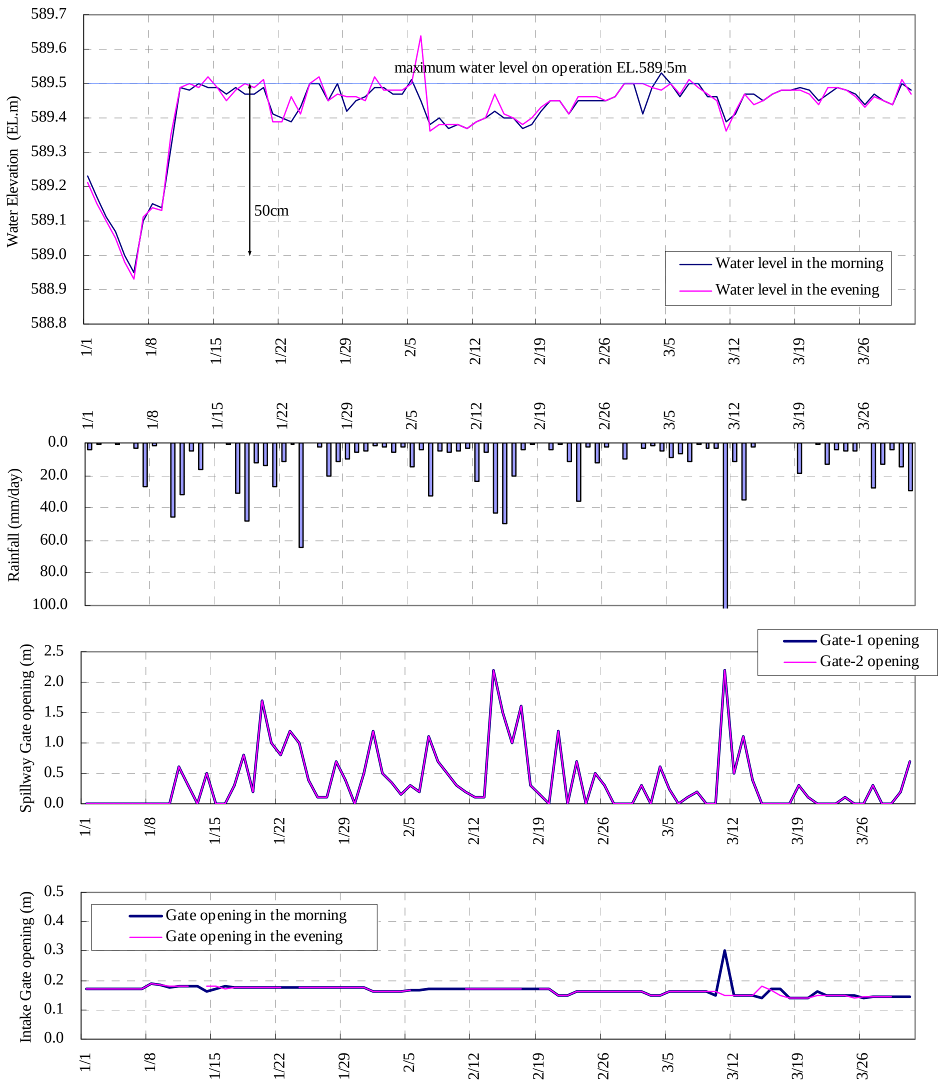
Figures 8.1.5 and 8.1.6 show the operation of both dams in the period from January to March in 2011.

As for the Rio Bonito Dam, total rainfall from January to March in 2011 was 1,048 mm.

Total rainfall in this period of the ANA stations in the Rio dos Cedros River are 552 mm at Timbo (1950 to 2006), 563 mm at Arrozeira (1950 to 2009), 559 mm at Barra do Avencal (1985 to 2006). Rainfall at the Rio Bonito Dam in this period was much more than the average rainfall from January to March in the Rio dos Cedros.

The water level at the Rio Bonito Dam was once drawn down to 589 m (50 cm from the maximum water level) in elevation in the beginning of January, and soon recovered in the middle of January. The water level was almost constant around 589.4 m to 589.5 m in elevation from the middle of January to March.

The gate opening of the spillway usually varied from 0 to 1.0 m, and more than 2.0 m during the period of heavy rainfall. On the other hand, the gate opening of the intake was almost constant around 0.15 to 0.2 m.

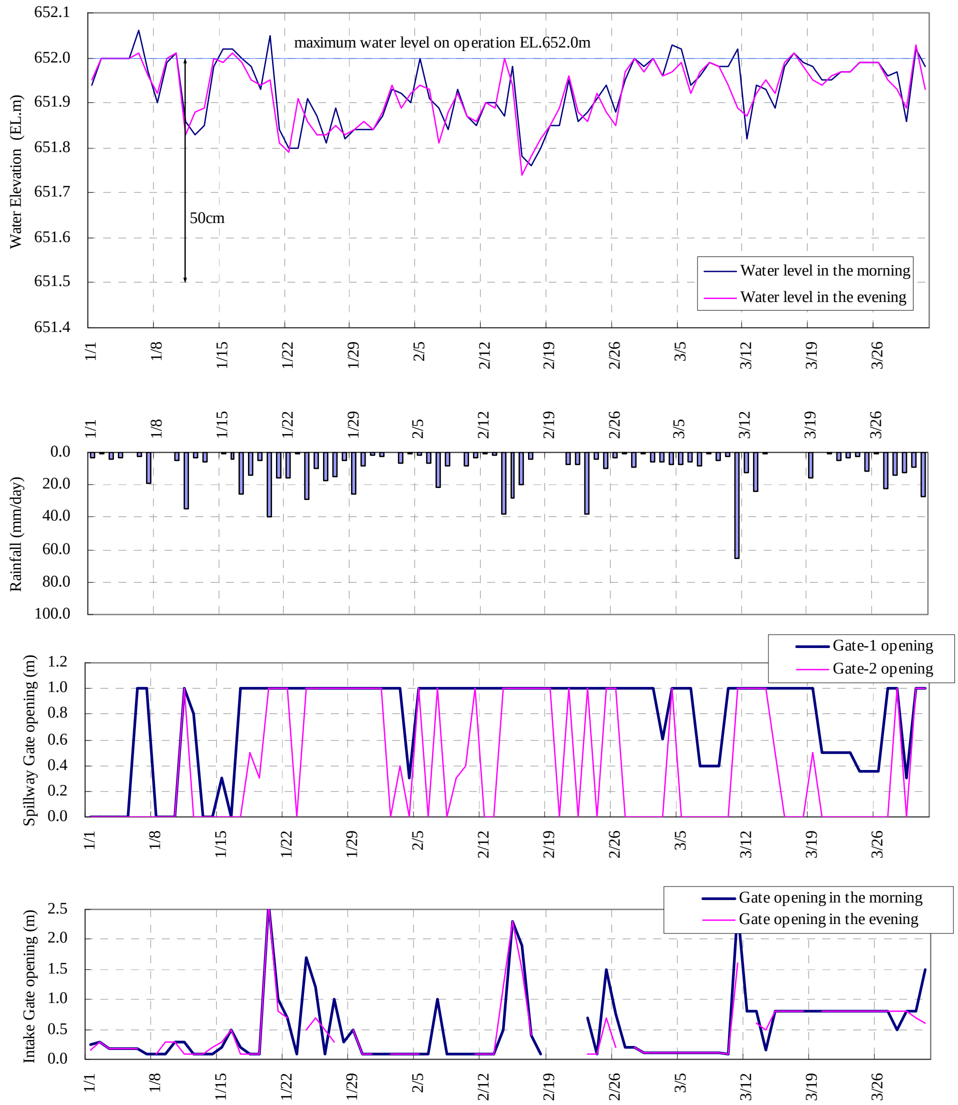


Source: CELESC

Figure 8.1.5 Operation of Rio Bonito Dam

As for the Pinhal Dam, total rainfall from January to March in 2011 was 825 mm. This was also much more than the average rainfall from January to March in the Rio dos Cedros.

The water level of Pinhal Dam had been maintained almost constant, varying in 20 cm from EL.651.8 m to EL.652 m. The gate opening of the spillway was usually 1.0 m fully. On the other hand the gate opening of the intake usually varies from 0.1 to 0.3 m, and more than 2.0 m during the period of heavy rainfall.



Source: CELESC

Figure 8.1.6 Operation of Pinhal Dam

The water levels of both dams were controlled to be maintained almost constant. The water level of Rio Bonito Dam was controlled mainly with spillway gate, and the water level of Pinhal Dam was controlled mainly with intake gate.

8.2 Dam Operation for Pre-releasing

8.2.1 Operation of the Hydropower Dams for Flood Control

(1) Basic Policy

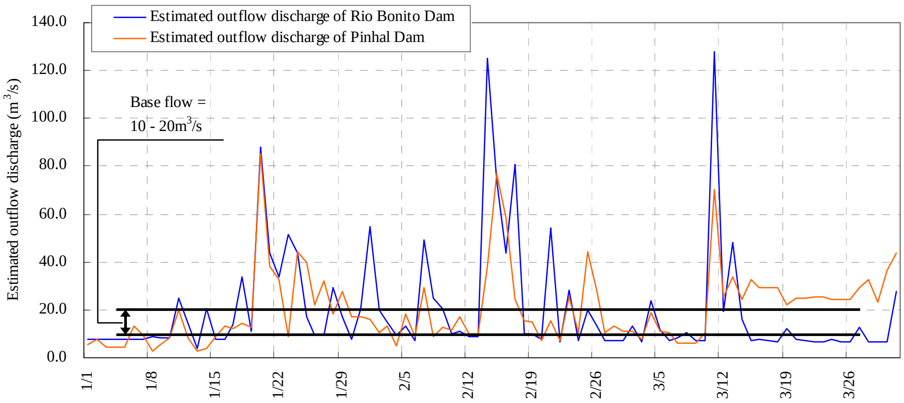
CELESC releases the stored water to lower the reservoir water level by 50 cm in the current operation, when floods are forecasted to occur by CIRAM. In this connection, pre-releasing method is proposed to mitigate flood damage in Timbo and Rio dos Cedros cities.

(2) Possible Pre-releasing Discharge from the Dams

According to the H-Q curve at both dams shown in Figures 8.1.3 and 8.1.4, the total discharge capacity is around 190 m^3/s at the Rio Bonito Dam at the maximum water level of 589.5 m in elevation, 80m^3/s at the Pinhal Dam at the maximum water level of 652 m in elevation, when the gates are fully opened.

On the other hand, Figure 8.2.1 shows the estimated outflow discharge at the both dams based on the operation records of gate openings and water levels.

The estimated outflow discharge is around 10 to 20 m^3/s during the period from January to March except floods. As the water levels of the dams during this period are almost constant, the base flow into the dams is also considered to be 10 to 20 m^3/s.



Source: JICA Survey Team

Figure 8.2.1 Estimated Outflow Discharge from Rio Bonito Dam and Pinhal Dam

(3) Required Flood Control Volume for Pre-releasing

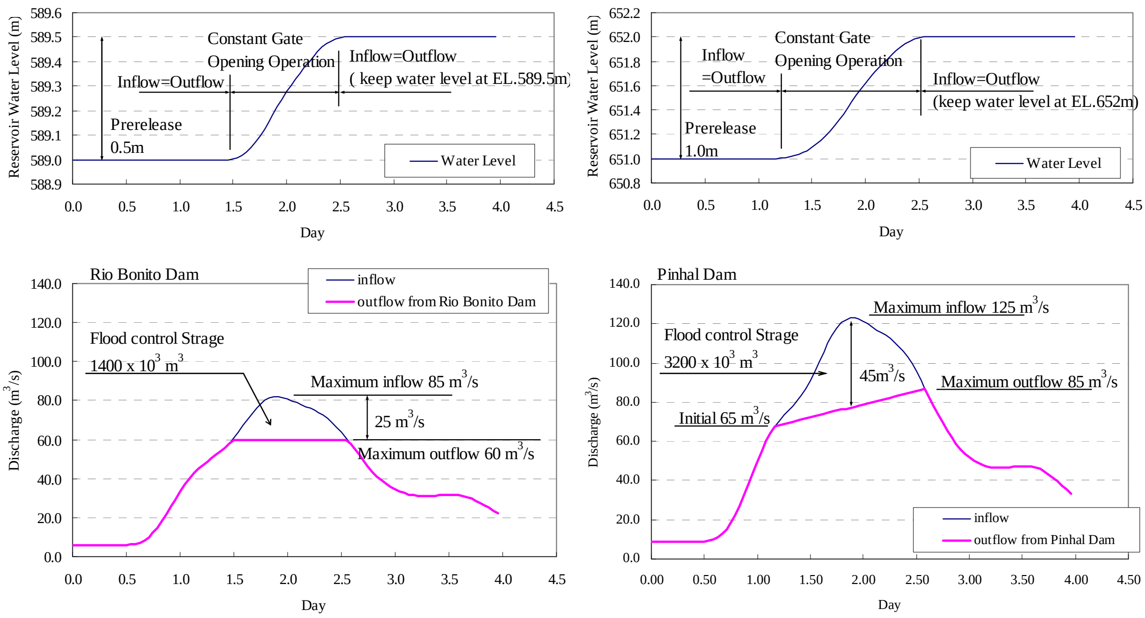
In order to regulate the outflow discharge from both dams not to exceed 140 m^3/s for the 10-year flood with a peak discharge of 210 m^3/s, the required flood control volume to be created by pre-releasing was examined by simulation of reservoir operation at both dams. The results of examination are summarized in Table 8.2.1. As indicated in this table, the required volume for pre-releasing was estimated to be 1.4 million m^3 for the Rio Bonito dam and 3.2 million m^3 for the Pinhal dam, respectively. Figure 8.2.1 shows the simulation results of the proposed flood control operations at both dams.

Table 8.2.1 Required Flood Control Volume to be Created by Pre-releasing at Two Dams

	Rio Bonito Dam	Pinhal Dam
Maximum water level in operation	EL.589.5 m	EL.652.0 m
Drawing down by pre-releasing	-0.5 m	-1.0 m
Water level after pre-releasing	EL.589.0 m	EL.651.0 m
Volume for flood control by pre-releasing	1400 x 10^6 m^3	3200 x 10^6 m^3
Maximum inflow discharge	85 m^3/s	125 m^3/s
Maximum outflow discharge	60 m^3/s	85 m^3/s
Reduction of discharge at the peak time of inflow	25 m^3/s	45 m^3/s

Operation of gates during flood control Gate opening of the spillway Gate opening of the intake	Constant opening 0.5 m 2.6 m	Constant opening 1.0 m 2.6 m
Operation of gates before flood control	Keep the water level at EL.589 m(inflow = outflow) by operating intake gate	Keep the water level at EL.651 m (inflow = outflow) by operating intake gate
Operation of gates after flood control	Keep the water level at EL.589.5 m (inflow = outflow) by operating spillway gate	Keep the water level at EL.652 m (inflow = outflow) by operating spillway gate

Source: JICA Survey Team



Source: JICA Survey Team

Figure 8.2.2 Operation of Rio Bonito Dam and Pinhal Dam for Flood Control

It is very important that the outflow discharge from dams must be kept less than or equal to the inflow discharge during any floods.

The water level shall reach the maximum water level (EL.589.5 m at the Rio Bonito Dam, EL.652 m at the Pinhal Dam) earlier than the time expected in the case of excess floods. The water level should be kept at the maximum water level above by controling the outflow discharge equal to the inflow by operating spillway gates.

(4) Operation Method of Pre-releasing

Based on the required flood control volume by pre-releasing in the above, pre-releasing discharge and duration of pre-releasing shall be determined as illustrated in Figure 8.2.3.

The discharge capacity of the Pinhal Dam is around 60 to 80 m^3/s at the water level of EL.651 to EL.652 m as indicated in Figure 8.1.4. However, as the base inflow into the Pinhal Dam is around 10 to 20 m^3/s as shown in Figure 8.2.1, the possible pre-releasing discharge from the Pinhal Dam is estimated around 40 to 60 m^3/s.

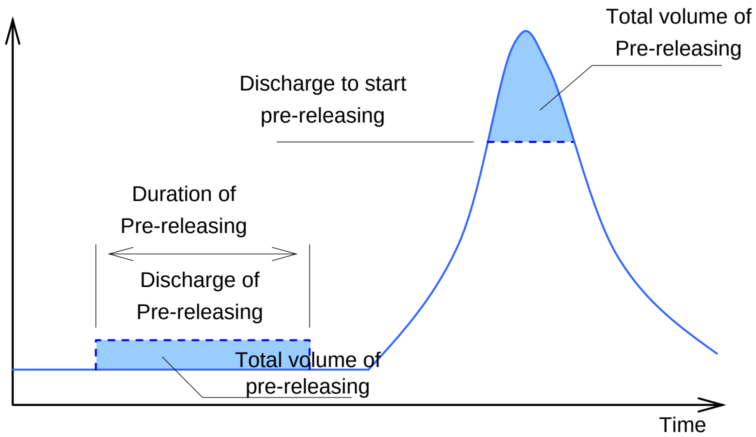
On the other hand, the required total volume of the pre-releasing is estimated 3200 x 10^6 m^3. Therefore the required time for pre-releasing is about 18 hours.

- Required Time for pre-releasing	18 hours
- Average pre-releasing discharge	Rio Bonito Dam 1400 x 10^3 m^3 / 18 hours = 22 m^3/s
	Pinhal Dam 3200 x 10^3 m^3 / 18 hours = 50 m^3/s
	Total 72 m^3/s

As the pre-releasing increases the flow in the downstream river, the operators at the dams and river administrator should pay attention to the security along the downstream river reaches. Some points to be noted for executing the pre-releasing are as follows.

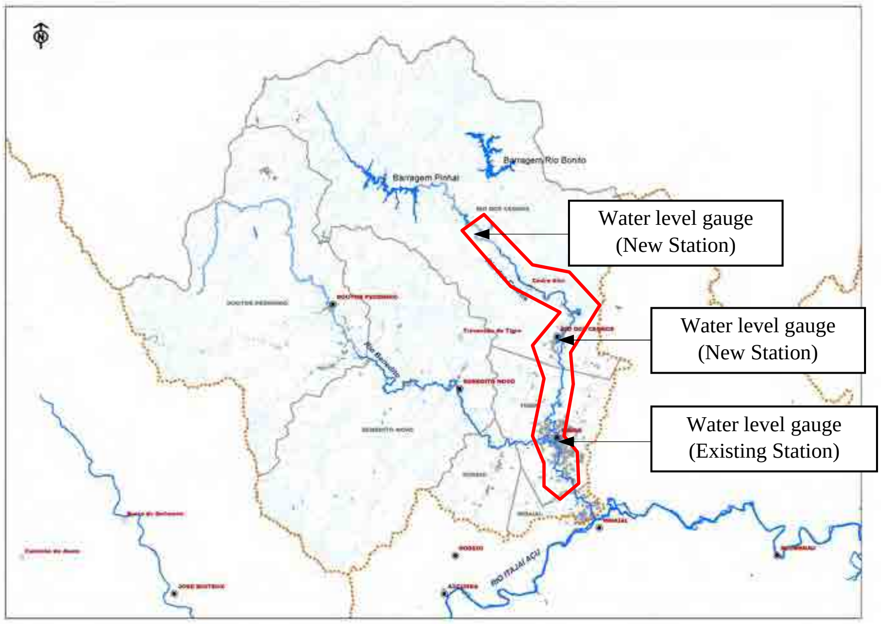
- For preventing overflowing from the river channel by the pre-releasing, water level along the downstream river reaches should be monitored in Timbo and Rio dos Cedros cities. Installation of 3 water level gauge stations was planned in Supporting Report Annex D.
- Warning and alert should be provided to the residents along the downstream river reaches by sirens before the pre-releasing. Installation of 3 sirens in the downstream river of the dams was also planned in Supporting Report Annex D.

Comparatively long time is needed for pre-releasing due to the small flow capacities of the spillway and intake of the Pinhal dam. It is recommended to increase the flow capacity of the spillway of the Pinhal dam by lowering the spillway top in order to reduce the time for pre-releasing.



Source: JICA Survey Team

Figure 8.2.3 Illustration of Pre-releasing Method



Source: JICA Survey Team

Figure 8.2.4 Location Map of the Monitoring and Warning for Pre-releasing

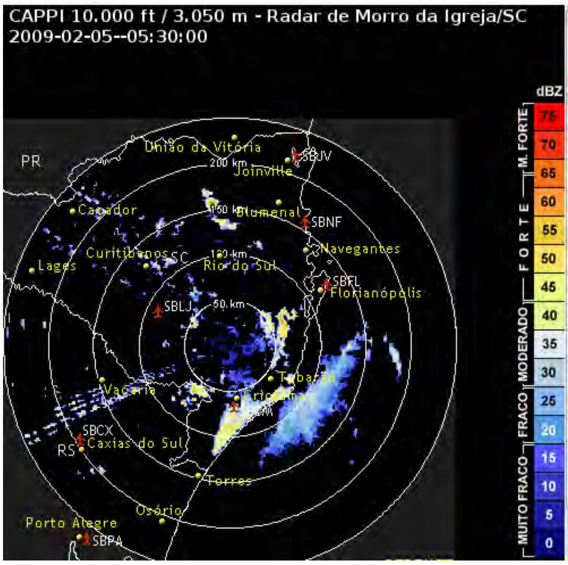
(5) Judgment for the Pre-releasing

1) Current Rainfall Forecast

As mentioned in Section 8.1, CELESC lowers the reservoir water level in advance by pre-releasing based on the forecasted rainfall information by CIRAM. The rainfall is forecasted by ETA model of INPE and WRF model of USA for the coming 5 days. The grid scale of the analysis is 40 km x 40 km, and 20 km x 20 km, respectively.

But the accuracy of the forecasting has not been satisfactory, as the meteorological radar has been installed only in Urubici, far from Rio dos Cedros city (see Figure 8.2.5).

At present, some organizations of the SC State like Defesa Civil, EPAGRI, SDS intend to establish a new rainfall forecasting system with satellite data from INPE, and also establish a flood forecasting system. Accuracy of the forecasting is expected to be improved by developing these new systems.



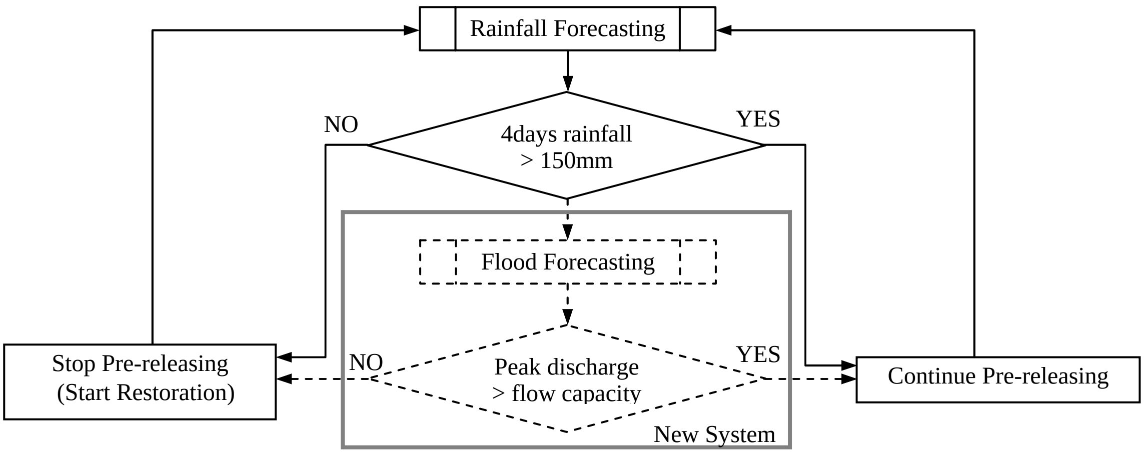
Source: SDS

Figure 8.2.5 Location of the Current Meteorological Rader and its Cover Area

2) Judgment for Pre-releasing

The flow capacity of the Benedito River in Timbo city is estimated more than the peak discharge of the 5-year flood, and is less than the 10-year flood discharge.

When the peak discharge is forecasted to be more than the current flow capacity in Timbo (5 to 10-year floods), the pre-releasing shall be determined to be executed. One of the criteria of the judgment may be the rainfall of the 150 mm/4 days (5-year probable rainfall). In addition, after the first judgment, the forecasting and judgment should be repeated continuously by updating the hydro- meteorological information.



Source: JICA Survey Team

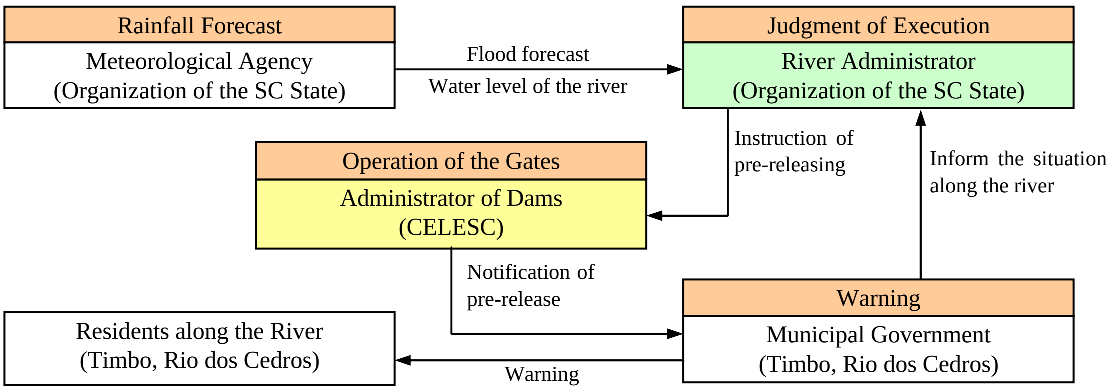
Figure 8.2.6 Flowchart of Judgment for Pre-releasing

Determination of judgment for pre-releasing shall need more detail study during the implemetation stage.

8.2.2 Recommendation of Organization for Operation

Figure 8.2.7 shows the recommendation of the organization for executing the pre-releasing from the two dams.

- As the river administrator should be responsible for the judgment and operation of the pre-releasing, he instructs the execution of the pre-releasing to CELESC based on the flood forecasting by CIRAM and monitored water levels along the Rio dos Cedros River.
- The gates operation at the dams is carried out by the operators of CELESC.
- CELESC should inform the pre-releasing to the municipal governments (Timbo and Rio dos Cedros) along the Rio dos Cedros River in advance, and municipal governments should alarm the residents along the river.
- If any flood attacked to the catchment area of both dams though the pre-releasing was execued, lowered water levels of the dam reservoirs might not restore. The State organization responsible for flood management and CELESC should discuss and decide the regulation of such compensations.



Source: JICA Survey Team

Figure 8.2.7 Recommendation of Organization for Dam Operation

CHAPTER 9 FEASIBILITY STUDY ON FLOODGATES IN ITAJAI MIRIM RIVER

9.1 Characteristic of Floods in Itajai Mirim River

9.1.1 Topographic Characteristic in Itajai City

(1) Itajai Mirim River

Itajai city is a famous port city located at the mouth of the Itajai River. An urban area in Itajai city is located in the downstream area of the BR-101 (federal road), and the upstream area of the BR-101 is mainly used for farmland and pasture.

The Itajai Mirim River is one of large tributaries of the Itajai River which joins the Itajai River at the urban center of Itajai city. The Itajai Mirim River originally flowed down with meandering through Itajai city, but the shortcut channel was constructed in 1970s. In this Chapter, original channel is called “the Old Mirim”, and shortcut channel is “the Canal” (the Canal is named in topographic map of IBGE).

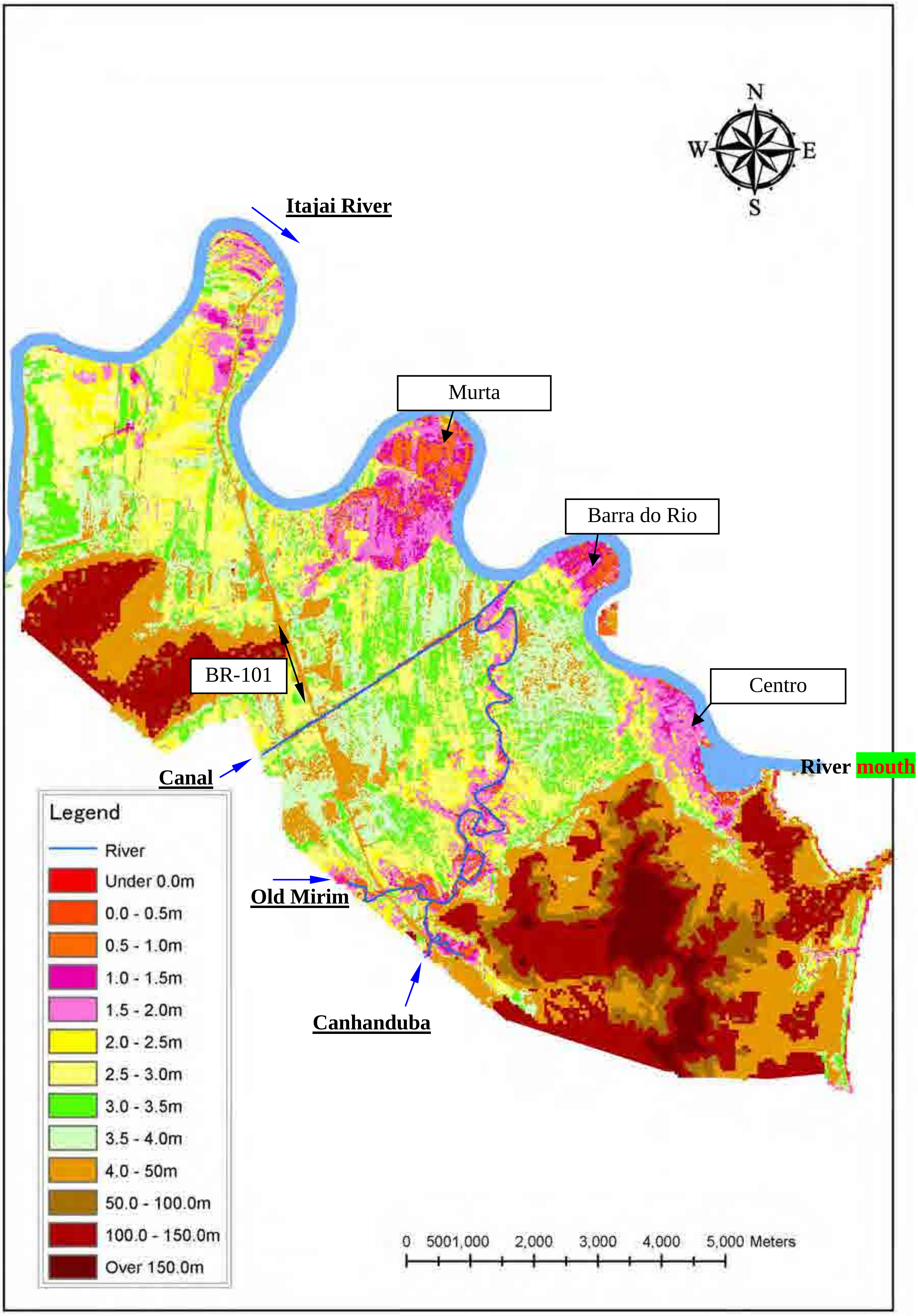
The Canal diverges from the Old Mirim in the upstream of the BR-101, and meets again with the Old Mirim at about 1km upstream point of confluence with the Itajai River. And small tributary named the Canhanduba River drains into the Old Mirim.

(2) Topographical Characteristics and Mitigation Measures for Flood

Figure 9.1.1 presents the distribution of ground elevation in Itajai city based on the 1/2000 topographical map prepared by municipal government of Itajai city. As indicated in this figure, the riparian area along the Old Mirim is generally low elevation varying EL.1.0 to 3.0 m. On the other hand, the area along the Canal is relatively high elevation of around EL.3.0 to 4.0 m. Though the Canal has larger flow capacity, the Old Mirim has caused frequent flooding and inundation to its riparian area. Two “floodgates” in the Old Mirim proposed in the M/P aim at mitigation against inundation along the Old Mirim.

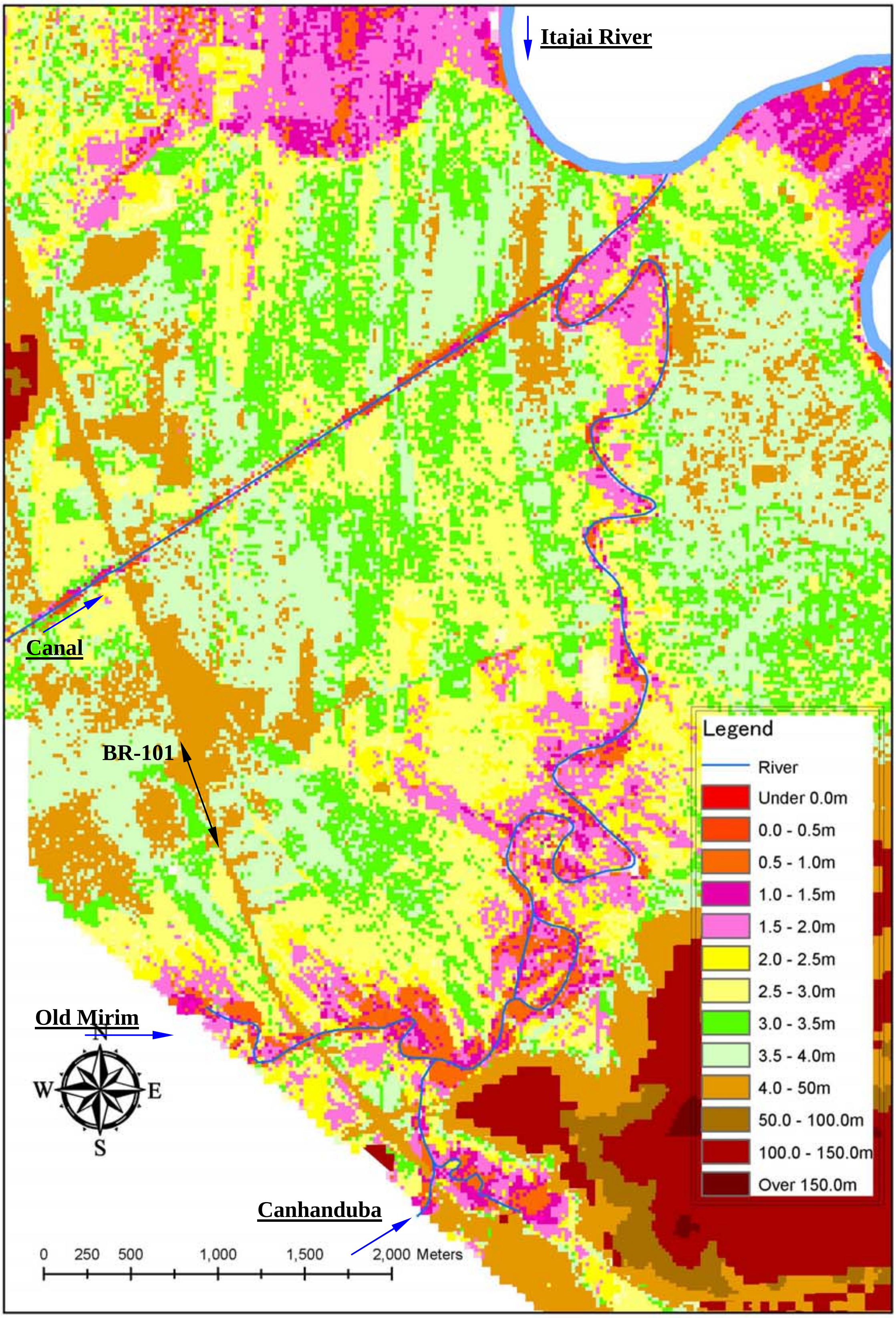
The inside area of the meandering stretch of the the Itajai River such as Centro, Barra do Rio, Murta district in Itajai city is extremely low in elevation of 1.0 to 2.0 m. These areas tend to be inundated by only tidal wave in the spring tide, and suffer more inundation by occurrence of even small floods when the high tide. The M/P proposes “floodway and diversion weir” against the 50-year flood in the Itajai River.

Farmland and pasture areas in the upstream of the BR-101 along both the Itajai River and Itajai Mirim River are the areas of floodplain, and have a function of natural retarding basin for Itajai city. The proposed mitigation measures such as “floodgates”, “floodway” are planned on the premise that the floodplain should be preserved. Therefore, any developments in the floodplain should be restricted, or increase of discharge caused by developments must be compensated by provision of other measures.



Source: Municipal Government of Itajai city

Figure 9.1.1 Distribution of Ground Elevation in Itajai City (1/2)



Source: Municipal Government of Itajai city

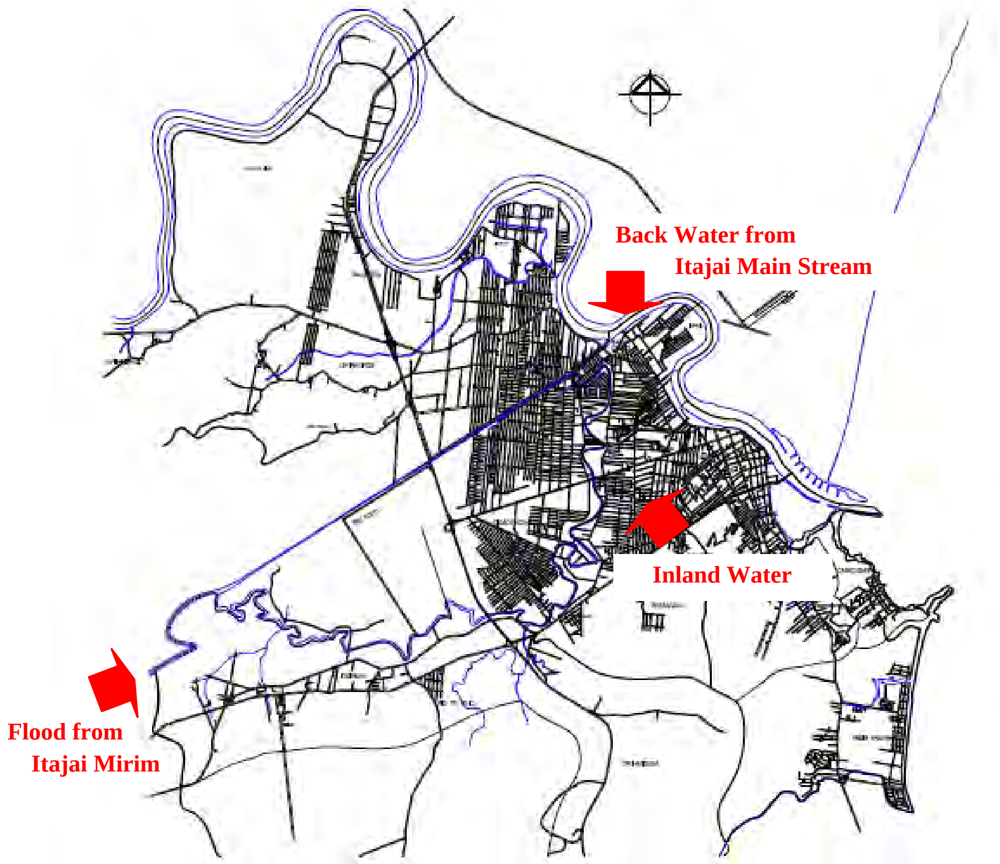
Figure 9.1.1 Distribution of Ground Elevation in Itajai City (2/2)

9.1.2 Flood Characteristics of Itajai Mirim River

(1) Causes of Inundation in Riparian Area of the Old Mirim

It is considered that there are mainly three causes of the inundation in Itajai city along the Old Mirim as illustrated in Figure 9.1.2.

The first is the flood from the upstream basin area of the Itajai Mirim River, the second is the backwater from the Itajai River, and the third is the inland water due to rainfall over this area as illustrated below.



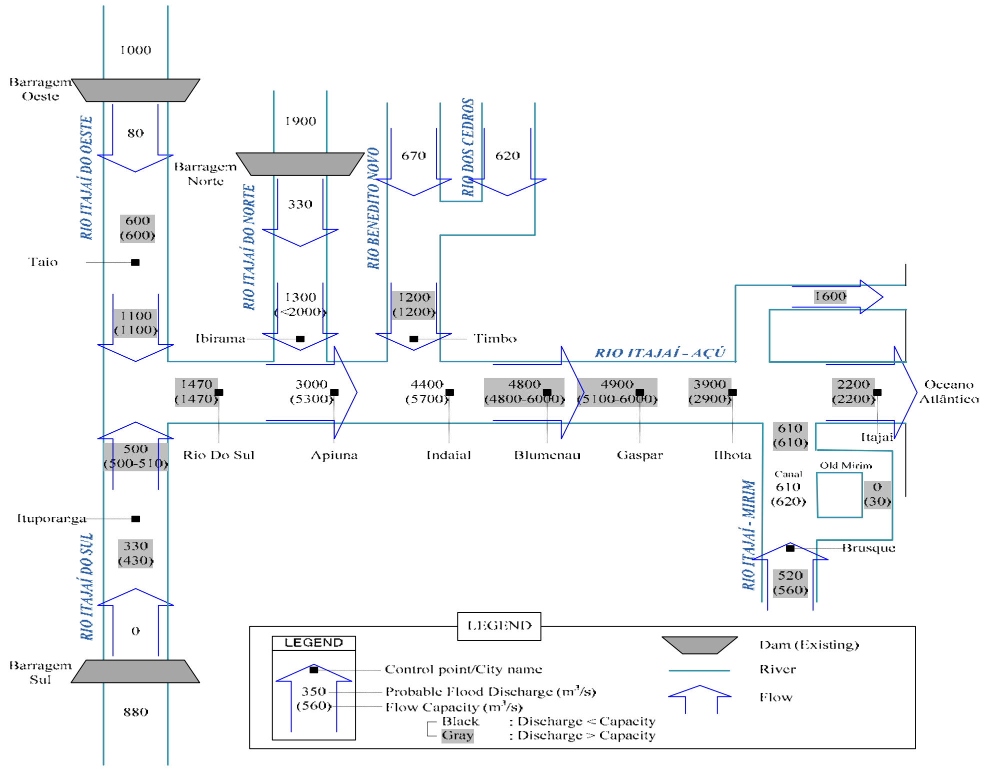
Source: JICA Survey Team

Figure 9.1.2 Causes of Inundation along the Old Mirim

(2) Probable Flood Discharge in the Itajai Mirim

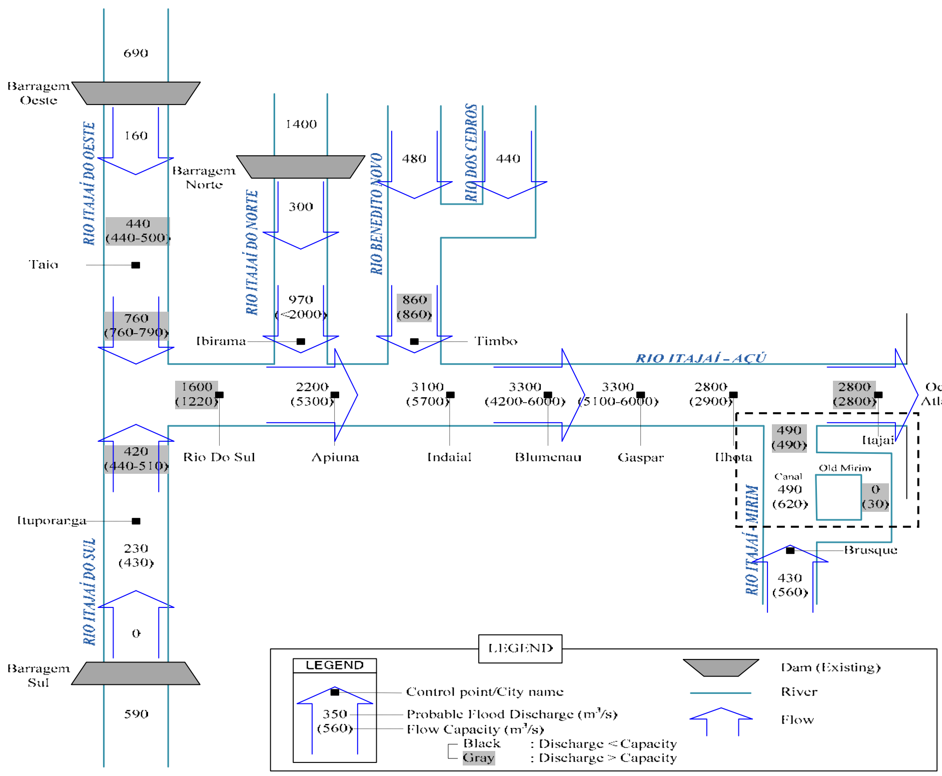
The State Government decided that the Itajai River should be protected from 50-year flood as an ultimate goal. Taking into consideration huge budget for construction, the government also decided a stage-wise development for implementation along this line, the M/P recommended the first stage project to be protected from a 10-year flood.

Figures 9.1.3 and 9.1.4 show the design discharge distribution of the 50-year and 10-year floods. These discharges are calculated on the assumption of implementation of the mitigation measures in the upstream area, such as floodway, dam heightening, river improvement, etc.



Source: JICA Survey Team

Figure 9.1.3 Design Discharge Distribution for 50-year Flood (Unit: m^3/s)



Source: JICA Survey Team

Figure 9.1.4 Design Discharge Distribution for 10-year Flood (Unit: m^3/s)

(3) Characteristics of Probable Floods in Itajai City

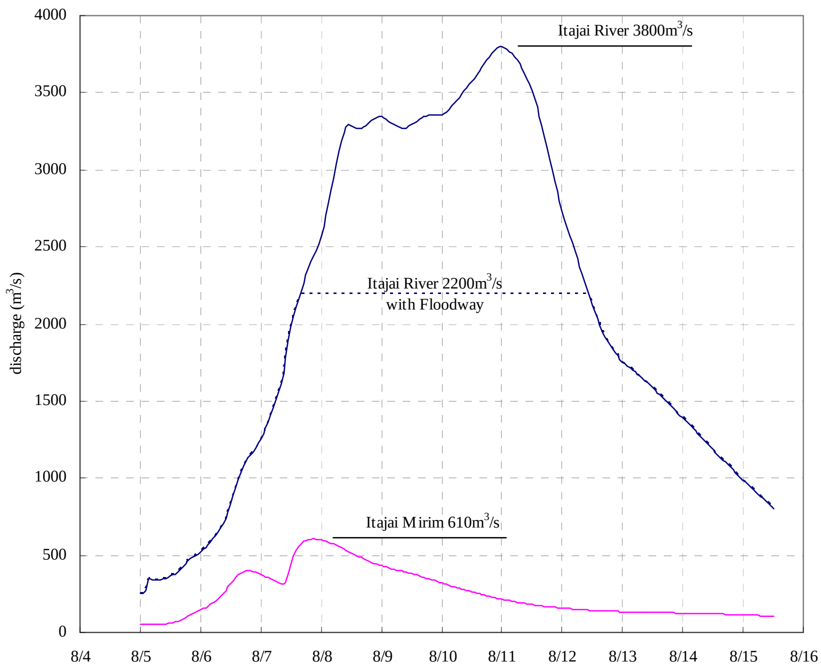
Hydrographs of 50-year and 10-year floods of both the Itajai and Itajai Mirim Rivers in Itajai city are shown in Figures 9.1.5 and 9.1.6. These hydrographs are estimated through runoff analysis and unsteady flow analysis. Details of flood runoff analysis are prepared in the Supporting Report A "Hydrology".

Figure 9.1.5 shows the 50-year flood hydrographs of the Itajai River together with the planned peak-cut hydrograph by the floodway. The 50-year flood hydrograph of the Itajai Mirim is already included the flood control effect by a new dam which is planned in the M/P in the upstream reaches of Brusque city.

In this F/S the design flood for the floodgate is applied the 50-year flood, considering that, once the gates are constructed for the 10-year flood, it would be difficult to be modified for the 50-year flood in the future without re-construction.

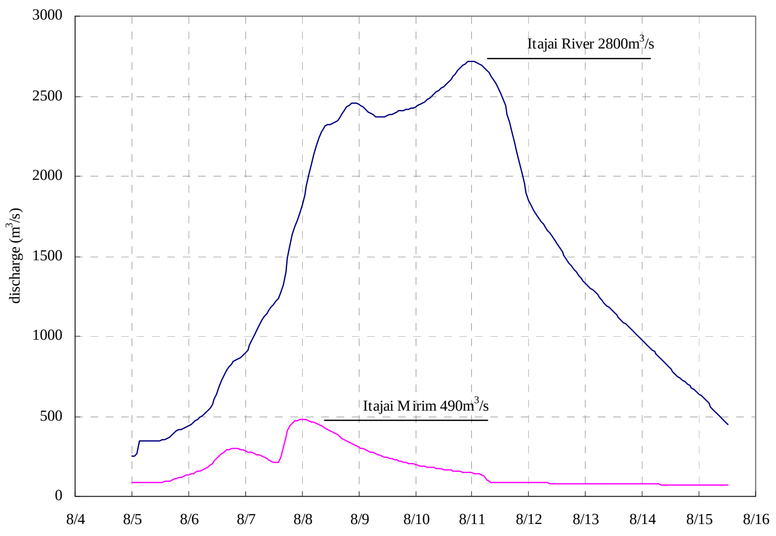
The characteristics of these hydrographs are described below.

- The peak discharge of the Itajai River come about three days later from the peak of the Itajai Mirim,
- The duration of the flood in the Itajai River is much longer than in the Itajai Mirim.



Source: JICA Survey Team

Figure 9.1.5 Hydrograph of 50-year Flood in Itajai City of Itajai River and Itajai Mirim



Source: JICA Survey Team

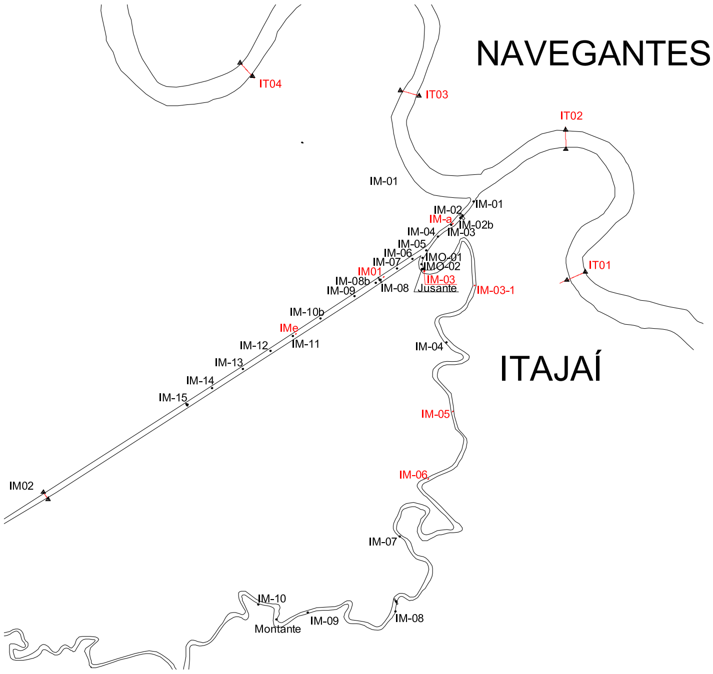
Figure 9.1.6 Hydrograph of 10-year Floods in Itajai City of Itajai River and Itajai Mirim

9.2 Flow Capacity of the Itajai Mirim River

9.2.1 Cross Sections of the Itajai Mirim River

The river cross section survey was carried out at 25 locations along the Itajai Mirim River (both of the Canal and Old Mirim) from March to May in 2011, to analyze the flow capacity of the Itajai Mirim River for provide design water level for the floodgates and associated dykes.

As, 9 cross sections have been already surveyed in 2010, totally 34 cross sections are available in the analysis. Among them, 21 cross sections are along the Canal, and 13 cross sections are along the Old Mirim.

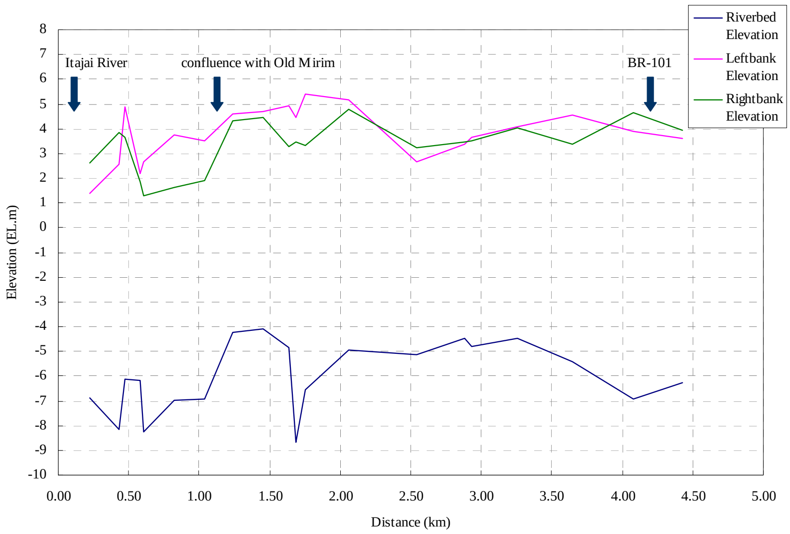


Source: JICA Survey Team

Figure 9.2.1 Locations of River Cross Section Survey

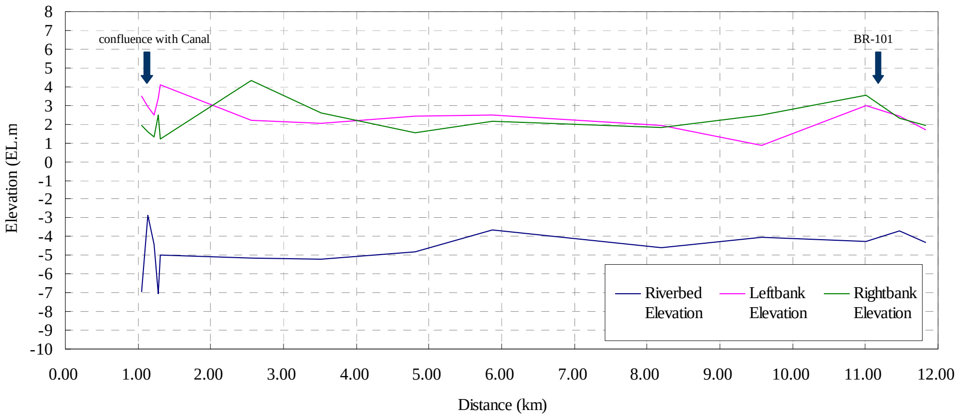
Figures 9.2.2 and 9.2.3, Table 9.2.1 show the elevations of riverbed, left bank, right bank, channel width at each cross section. Geometric characteristics of the channel are described below.

- Significant longitudinal gradient is not recognized in both rivers.
- Riverbed elevation of the Canal is in the range of -8 to -4 m, and riverbed elevation of the Old Mirim varies from -5 to -3.5 m except near the confluence.
- Riverbank elevation of the Canal varies from 1.5 to 5.5 m, and is remarkably low (1.5 to 2.0 m) especially on the downstream stretch from 0.6 to 1.0 km.
- Riverbank elevation of the stretch around 2.5 km along the Canal is also low (about 3.0 m).
- Riverbank elevation of the Old Mirim is very low except the right bank stretch around 2.5 km.
- Channel width of the Canal varies from 55 to 85m, and the Old Mirim is in 45 m to 70 m.



Source: JICA Survey Team

Figure 9.2.2 Longitudinal Profile of Canal



Source: JICA Survey Team

Figure 9.2.3 Longitudinal Profile of Old Mirim

Table 9.2.1 Elevation Data of Each Cross Section

Canal

Section surveyed in 2010	Section surveyed in 2011	Interval (m)	Distance (km)	Riverbed Elevation (EL.m)	Leftbank Elevation (EL.m)	Rightbank Elevation (EL.m)	Channel Width (m)	remarks
	IM-01	-209.2	0.2209	-6.873	1.371	2.622	70.586	
	IM-02	-39.7	0.4301	-8.16	2.588	3.848	88.235	
	IM-02b	-112.9	0.4698	-6.109	4.9	3.651	65.205	
IMa		0.0	0.5827	-6.152	2.171	1.853	56.757	surveyed in 2010
	IM-03	23.5	0.6062	-8.243	2.657	1.281	57.733	
	IM-04	216.2	0.8224	-6.993	3.729	1.633	61.092	
	IM-05	212.5	1.0349	-6.945	3.494	1.915	67.639	
	IM-06	198.6	1.2335	-4.214	4.615	4.333	64.867	
	IM-07	216.1	1.4496	-4.081	4.713	4.467	83.126	
IM01		184.1	1.6337	-4.846	4.917	3.272	76.052	surveyed in 2010
	IM-08	52.6	1.6863	-8.68	4.475	3.478	79.121	
	IM-08b	67.4	1.7537	-6.548	5.399	3.301	71.085	
	IM-09	302.8	2.0565	-4.932	5.154	4.775	67.965	
	IM-10b	483.7	2.5402	-5.123	2.673	3.219	64.833	
IMe		344.3	2.8845	-4.46	3.374	3.472	80.243	surveyed in 2010
	IM-11	45.9	2.9304	-4.804	3.658	3.534	77.642	
	IM-12	322.4	3.2528	-4.488	4.073	4.011	75.318	
	IM-13	394.6	3.6474	-5.397	4.562	3.374	78.767	
	IM-14	432.6	4.0800	-6.909	3.874	4.627	67.88	
	IM-15	350.4	4.4304	-6.267	3.602	3.925	76.005	
IM02			6.4432	-3.759	2.387	2.243	56.343	surveyed in 2010
IM03			11.3117	-3.494	4.177	4.456	66.062	surveyed in 2010

Old Mirim

Section surveyed in 2010	Section surveyed in 2011	Interval (m)	Distance (km)	Riverbed Elevation (EL.m)	Leftbank Elevation (EL.m)	Rightbank Elevation (EL.m)	Channel Width (m)	remarks
	IM-05	-99.0	1.0414	-6.945	3.494	1.915	67.639	Itajai River
	IMO-01	-79.0	1.1404	-2.881	2.922	1.573	59.542	
	IMO-02	-59.2	1.2194	-4.439	2.483	1.313	45.63	
	Jusante	-33.2	1.2786	-7.056	3.366	2.471	54.19	flood control gate site
IMb	IMO-03	0.0	1.3118	-4.993	4.098	1.21	64.194	surveyed in 2010
IM11	IMO-03-1	1,247.0	2.5588	-5.166	2.215	4.334	60.974	surveyed in 2010
	IMO-04	963.3	3.5221	-5.19	2.049	2.574	48.482	
IMc	IMO-05	1,279.9	4.8020	-4.835	2.437	1.533	49.267	surveyed in 2010
IMd	IMO-06	1,073.9	5.8759	-3.646	2.469	2.146	68.921	surveyed in 2010
	IMO-07	2,315.1	8.1910	-4.583	1.922	1.805	73.487	
	IMO-08	1,377.7	9.5687	-4.04	0.892	2.49	67.582	
IM12	IMO-09	1,439.8	11.0085	-4.24	2.993	3.55	51.927	surveyed in 2010
	Montante	458.1	11.4666	-3.728	2.453	2.338	52.78	flood control gate site
	IMO-10	362.1	11.8287	-4.306	1.682	1.919	52.849	
IM03			23.1546	-3.494	4.177	4.456		surveyed in 2010

Source: JICA Survey Team

9.2.2 Estimation of Flow Capacity of the Itajai Mirim River

(1) Flow Capacity

The Flow Capacity of the Itajai Mirim River is estimated by the non-uniform flow calculation. The flow analysis was carried on the following conditions,

1) Hydraulic Condition

a) The boundary condition of the non-uniform flow calculation is defined by the water level at the downstream end of the Itajai Mirim (the junction to the Itajai River), which is calculated by non-uniform flow calculation along the Itajai River.

i) The variables are defined as follows in this Supporting Report.

Q_1: discharge of the Itajai Mirim River

WL_1: water level at any points of the Itajai Mirim River when Q_1 flows in the Itajai Mirm

Q_0: discharge of the Itajai River when Q_1 flows in the Itajai Mirm River

WL_0: water level at the downstream end of Itajai Mirim when Q_0 flows in the Itajai River

ii) Relationship between WL_0 and Q_0 is as following equation estimated by the non-uniform flow calculation, when sea water level is high water (= 1.49 m).

$$WL_0 = 0.0000000434\ Q_0^2 + 0.0001505921\ Q_0 + 1.3959645420$$

iii) Relationship between Q_1 and Q_0 is defined as relationship of the probable peak discharge in each river.

$$Q_1 = 0.00002\ Q_0^2 + 0.106\ Q_0 + 39.4$$

iv) Boundary condition when discharge from the Itajai Mirim is Q_1 will be able to be calculated from ii) and iii).

b) Roughness coefficients of the Itajai River, the Canal and the Old Mirim are assumed respectively 0.030, 0.032 and 0.040 (see table x.x.x)

c) The starting channel section of the non-uniform flow calculation is the downstream end of the Itajai Mirim River under the given discharge for the water level calculation. Then the given discharge is tentatively divided into two discharges. This tentative distribution rate is finalized through several trial calculations to obtain the same water level at the upstream bifurcation of the Itajai Mirim River. The distribution of the discharge is summaried in the Table 9.2.2.

Table 9.2.2 Distribution of Discharge between Canal and Old Mirim

Discharge from the Itajai Mirim (1)	Discharge of the Canal (2)	Dicharge of the Old Mirim (3)	Distribution rate to the Canal (2)/(1)
100 m^3/s	75 m^3/s	25 m^3/s	0.75
200 m^3/s	148 m^3/s	52 m^3/s	0.74
300 m^3/s	216 m^3/s	84 m^3/s	0.72
400 m^3/s	276 m^3/s	124 m^3/s	0.69
500 m^3/s	325 m^3/s	175 m^3/s	0.65
600 m^3/s	378 m^3/s	222 m^3/s	0.63
700 m^3/s	441 m^3/s	259 m^3/s	0.63
800 m^3/s	504 m^3/s	296 m^3/s	0.63

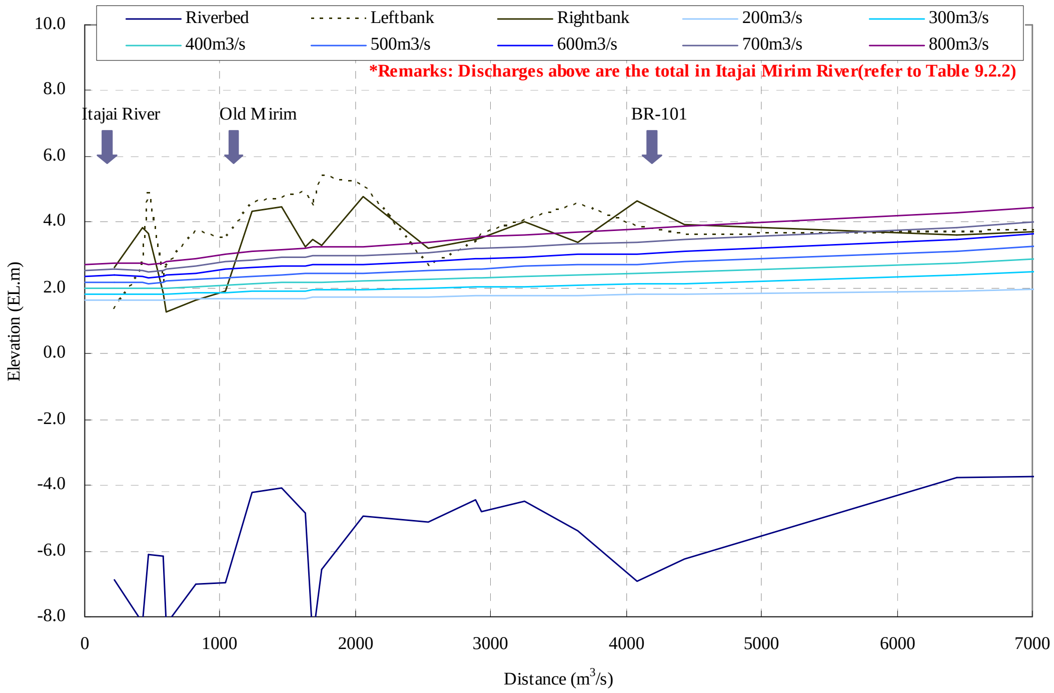
Source: JICA Survey Team

2) Results of Non-uniform Flow Calculation

The results of the non-uniform flow calculation are summaried below.

a) Canal

- The flow capacity on the right bank of the downstream stretch (from 0.6 km to 1.0 km) is extremely low. It therefore is considered that inundation would occur even when the discharge is less than 200 m^3/s. The flow capacity in this stretch is evaluated lower than the 5-year flood discharge (see Figure 9.2.6).
- Riverbank elevation of the stretch around 2.5km also is low (about 3.0 m). The flow capacity of this stretch is estimated to be about 600 m^3/s in the Itajai Mrim (378 m^3/s in the Canal, see Table 9.2.2). This is equivalent to the discharge of about 20 to 25-year flood discharge (see Figure 9.2.6).
- The upstream stretch of the BR-101 along the Canal has also low riverbank, and the flow capacity of this stretch is around 500 to 600m^3/s (325 to 378 m^3/s in the Canal) which is equivalent to about 15 to 20-year flood discharge.
- Other stretch (see Figure 9.2.4) has the flow capacity of more than 800m^3/s (504 m^3/s in the Canal). The flow capacity in this stretch is more than 50-year flood discharge.

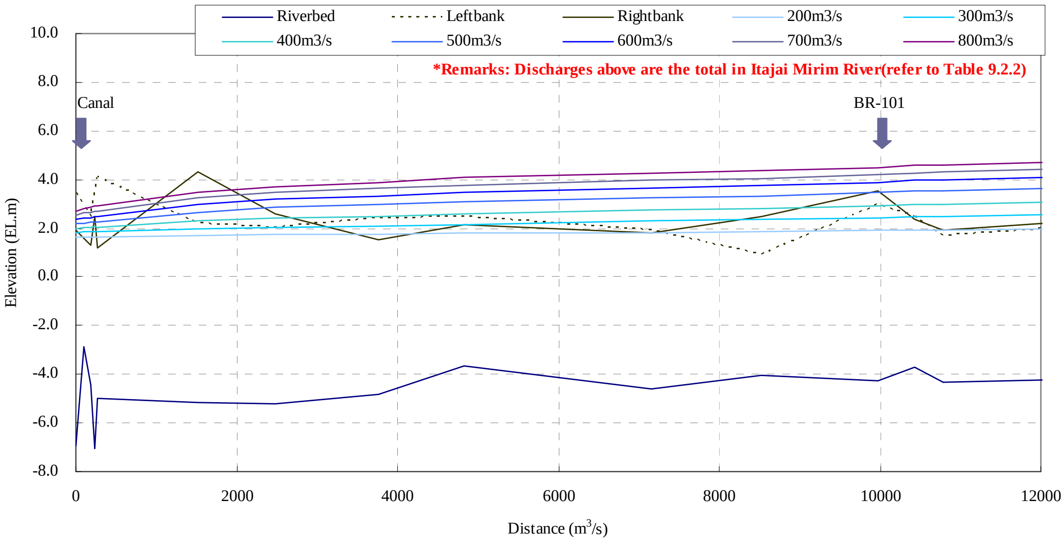


Source: JICA Survey Team

Figure 9.2.4 Water Levels by Discharge in Canal

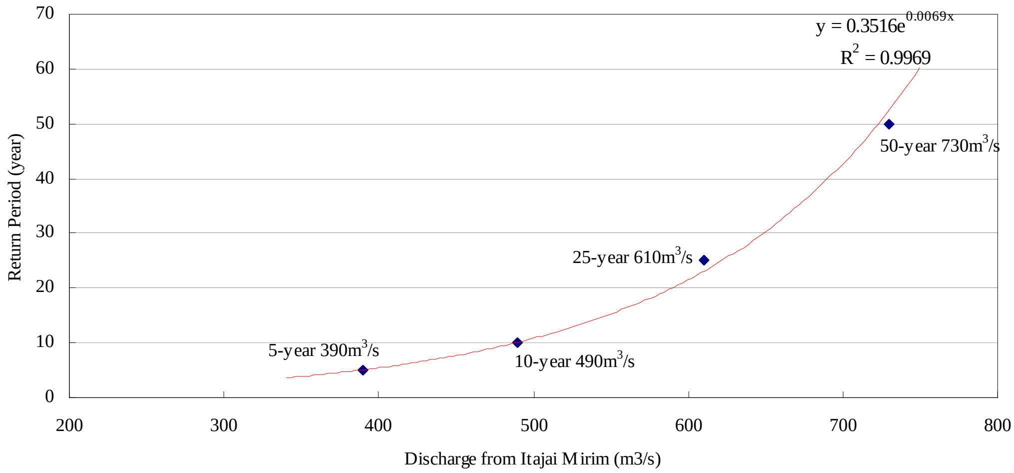
b) Old Mirim

- Riverbank elevation is very low except the right bank stretch around 2.5 km.
- The flow capacity varies 200 to 400 m^3/s in the Itajai Mirim River (52 to 124 m^3/s in the Old Mirim), which is evaluated to be less than 5-year flood discharge.
- The elevations in the stretch of 0 to 300 m on the right bank, and around 8.5 km on the left bank are extremely low. According to Defesa Civil of Itajai city, in this area flooding occurs even in times of spring tide and small flood.



Source: JICA Survey Team

Figure 9.2.5 Water Levels by Discharge in Old Mirim



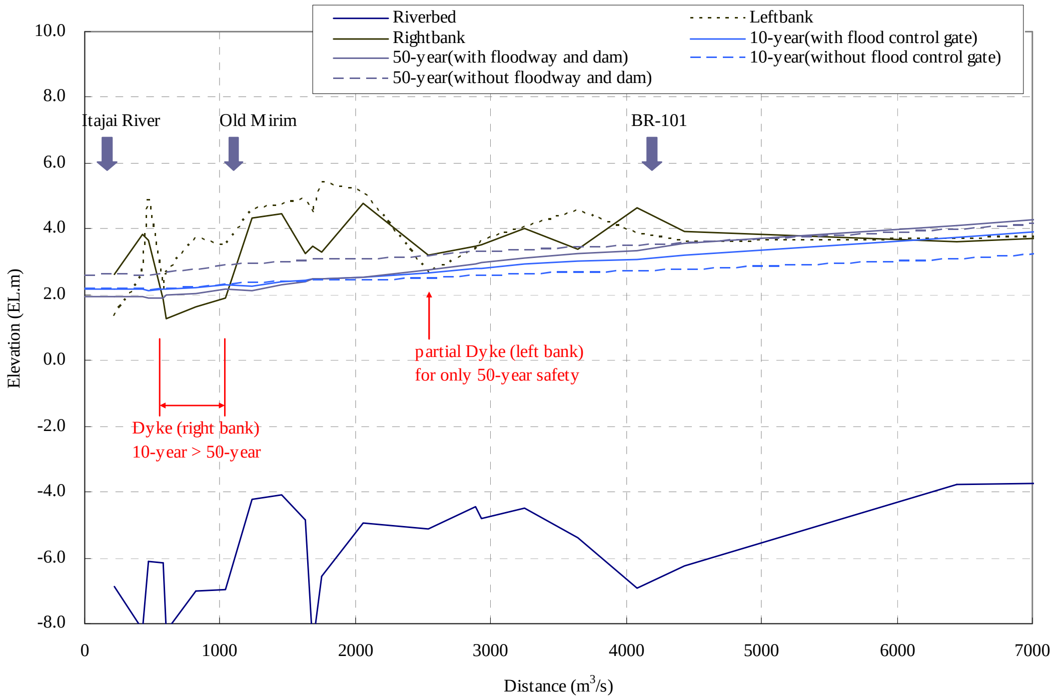
Source: JICA Survey Team

Figure 9.2.6 Relationship between Return Period and Discharge in Itajai Mirim

(2) Water Level by Probable Flood

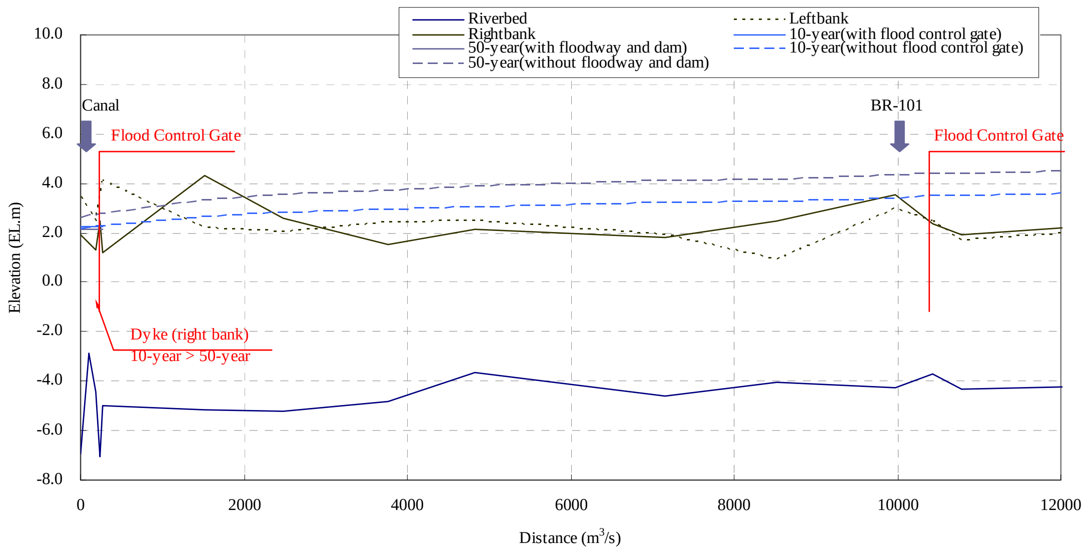
Figures 9.2.7 and 9.2.8 present the variation of water levels in the Itajai Mirim due to the flood with return period 10 and 50 years.

- In the stretch of around 500 m from the confluence of the Itajai River, the height of the right bank is lower than the water level of 10-year and 50-year flood.
- Left bank of the stretch around 2.5 km in the Canal is lower than the water level of 50-year flood.
- The downstream stretch of the “downstream floodgate” along the Old Mirim also needs dyke on right bank, and the elevation of this dyke is also decided by 10-year flood.
- The both bank along the Old Mirim are lower than the water level of 10-year and 50-year flood except the stretch from 0 to 2 km.



Source: JICA Survey Team

Figure 9.2.7 Water Levels by the 10 and 50-year Floods in the Canal



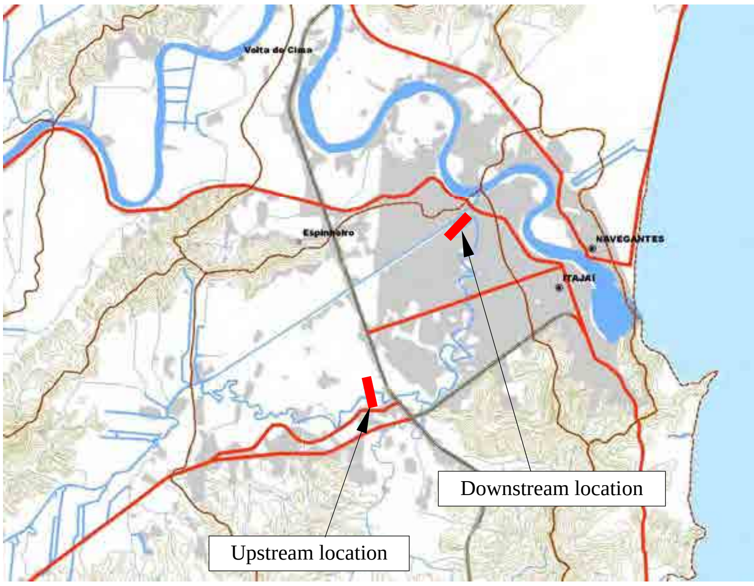
Source: JICA Survey Team

Figure 9.2.8 Water Levels by 10 and 50-year Floods in Old Mirim

9.3 Function and Operation of Floodgates

9.3.1 Function of Floodgates

Floodgates would be installed at two locations on the Old Mirim as shown in Figure 9.3.1 below. The gates of upstream and downstream locations are herein called respectively “downstream gate” and “upstream gate”.



Source: JICA Survey Team

Figure 9.3.1 Location Map of Floodgates in Old Mirim

As mentioned in Sections 9.1 and 9.2, as riparian area of the Old Mirim has lower ground elevation than the Canal, this area has been suffering from frequent flooding and inundations.

The construction department of the municipal government of Itajai city has been improving the current sewerage system. The upstream gate would prevent the flood from the Itajai Mirim River from entering the urban area. And the downstream gate would avoid the intrusion of backwater from the Itajai River.

9.3.2 Operation of Floodgates

This section explains the operation procedure of the floodgates. Some technical words used in this section are defined as follows.

- <u>Back water level</u>: Water level of the downstream end of the Old Mirim during floods of the Itajai River.

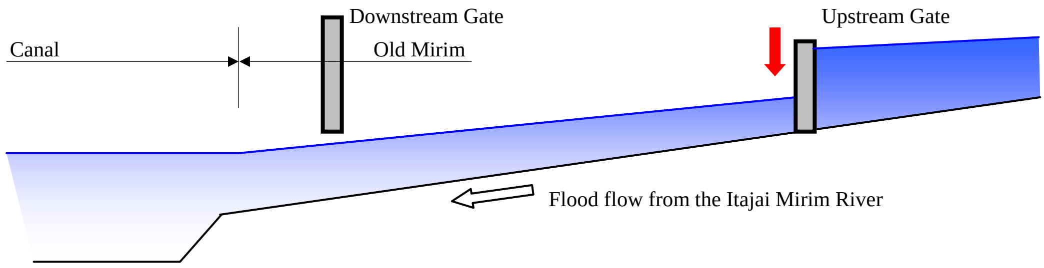
- <u>Inland water level</u>: Water level of the Old Mirim while the downstream gate is closed.

- <u>Allowable inland inundation level</u>: Allowable maximum inland water level in the riparian area along the Old Mirim while the design flood occurs.

- <u>Critical water level</u>: Back water level at the time when the downstream gate should be closed.

(1) Basic Procedure of the Operation

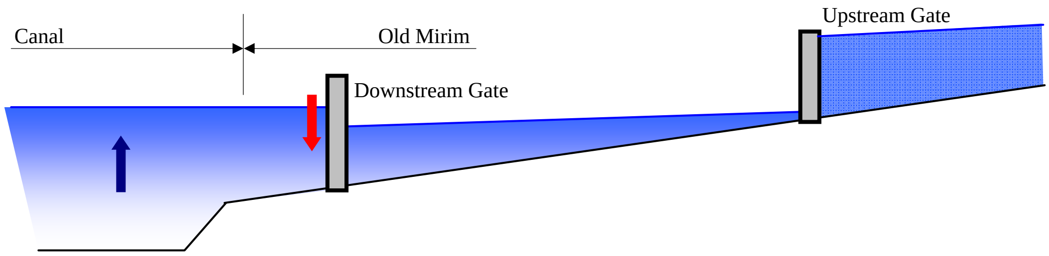
1) The upstream gate shall be closed when flood discharge exceeds the flow capacity of the Old Mirim as illustrated in Figure 9.3.2.



Source: JICA Survey Team

Figure 9.3.2 Operation of Floodgates (1/3)

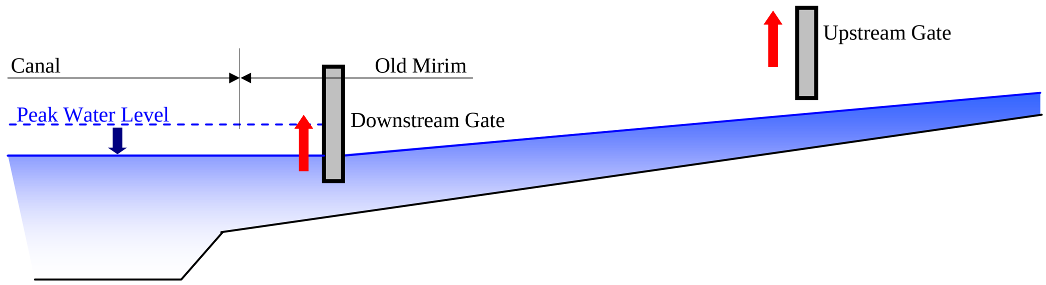
2) When the back water level of the Itajai River reaches the critical water level, the downstream gate shall be closed.



Source: JICA Survey Team

Figure 9.3.2 Operation of Floodgates (2/3)

3) When the back water level falls down and becomes equivalent to the inland water level of the Old Mirim, the downstream gate shall be opened. When the upstream gate is opened, released discharge from the gate shall be less than the flow capacity of the Old Mirim.



Source: JICA Survey Team

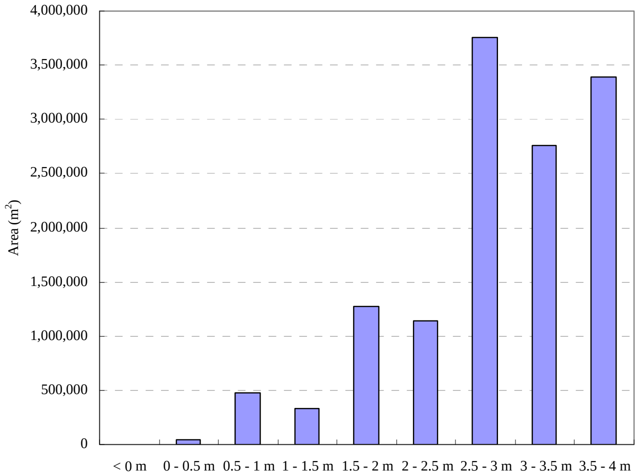
Figure 9.3.2 Operation of Floodgates (3/3)

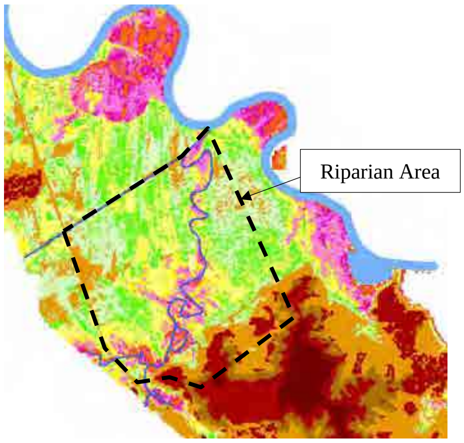
The water level of Old Mirim must not be higher than Canal when the downstream gate is closed. As mistakes of the gates operation may cause man-made inundation, the operation rules of floodgates should be elaborated carefully.

(2) Allowable Inland Inundation Level in the Riparian Area along the Old Mirim

While both the downstream and upstream gates are closed, inland water level of the Old Mirim may rise because of the inflow thereto from inland drainage area. Therefore, the allowable nland inundation level" should be defined to reflect the flood operation of the gates operation.

Almost of riparian area along the Old Mirim is higher than EL.1.5 m, and almost no residential area is located in the low-lying area of less than EL.1.5 m.





Source: JICA Survey Team

Figure 9.3.3 Area by Elevation in Riparian Area along Old Mirim

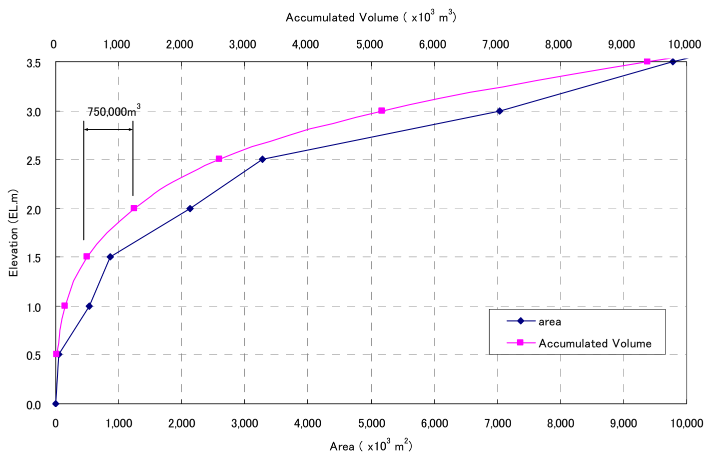
Water level due to the 10-year flood in riparian area along the Old Mirim is around EL.2 to EL.3 m as indicated in Figure 9.2.8. As the lowest residential area is around EL.1.5 to EL.2.5 m, the inundation depth is considered around EL.0.5 to EL.1.5 m in the lowest area. This depth may disturb evacuation activities and bring some damages on the property.

It is difficult to reduce the inundation depth completely to zero, but is possible to mitigate to smaller depth. The allowable inland inundation level is the design water level to study the specification and operation of flood mitigating facilities, and this inundation level must not be the depth which brings huge damage to property or human lives.

In this study, the allowable inland inundation level is defined to be EL.2.0 m (the inundation depth is EL.0.5 m in the lowest area), because this depth is almost equivalent to the height of knees and may not bring such the huge damage and may not disturb evacuation so much.

(3) Inland Storage Volume in the Riparian Area of the Old Mirim

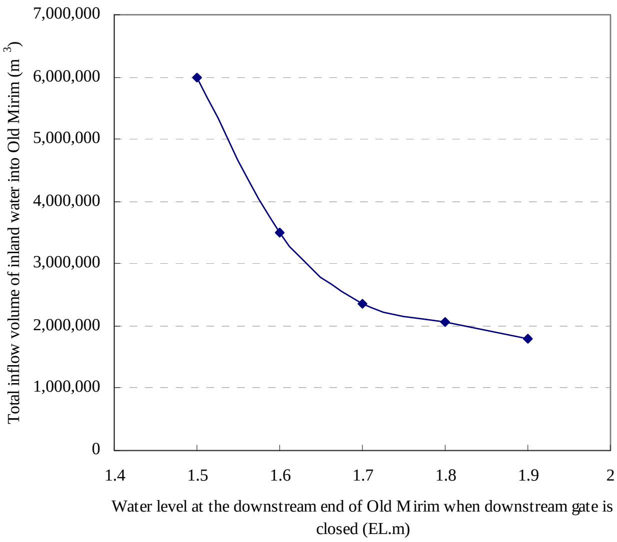
As shown in Figure 9.3.4 inland storage volume from EL.1.5 m to EL.2.0 m, for example, in the riparian area along the Old Mirim is 750,000 m^3. This indicates that inflow volume of inland water is allowed up to 750,000 m^3, if the downstream gate is closed when the back water level from the Itajai River reaches to EL.1.5 m.



Source: JICA Survey Team

Figure 9.3.4 H-A and H-V Curve of Riparian Area along Old Mirim

But, in fact, the total volume of inland water flowing into the Old Mirim is much more than allowable volume (it is less than 750,000 m^3 as shown in figure 9.3.4) even if the downstream gate is closed at anytime. For example, after the closure of the downstream gate when the back water level was EL.1.5m, the total inflow volume of inland water to the Old Mirim during flood duration would reach 6,000,000 m^3 (Figure 9.3.5).



Source: JICA Survey Team

Figure 9.3.5 Total Volume of Inland Water into Old Mirim

Most of inland water comes from the Canhanduba River (catchment area = 89 km^2), and the discharge from the Canhanduba River is almost less than 10 m^3/s (see Figure 9.3.8). But the flood duration of the Itajai River is so long that the downstream gate must be also closed for a long time. This indicates that the inland water must be forced to be drained by other measures.

(4) Operation of Floodgates for 10-year Flood

1) Necessity on Hydrological Information for Operation

The floodgates are operated according to the variation of water level of the Old Mirim. The upstream gate would be closed when the discharge from the Itajai Mirim reaches to the flow capacity of the Old Mirim, in this respect, operation needs the information on the water level of the Old Mirim in the urban area (in the downstream area of the BR-101). On the other hand, the downstream gate would be closed when the back water level at the downstream end of the Old Mirim reaches to the critical water level. Therefore, the operation of downstream gate also needs the information on the water level at the downstream end of the Old Mirim.

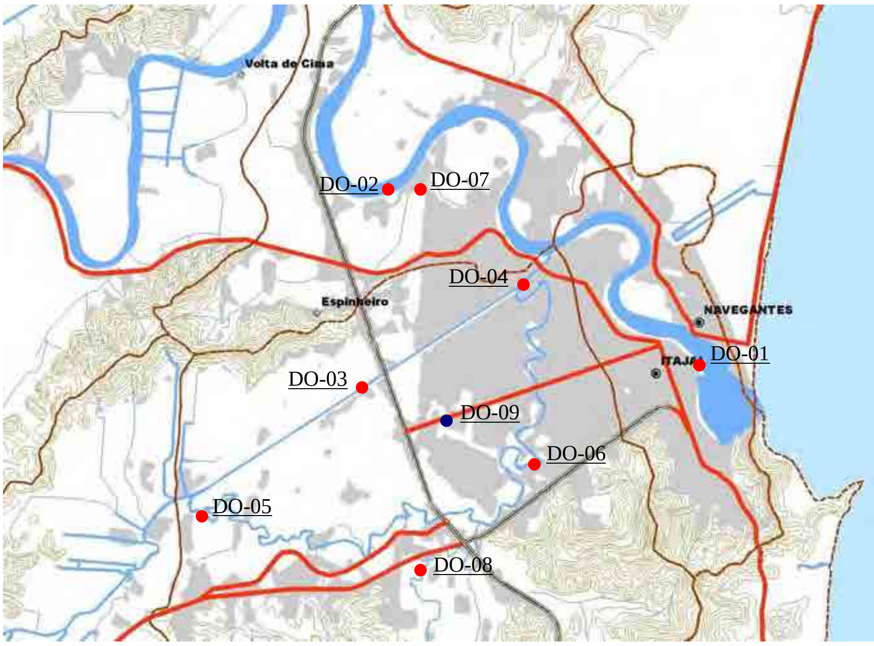
Civil Defense of the municipal government in Itajai city has already installed 9 gauges of water level and rainfall in February 2011. Table 9.3.1 shows the location of the gauges. Location map is shown in Figure 9.3.6.

Both Gauges “DO-06” and “DO-04” will be used for operation of both floodgates.

Table 9.3.1 Location of Water Level and Rainfall Gauges Installed by Itajai City

Location No.	Location	Remarks
DO-01	At the river mouth of the Itajai River	
DO-02	On the Itajai River, upper of urban area in Itajai city	
DO-03	On the Canal, upper of urban area in Itajai City	
DO-04	Confluence of the Canal and Old Mirm	to be used for downstream gate operation
DO-05	Upstream reach of the Old Mirim	
DO-06	On the Old Mirim, urban area in Itajai city	to be used for upstream gate operation
DO-07	On the Murta River	
DO-08	On the Canhanduba River	
DO-09	Office of Defesa Civil, Itajai city	rainfall gauge only

Source: JICA Survey Team

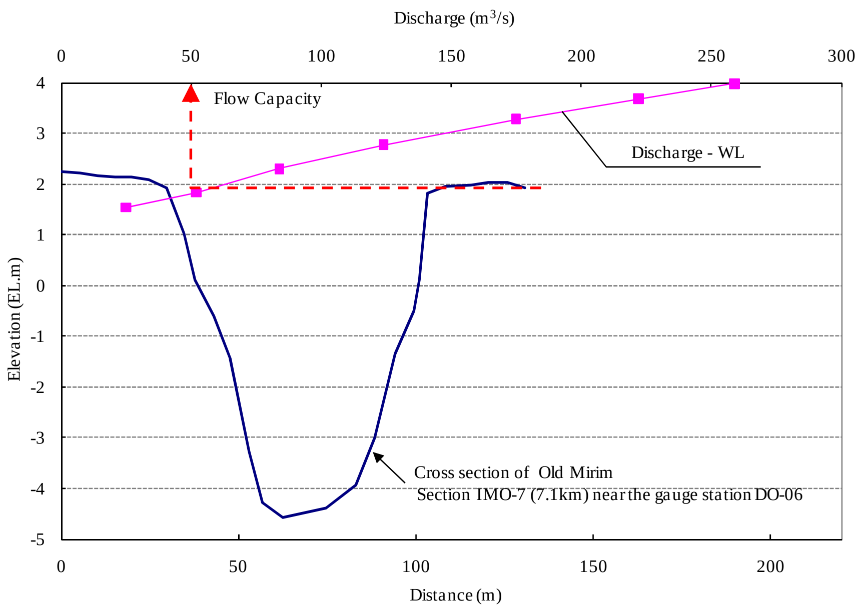


Source: JICA Survey Team

Figure 9.3.6 Location of Water Level and Rainfall Gauges Installed by Itajai City

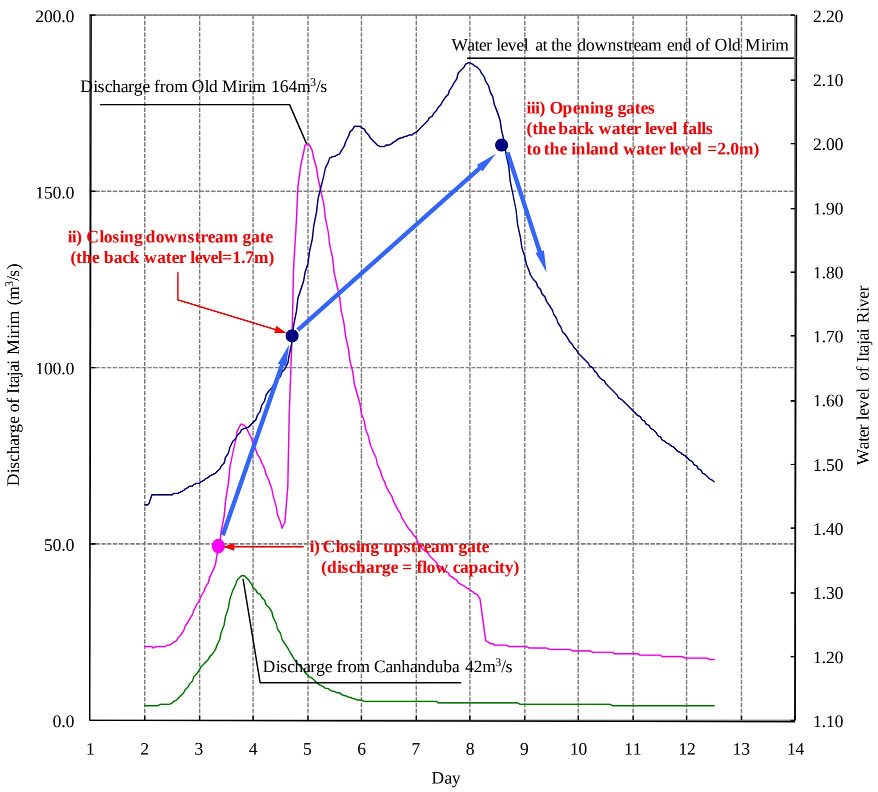
2) Water Level of the Gates Operation

i) When the flood discharge into the Old Mirim reaches to the flow capacity of the Old Mirim, upstream gate should be closed as shown in Figure 9.3.8. The flow capacity is equivalent to the water level of EL.2.0 m at the gauge DO-06 as shown in Figure 9.3.7.



Source: JICA Survey Team

Figure 9.3.7 Relation of Water Level and Discharge at the Gauge DO-06



Source: JICA Survey Team

Figure 9.3.8 Operation of Floodgates for 10-year Flood

ii) When the back water level from the Itajai River (at the confluence with the Itajai Mirim) reaches to EL.1.7 m, the downstream gate should be closed (see Figure 9.3.8).

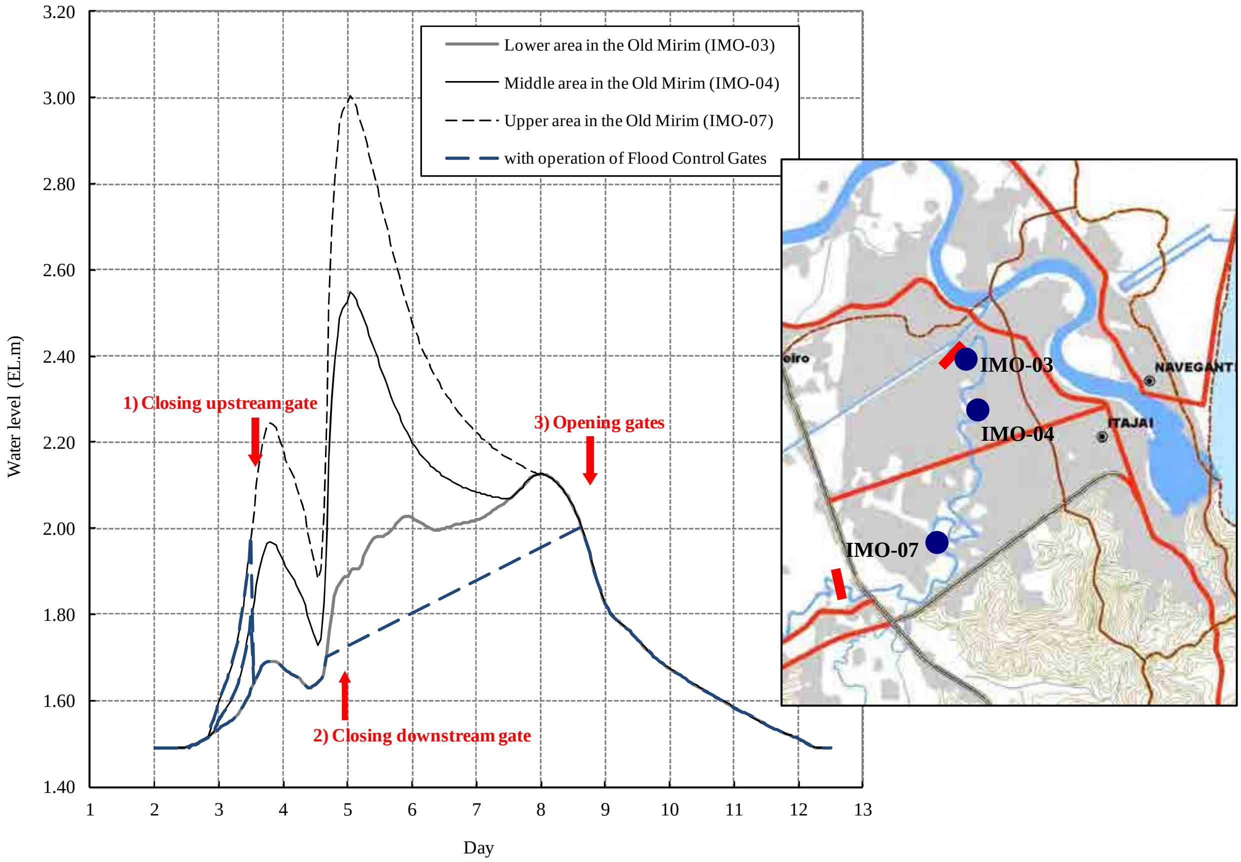
iii) When the back water level falls down to be equal to the inland water level of the Old Mirim (it must be EL.2.0 m as the allowable inland inundation level for design flood) after the peak of the back water level of the Itajai River, both the downstream and upstream gates will be opened in this order (see Figure 9.3.8).

It should be noted that the inland water from the Canhanduba River must be drained by other measure and the drainage discharge is about 7.0 m^3/s to maintain the inland water level as EL.2.0 m.

9.3.3 Effectiveness of Floodgates for 10-year flood

The effectiveness of floodgates for the 10-year flood is indicated in Figure 9.3.9. Maximum inland water levels at IMO-03, IMO-04, and IMO-07 without the floodgates are about EL.2.1 m, 2.5 m, 3.0 m in elevation (locations are shown in Figure 9.2.1). And the maximum inland water level with operation of floodgates is EL.2.0 m.

This implies that reduction of maximum inland water level is 0.1 m at IMO-03, 0.5 m at IMO-04, and 1.0 m at IMO-07. Furthermore, the floodgates will be also able to reduce the duration of high inland water level.



Source: JICA Survey Team

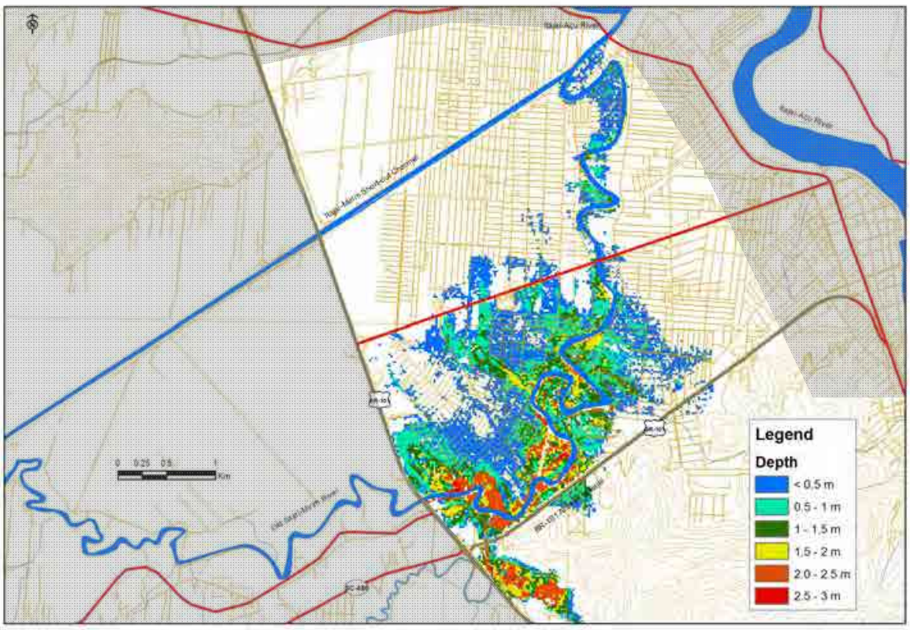
Figure 9.3.9 Effectiveness of Floodgates Operation for the 10-year Flood

Inundation area and depth in the downstream area of BR-101 along the Old Mirim with and without the floodgates are illustrated in Figure 9.3.10 and 9.3.11. The effectiveness of the floodgates is evaluated by means of the comparison of with and without the floodgates as summarized in Table 9.3.2.

Table 9.3.2 Estimated Inundation Area along the Lower Old Mirim

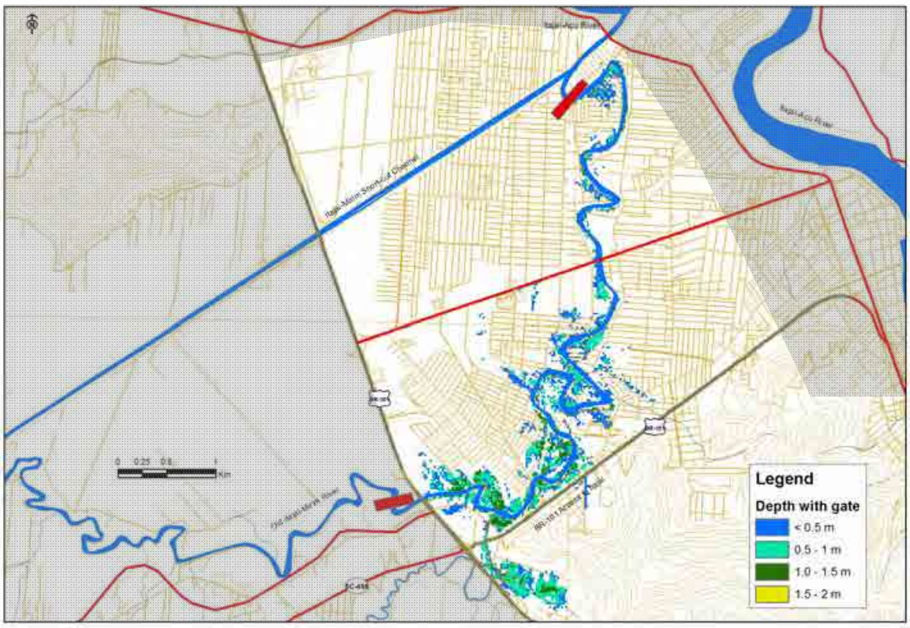
Inundation depth (m)	Area (m^2) without gate control	Area (m^2) with gate control	Effectiveness (m^2)
< 0.5	2,216,400	564,400	1,652,000
0.5 – 1.0	1,299,600	527,600	772,000
1.0 – 1.5	848,800	242,000	606,800
1.5 – 2.0	431,600	22,000	409,600
2.0 – 2.5	441,200	0	441,200
2.5 – 3.0	40,000	0	40,000
Total	5,277,600	1,356,000	3,921,600

Source: JICA Survey Team



Source: JICA Survey Team

Figure 9.3.10 Estimated Inundation Area along the Lower Old Mirim without Floodgates



Source: JICA Survey Team

Figure 9.3.11 Estimated Inundation Area along the Lower Old Mirim with Floodgates

Table 9.3.3 and Figure 9.3.16 shows the estimated inundation area by probable flood without floodgate.

Table 9.3.3 Estimated Inundation Area along the Lower Old Mirim by Probable Flood

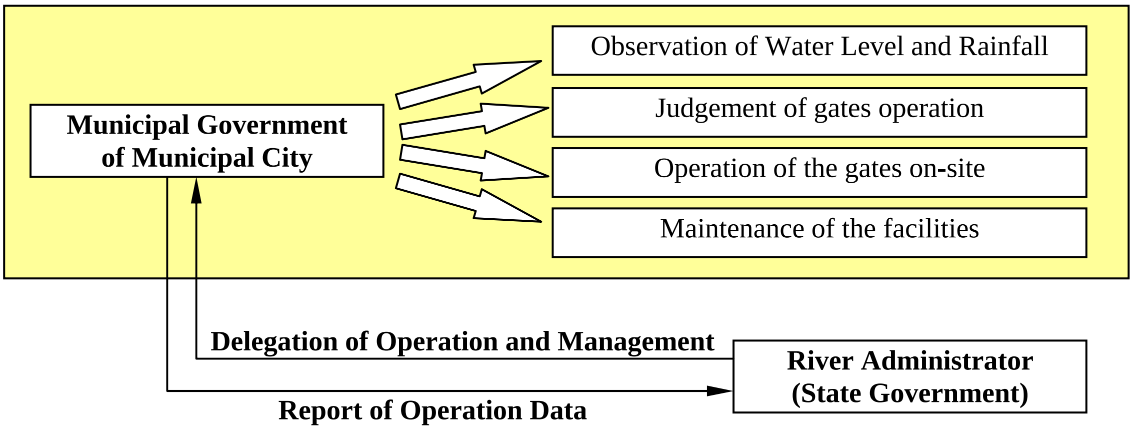
Inundation depth (m)	5-year (m^2)	10-year (m^2)	25-year (m^2)	50-year (m^2)
<0.5m	1,353,600	2,216,400	2,524,000	2,906,400
0.5-1m	845,200	1,299,600	2,070,400	2,641,200
1-1.5m	395,200	848,800	1,318,800	2,140,400
1.5-2m	477,600	431,600	865,600	1,367,200
2-2.5m	20,400	441,200	474,800	888,800

2.5-3m	1,200	40,000	392,000	449,600
3-3.5m	-	-	98,800	424,400
3.5-4m	-	-	-	72,400
Total	3,093,200	5,277,600	7,744,400	10,890,400

Source: JICA Survey Team
Remark: the inundation area of 50-year flood does not assume the floodway of Itajai River

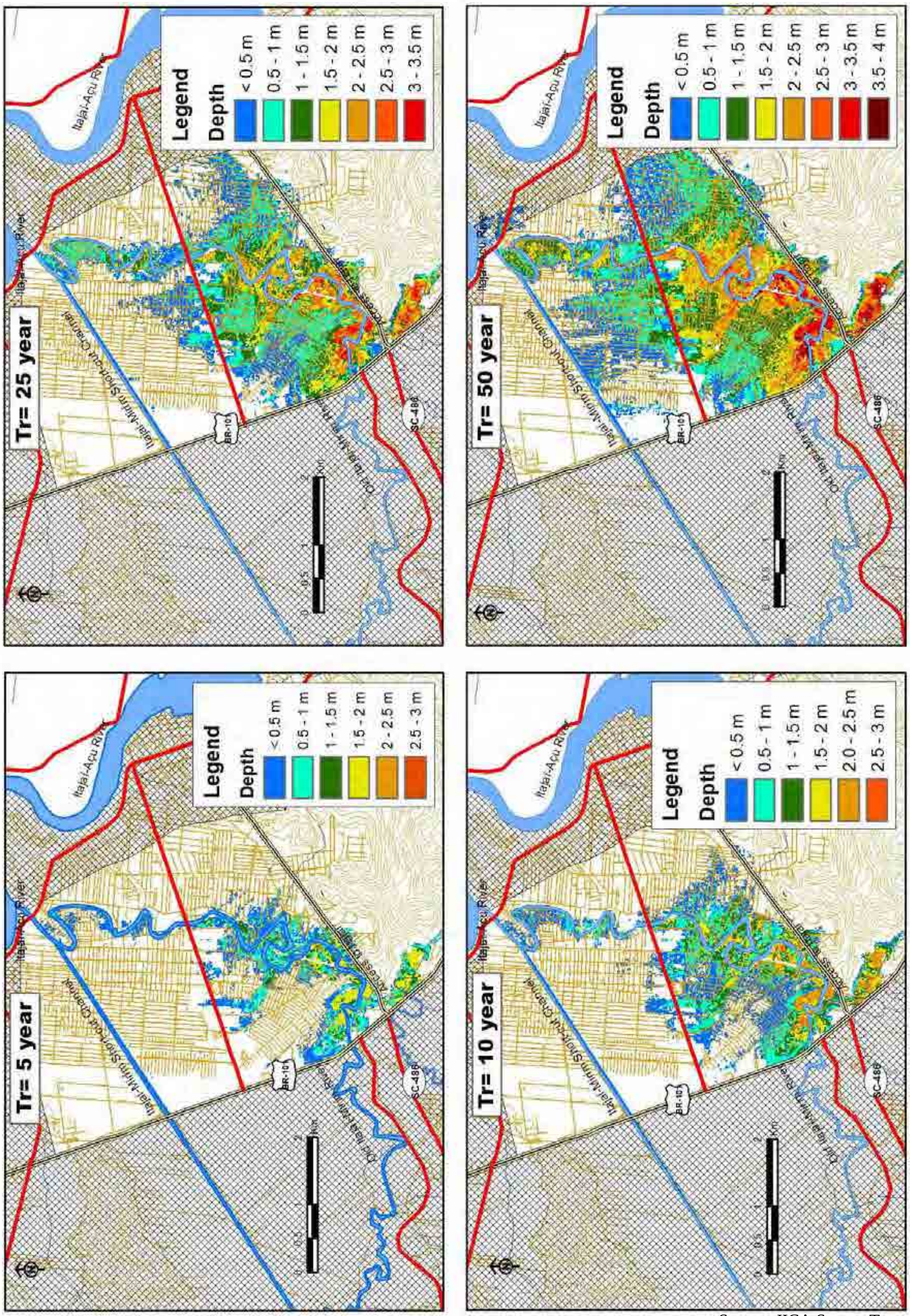
9.3.4 Recommendation of Organization for Operation

The operation of floodgates needs hydrological information only around Itajai city, and operation of the floodgates affects to only Itajai city area. The operation shall be executed by the municipal government of Itajai city.



Source: JICA Survey Team

Figure 9.3.12 Recommendation of Organization for Operation



Source: JICA Survey Team

Figure 9.3.13 Estimated Inundation Area along the Lower Reachs of Old Mirim by Probable Flood

9.4 Design Condition of the Related Facilities

9.4.1 Floodgates

Floodgates are planned at the two locations as shown in Figure 9.3.1.

(1) Downstream Gate

As for the downstream gate, inland water level is lower than back water level. Therefore the height of the gate should be determined from the back water level.

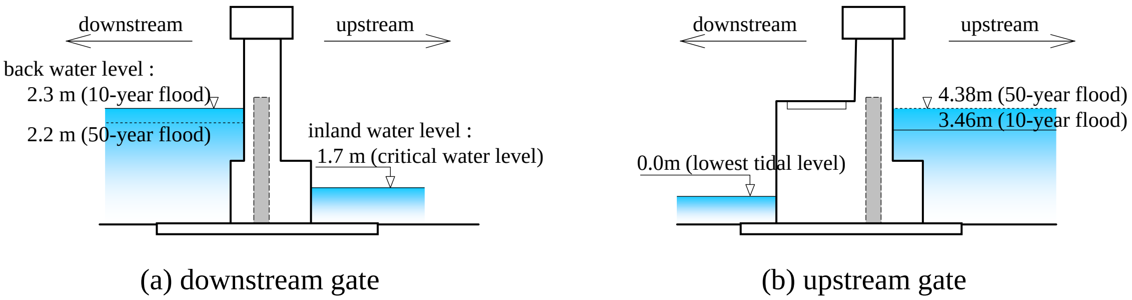
The maximum back water level is EL.2.3 m of the 10-year flood. Water level of the 50-year flood is lower than EL.2.3 m because of effectiveness of the floodway in the Itajai River. The minimum inland water level during gate closing is EL.1.7 m (see Figure 9.4.1). These would be used as the design water levels of the downstream gate.

(2) Upstream Gate

As for the upstream gate, upstream water level is always higher than downstream one. Therefore, the gate height is determined from upstream water level.

As shown in Figure 9.2.8, water levels at the upstream gate without floodgates are EL.3.46 m in the 10-year flood, EL.4.38 m in the 50-year flood. These would be used as the design water levels of the upstream gate.

In the stage-wise implementation, though concrete structure would be designed for 50-year flood, gate leaf would be installed for 10-year flood in the first stage.



Source: JICA Survey Team

Figure 9.4.1 Design Water Level of Floodgates

Details of the design condition are discussed separately in Supporting Report F Structural Design and Cost Estimate.

9.4.2 Dyke

As mentioned in sub-section 9.2.2 (2), some stretch along the right bank in the Canal does not have enough flow capacity for 10-year flood. Therefore dyke should be provided to prevent overflowing from this stretch. The height of the dyke is determined from the water level of the 10-year flood. The water level of the 50-year flood is lower than the 10-year flood because of the floodway (which should be implemented in the final phase of implementation of the measures proposed in the M/P for 50 year flood).

9.4.3 Drainage Facilities

(1) Drainage Channel Connected Canhanduba River to Old Mirim

As described in sub-section 9.3.2 (3), the inland water should be forced to be drained to keep the inland water level not exceed EL.2.0 m. Almost of the inland water comes from the Canhanduba River. Conceivable measures to fulfill the requirement above are as follows.

1) Pumping station from the Old Mirim to the Itajai River

In this measure, inland water is directly drained to the Itajai River from the Old Mirim by pumping station to be installed near the junction of the Itajai Mirim and Itajai River.

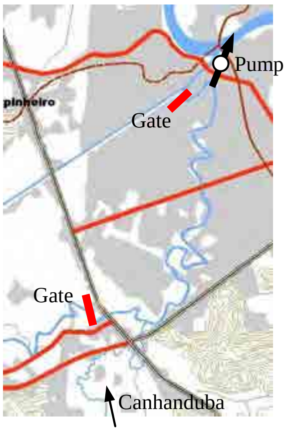
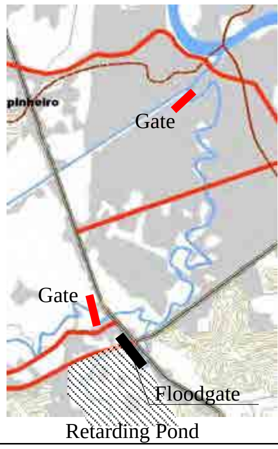
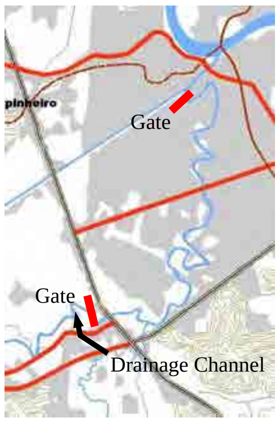
2) Floodgate along the Canhanduba River

Another floodgate would be installed additionally in the the Canhanduba River at the upstream of the BR-101. This gate would prevent the flood from the Canhanduba River from flowing into the Old Mirim, having a function as retarding pond.

3) Diversion channel from the Canhanduba River to upstream of the Old Mirim

A diversion channel would be provided to connect the Canhanduba River to the Old Mirim in the upstream reach of the BR-101 to prevent flood from the Canhanduba River from flowing into the inland area along the Old Mirim.

Table 9.4.1 Comparison of Drainage Facility for Inland Water from Canhanduba River

Alternatives	Pumping Station from Old Mirim to Itajai River	Floodgate and Retarding Pond	Drainage Channel from Canhanduba to Old Mirim
Location of the Installation			
Cost	most expensive	comparatively expensive	not expensive
Impact	no impact	Retarding pond affects the upstream agricultural area along the Canhanduba River.	no impact
Evaluation	-	-	good

Source: JICA Survey Team

The general feature of this drainage channel is as follows.

- The length of this channel is about 1 km which is almost excavated open channel except calvert stretch at the crossing point with roads
- The design discharge of the channel is 7 m^3/s to keep the allowable inland inundation level (= EL.2.0 m) for 10-year flood.

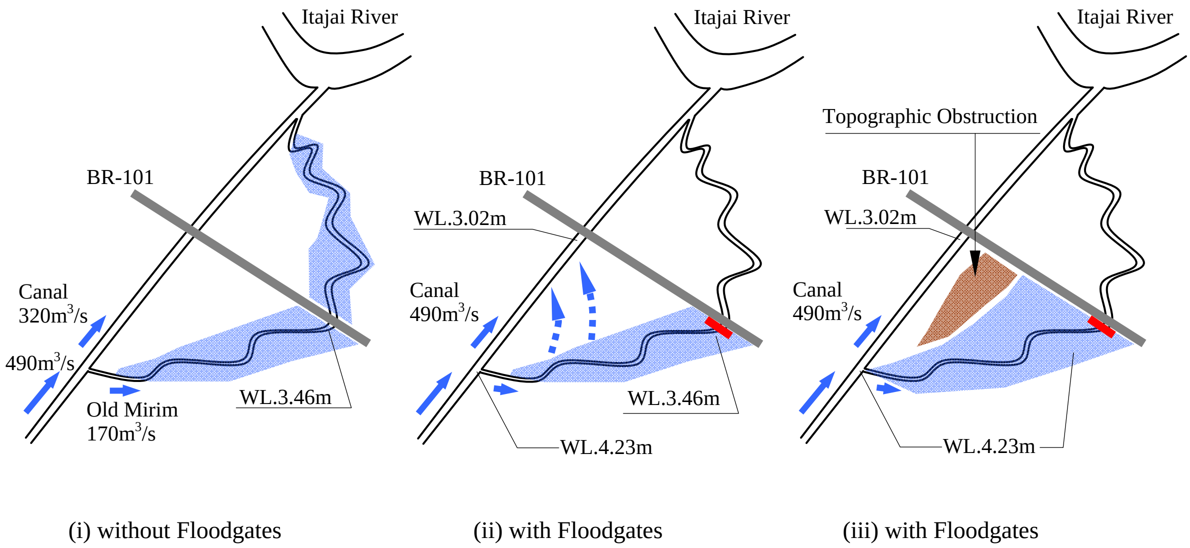
Meanwhile, as the drainage facility mentioned above is planned against the 10-year flood, inland watar level might rise higher than allowable inland inundation level in case of larger floods than the 10-year flood. When the inland water level rises to be higher to the back water level, downstream gate should be opened in order to avoid the man-made inundation. It might be needed to consider installation of some pump facilities so that the floodgates work effectively against the larger floods.

(2) Necessity of Drainage Channel Connected the Old Mirim to the Canal

Water elevation at the upstream of the BR-101 along the Canal is estimated lower than Old Mirim by non-uniform flow calculation as shown in Figures 9.2.7 and 9.2.8. The flood water overflowing from the Old Mirim shall flow into the Canal naturally during the upstream gate closing. Therefore, the upstream area of the Old Mirim may not be affected negatively by closure of the upstream gate as illustrated in Figure 9.4.2 (ii).

But if there is some topographic obstruction like slightly elevated ground between the Old Mirim and the Canal as illustrated in Figure 9.4.2 (iii), the inundation level in the upstream area along the Old Mirim would rise because of the retention.

It is recommended that the impact to the inundation level in the upstream area of the BR-101 shall be studied by two-dimensional inundation analysis, after completion of the ongoing aerial topographical survey by the State Government.



Source: JICA Survey Team

Figure 9.4.2 Necessity of drainage in the upstream area of the BR-101