Brazil
Santa Catarina State

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

FINAL REPORT

VOLUME III :SUPPORTING REPORT

NOVEMBER 2011

JAPAN INTERNATIONAL COOPERATION AGENCY

NIPPON KOEI CO., LTD

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Composition of Reports

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VOLUME II	MAIN REPORT
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EXCHANGE RATE

The exchange rate used in this Study is:	
Master Plan (2010/10)	Brazilian Real (R$1.0)=US Dollar (US$0.58) = Japanese Yen(Y47.87)
Feasibility Study(2011/06)	Brazilian Real (R$1.0)=US Dollar (US$0.63) = Japanese Yen(Y50.71)

Supporting Report

(A) Hydrology
(B) Flood Mitigation Plan
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Supporting Report (A)

Hydrology

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

FINAL REPORT

VOLUME III : SUPPORTING REPORT
ANNEX A : HYDROLOGY

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CHAPTER 1 INTRODUCTION

The main purposes of the hydrological studies for the “Preparatory Survey for the Project on the Disaster Prevention and Mitigation Measures for Itajaí River Basin” are the high intensitive rainfall and flood discharges. However, in order to comprehend better these phenomena in the watershed it is necessary to take into account its physiographic, meteorological, climatological and hydrological characteristics.

CHAPTER 2 ITAJAÍ RIVER

The Itajaí-Açu River, or simply Itajaí River how it is usually called, is a brazilian river located in the South region, on the Santa Catarina State and its basin is located in the Atlantic Forest area, running from west to east direction, until it achieves the Atlantic Ocean. The size of the basin is medium and the total drainage area is about 14.933 km².

The river becomes to be called Itajaí from the municipality of Rio do Sul, by the confluence between Itajaí do Sul River and Itajaí do Oeste River. The major tributaries by the left bank are the Itajaí do Norte River or Hercílio (on the boundary of Lontras and Ibirama), the Benedito River (and its tributary the Cedros River, in Indaial), and the Luís Alves (in Ilhota). Itajaí River receives water from its main tributary by the right bank, the Itajaí-Mirim River in Itajaí city, 8 kilometers before its river mouth on the Atlantic Ocean. The Itajaí River, therefore is composed by six large sub-basins of tributaries rivers and also the incremental area between these sub-basins, as showed in the Figure 2.1.1.

The basin territory is divided in three big natural compartments due to its geological and geomorphological characteristics – the upper valley, the mid-valley and the low valley. The upper valley includes the entire drainage area by the upstream and the confluence between the rivers Itajaí do Norte (Hercílio) and Itajaí. On this area is also located the headborders of the Itajaí-Mirim river. The mid-valley includes the area between the mencioned confluence and the Blumenau City; from this place the low valley starts and it is influenced by the tide conditions because of its low slope in this strecht.

The drainage areas of major rivers and main fluviometric stations are presented on the Table 2.1.1.

Table 2.1.1 Drainage Areas

Area de Drenagem das Subbacias Area (km²)			
SUBBACIA	Area (km²)	Estação Fluviométrica	Area (km²)
RIO ITAJAÍ DO NORTE OU HERCÍLIO	3.353,98	Barragem Norte	2.330,5
		Ibirama	3.335,4
RIO ITAJAÍ DO OESTE	3.014,37	Barragem Oeste	851,2
		Rio Trombudo	590,9
		Taio	1.569,9
RIO ITAJAÍ DO SUL	2.026,87	Barragem Sul	1.165,4
		Ituporanga	1.645,3
RIO BENEDITO	1.500,30	Rio Benedito	830,9
		Rio dos Cedros	600,3
		Barragem Pinhal	179,9
		Barragem Rio Bonito	119,8
		Timbo Novo	1.431,3
LUIS ALVES	580,01	Luis Alves	157,3
RIO ITAJAÍ-MIRIM	1.678,86	Brusque	1.206,6
		Canal Junction	1.540,3
RIO ITAJAÍ AÇÚ (Entre confluências)		Rio do Sul Novo	5.041,6
		Apiuna Nova	9.288,8
		Indaial	11.276,4
		Ribeirão da Velha	56,6
		Blumenau	11.922,7
		Rio Garcia	158,3
		Gaspar	12.271,9
		Ilhota	12.498,6
		Após a confluência com o Rio de Luís Alves	13.093,8
		Após a confluência com o Rio Itajaí-Mirim	14.914,8
		Desembocadura	14.933,2
Total área de captação da Bacia Itajaí	14.933,23		

Source: JICA Survey Team

The major part of the Itajaí basin area is composed by forest and large extension of grazing pasture. The population is concentrated nearby the river banks. On this place there are big cities where the density is around 100 thousand to 300 thousand people, such as Itajaí (in the river mouth), Blumenau (70 km from the river mouth) and Rio do Sul (191 km from the river mouth).

In relation to the fluviometric channel, the Itajaí River has a riverbed slope between 1/15.000 and 1/20.000, from the river mouth until Blumenau City. So, it is a very flat stretch. The altitude of the riverbed in Blumenau is lower than the mean of the sea level. The intermediate river stretch, by the Blumenau upstream to the Lontras City (around 170 km from the mouth), has a very steep slope between 1/100 and 1/1.500. And the Rio do Sul and Lontras stretch slope is reasonably flat with a slope of 1/3.000.

The river width is from 200 to 300 meters in the lower valley stretch; between 150 to 200 meters near to Blumenau; between 100 to 150 meters in Rio do Sul. And as it moves upstream, it becomes increasingly narrow.

Currently, in the Itajaí River there are no dykes ou remarkable rectified channel, except partial interventions, such as the concrete cribs from the port complex and the Itajaí Mirim River rectified channel. The Itajaí River channel keeps almost all of its natural shape.

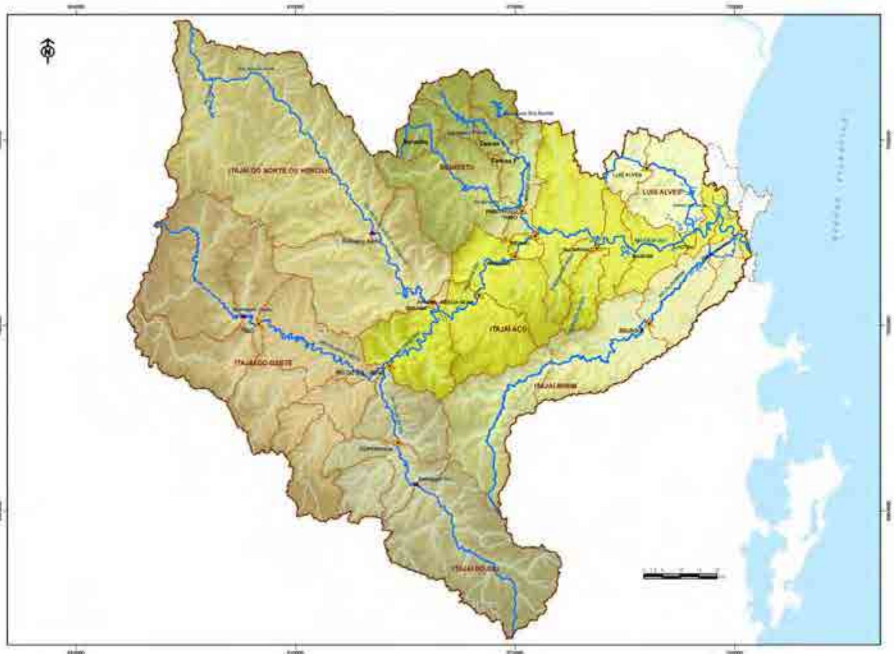
The length of the main thalwegs are presented in the Table 2.1.2.

Table 2.1.2 Main Itajaí Basin Rivers Length

Comprimento de Drenagem dos Rios Distancia (km)				
RIO	Comprimento principal (km)		Ponto de coleta de dados	Distancia (km)
RIO ITAJAÍ DO NORTE OU HERCÍLIO	150,28		Barragem Norte	46,22
			Ibirama	4,04
RIO ITAJAÍ DO OESTE	136,96		Barragem Oeste	77,58
			Taio	68,15
RIO ITAJAÍ DO SUL	110,63		Barragem Sul	43,81
			Ituporanga	25,46
RIO BENEDITO	84,21		Timbo Novo	10,25
LUIS ALVES	Com Canal	61,12	Luis Alves	40,30
	Rio	73,95	Luis Alves	53,14
RIO ITAJAÍ-MIRIM	Com Canal	169,49	Brusque	37,72
			Até a confluência com o canal Junction	8,44
	Rio	181,33	Brusque	49,57
			Até a confluência com o canal Junction	20,28
RIO ITAJAÍ AÇU	190,51		Até a confluência com o Rio Itajaí do Oeste	190,51
			Rio do Sul Novo	189,94
			Até a confluência com o Rio Itajaí do Norte	151,07
			Apiuna Nova	130,96
			Warnow	106,55
			Até a confluência com o Rio Benedito	97,59
			Indaial	97,50
			Ribeirão da Velha	20,18
			Blumenau	69,04
			Rio Garcia	42,10
			Até Gaspar	52,07
			Até Ilhota	36,63
			Até a confluência com o Rio de Luis Alves	31,31
			Até a confluência com o Rio Itajaí-Mirim	7,21
Total comprimento do Rio Itajaí	301,14			

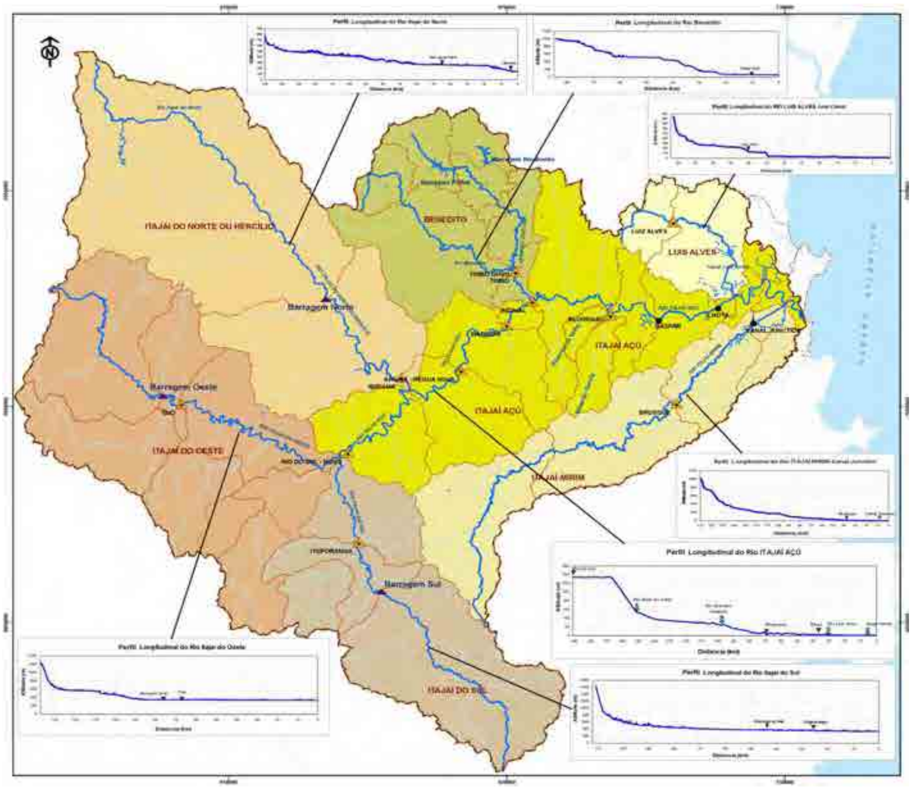
Source: JICA Survey Team

The Figure 2.1.1 presentes the Itajaí River Basin map. In the Figure 2.2 the longitudinal profile of the main rivers form the basin is presented.



Source: JICA Survey Team (Based on data from IBGE, EPAGRI, CIRAM, ANA)

Figure 2.1.1 Itajaí River Basin map including drainage areas



Source: JICA Survey Team (Based on data from IBGE, EPAGRI, CIRAM, ANA)

Figure 2.1.2 Rivers of Itajaí River Basin longitudinal profile and distances from the main rivers

Blumenau, located in the Itajaí River basin, is one of the cities which are suffering with the often floods. The representative Flood events that occurred recently were: July, 1983; August, 1984 and November, 2008. The largests flood disasters happened in the lower valley (Itajaí, Gaspar and Blumenau). In the upper valley (Rio do Sul) and in certain small and average size cities in the tributaries rivers bank floods are becoming more frequent. In Indaial city and in the mid-valley, where the slope is steep, the disasters were smaller.

The Santa Catarina State has implemented some protection measures against flood through the exclusive flood contention dam buildings; such as the Oeste and Sul dams, in the 70's and the Norte dam in the 90's. There are no significative flood contention infrastructure and no large structural measures, except those dams mentioned before. However, the Civil Defenses from the main cities, as Blumenau, had firmed a cooperation agreement with FURB and CIRAM and implemented the prevention system and warning due to mitigate disasters.

CHAPTER 3 METEOROLOGY AND CLIMATOLOGY

The Itajaí River Basin climate, according to the Köppen climate classification, belongs to the category 'Cfa' humid temperate with hot summers. For the climate classification and characterization of the climate variables were used provided data from the Itajaí River basin stations by EPAGRI-CIRAM. The used data came from the following stations: Rio do Campo Meteorological Station – 639 (from June 1st, 1994 to July 31th, 2010), Ituporanga Meteorological Station – 191 (from October 1st, 1985 to July 31th, 2010), Indaial Meteorological Station – 167 (from December 1st, 1970 to July 31th, 2010) and Itajaí Meteorological Station – 83 (from August 4th, 1980 to July 31th, 2010). The variable seasonality analysis observed in these stations is impaired due to the limited information availability and different periods observed at each station. According to EPAGRI, the Rio do Campo Station – 639 presents a disable observation, furthermore its observed data present the shortest duration. Therefore, some information seems to be inconsistent, mainly when its observations are compared to the other stations.

3.1 Temperatures

The hottest trimester includes the months: December, January and February, the mean of temperature on this trimester is around 22º C in the upper valley and 24º C in both lower and mid-valley. The absolute maximum range from 28ºC to 43ºC in the entire basin; the lower temperature happens in winter season in July, and the higher one in the summer season, generally in January.

The coldest trimester occurs from June to August, the mean of temperature is around 13ºC in the upper valley and 16ºC in the lower and mid-valley. The absolute minimum range of -5,4ºC to 15ºC. The lower temperatures happen in the winter in the upper valley; the higher temperatures happen in the summer in the lower and mid-valley.

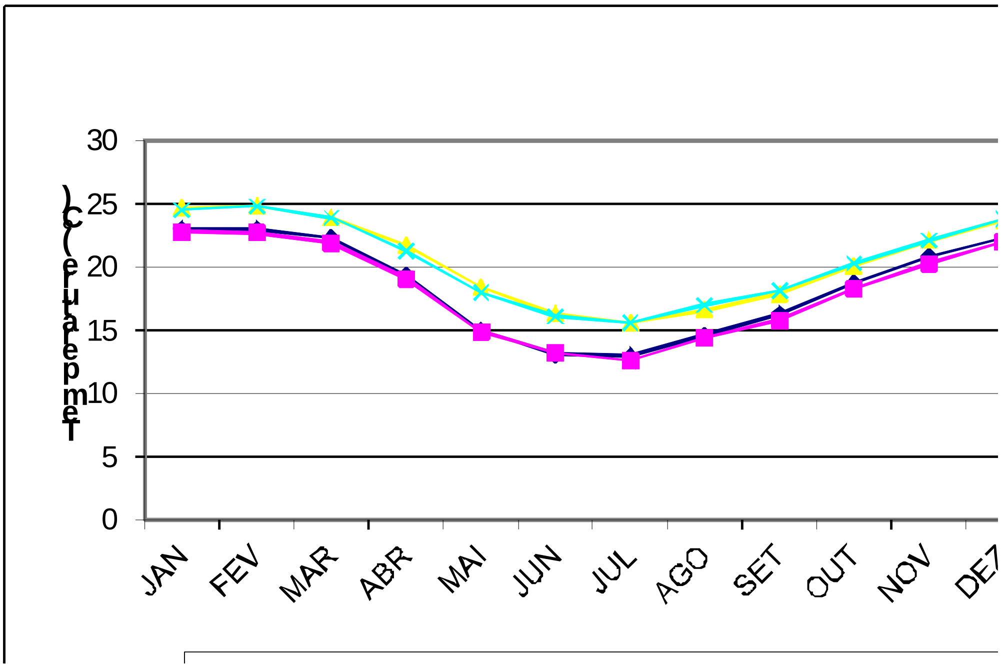
The Table 3.1.1 presents the monthly mean of temperature in the indicated stations:

Table 3.1.1 Means of monthly and annual temperatures (ºC)

Month	Rio do Campo	Ituporanga	Indaial	Itajaí
January	23,0	22,8	24,5	24,7
February	23,0	22,7	24,8	24,8
March	22,3	21,9	23,9	23,9
April	19,3	19,1	21,3	21,7
May	15,0	14,9	18,0	18,4
June	13,1	13,2	16,1	16,3
July	13,0	12,6	15,6	15,6
August	14,6	14,4	17,0	16,6
September	16,3	15,8	18,1	17,9
October	18,7	18,3	20,3	20,1
November	20,8	20,3	22,1	22,1
December	22,3	22,0	23,8	23,7
Annual	18,5	18,2	20,5	20,5

Source: JICA Survey Team

In the following Figure 3.1.1 presents the plot of monthly mean of temperatures.



Source: JICA Survey Team

Figure 3.1.1 Monthly mean of temperatures (ºC)

It is notable that in places near to the coast the temperature variation is lower; the months are hotter in summer and less cold in winter.

3.2 Monthly Rainfall

The rainiest trimester occurs in the summer months of December, January, February, while the driest period occurs in the winter. It is relative, however, a month can be extremelly humid in a certain year, and extremelly dry in another. Rainfalls that cause floods can happen in any period of the year.

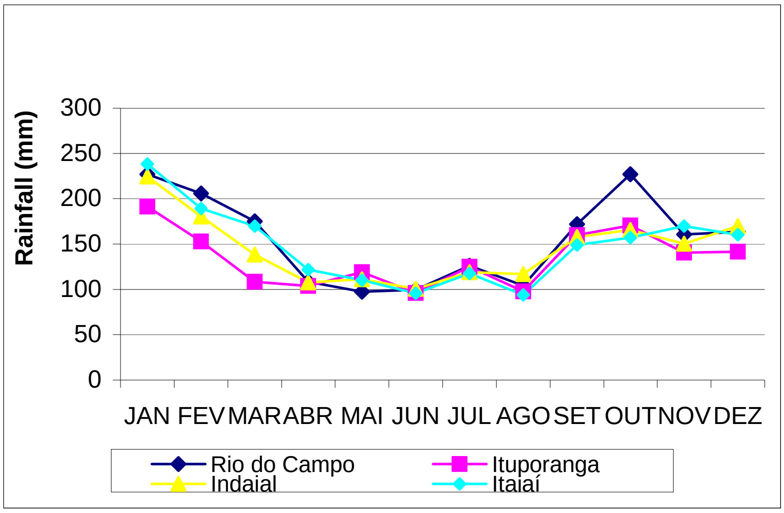
The monthly mean of rainfall of the indicated stations is presented in the Table 3.2.1.

Table 3.2.1 Mean of Annual and Monthly Rainfall (mm)

Month	Rio do Campo	Ituporanga	Indaial	Itajaí
January	227,0	191,4	224,6	238,2
February	205,6	152,7	180,4	189,3
March	174,9	108,2	138,5	169,6
April	108,4	103,6	107,6	121,7
May	97,3	118,8	111,3	110,0
June	99,5	96,0	100,7	95,6
July	126,1	125,0	118,9	117,7
August	104,2	97,7	117,0	94,0
September	171,9	159,9	157,6	148,8
October	226,9 *	170,4	165,7	156,9
November	160,5	140,5	150,3	169,7
December	163,5	141,4	169,7	160,3
Annual	1.865,8 *	1.605,6	1.742,3	1.771,8

* Value apparently inconsistent
Source: JICA Survey Team

In the following Figure 3.2.1 the montlhy mean of the rainfall plot is presented.



Source: JICA Survey Team

Figure 3.2.1 Monthly Mean of Rainfall

In general, the mean of rainfall deacreses from the cost to the inland. The Rio do Campo rainfall station is an exception to this standard, because of the reasons mentioned before.

3.3 Monthly Mean of Rainy Days

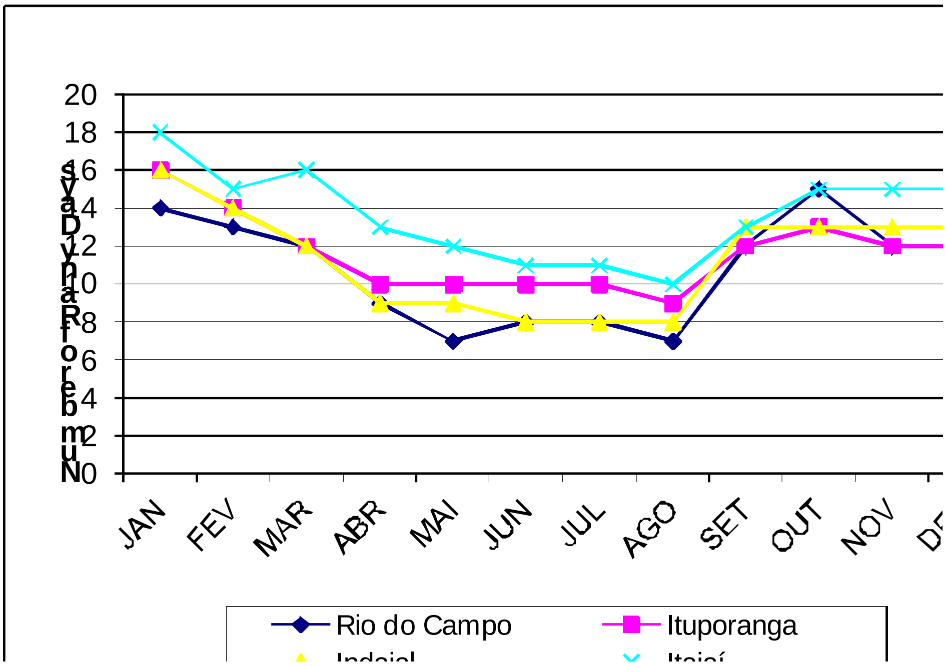
In the Table 3.3.1 the monthly mean of rainy days is presented.

Table 3.3.1 – Mean of Monthly and Annual Rainfall Days

Month	Rio do Campo	Ituporanga	Indaial	Itajaí
January	14	16	16	18
February	13	14	14	15
March	12	12	12	16
April	9	10	9	13
May	7	10	9	12
June	8	10	8	11
July	8	10	8	11
August	7	9	8	10
September	12	12	13	13
October	15	13	13	15
November	12	12	13	15
December	12	12	13	15
Annual	129	140	136	164

Source: JICA Survey Team

In the Figure 3.3.1 the monthly mean of rainfall days is presented.



Source: JICA Survey Team

Figure 3.3.1 Monthly mean of rainy days

As the monthly mean of rainfall, the mean of rainy days also decreases from the coast to the inland. Possible outliers values are due to different periods of data observation.

3.4 Maximum Rainfall in 24 hours

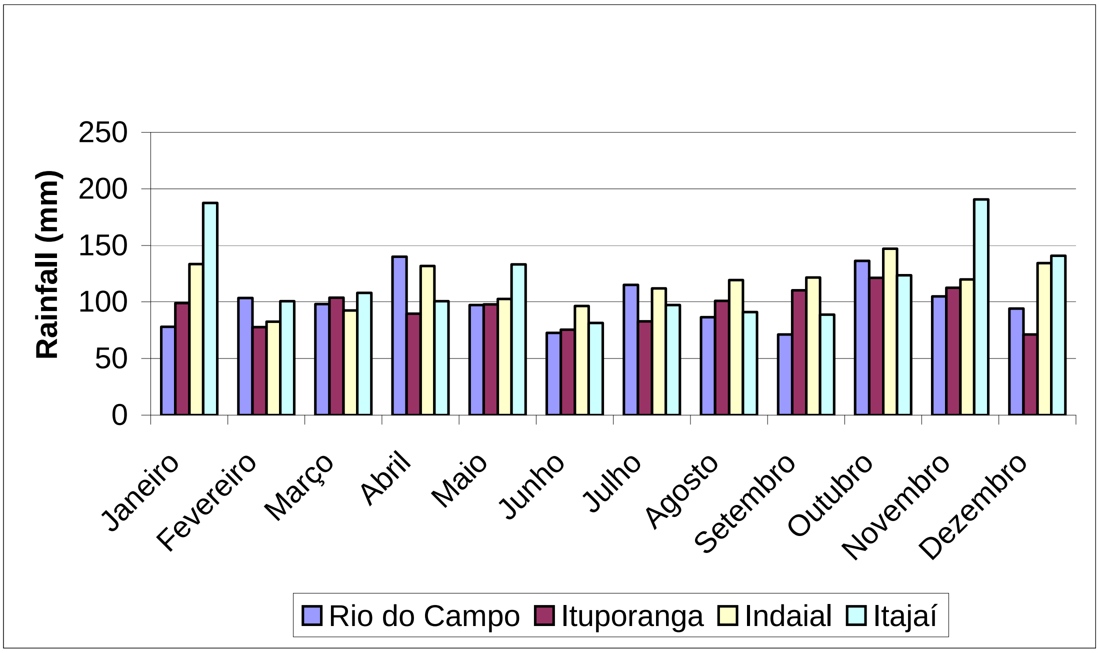
In the following Table 3.4.1 it is presented the maximum rainfall observed in 24 hours in the considered stations for each month.

Table 3.4.1 Maximum Rainfall (mm) in 24 hours and Occurrence Time

Month	Rio do Campo		Ituporanga		Indaial		Itajaí	
January	78,0	17/01/2009	99,0	15/01/2000	133,5	10/01/2002	187,5	24/01/1999
February	103,6	01/02/1998	77,8	01/02/1997	82,6	28/02/1998	100,7	14/02/1987
March	98,0	07/03/2003	103,8	09/03/2009	92,4	03/03/2003	108,0	25/03/1982
April	140,0	23/04/2010	89,7	26/04/2004	131,8	04/04/2005	100,8	21/04/2008
May	97,2	18/05/2007	97,8	04/05/2001	102,7	29/05/1992	133,1	29/05/1992
June	72,6	19/06/1998	75,5	30/06/2002	96,3	21/06/1991	81,5	27/06/1997
July	115,1	30/07/1999	83,0	09/07/2007	112,1	03/07/1999	97,3	03/07/1999
August	86,4	01/08/2009	101,0	31/08/2005	119,3	31/08/2005	91,2	06/08/1984
September	71,4	25/09/1997	110,2	14/09/2004	121,7	14/09/2004	88,8	28/09/2009
October	136,2	01/10/2001	121,4	01/10/2001	147,2	01/10/2001	123,6	01/10/2001
November	105,0	29/11/2002	112,6	21/11/2000	119,9	23/11/2008	190,5	23/11/2008
December	94,2	06/12/2007	71,4	16/12/2003	134,4	03/12/1972	140,8	29/12/1995

Source: JICA Survey Team

In the following Figure 3.4.1 is presented the maximum rainfall plot in 24 hours in each considerated station.



Source: JICA Survey Team

Figure 3.4.1 Maximum rainfall in 24 hours

The intense rainfall occurs in all the months of the year, generally.

3.5 Relative Humidity

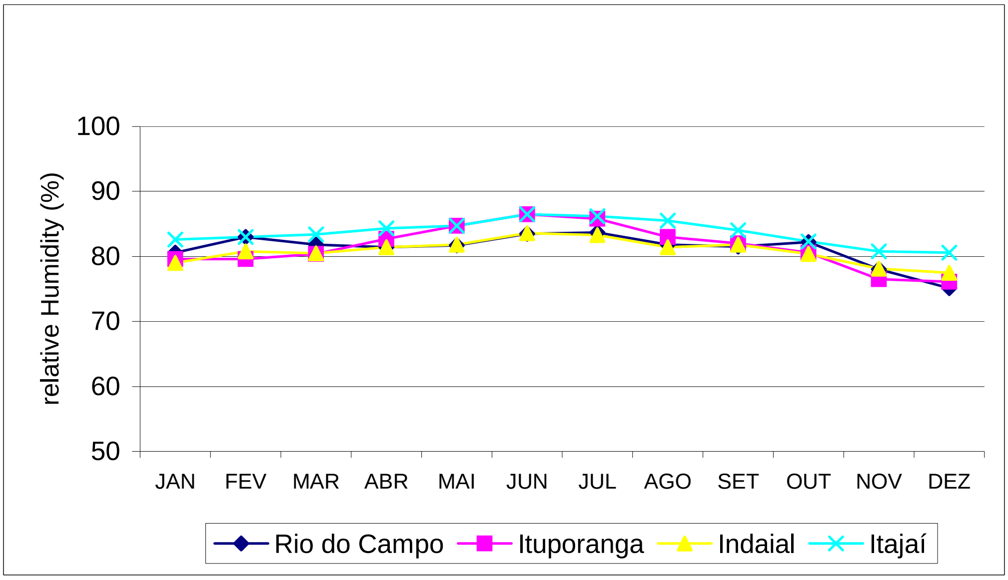
In the following Table 3.5.1 the monthly mean of the relative humidity in the considered stations is presented.

Table 3.5.1 Relative Humidity Monthly and Annual

Month	Rio do Campo	Ituporanga	Indaial	Itajaí
January	80,6	79,6	79,0	82,6
February	83,0	79,6	80,8	83,0
March	81,8	80,4	80,5	83,4
April	81,4	82,7	81,4	84,3
May	81,7	84,7	81,8	84,7
June	83,5	86,5	83,6	86,5
July	83,7	85,8	83,3	86,2
August	81,8	83,0	81,4	85,5
September	81,5	82,0	81,8	84,0
October	82,2	80,6	80,4	82,3
November	78,0	76,5	78,1	80,8
December	75,1	76,1	77,5	80,6
Annual	81,2	81,5	80,8	83,7

Source: JICA Survey Team

The monthly mean of relative humidity are plot in the following Figure 3.5.1. It is notable that the quarter (from May to August) presents the highest monthly mean of relative humidities.



Source: JICA Survey Team

Figure 3.5.1 Relative Humidity (°C) Monthly

3.6 Evaporation - Class A Pan

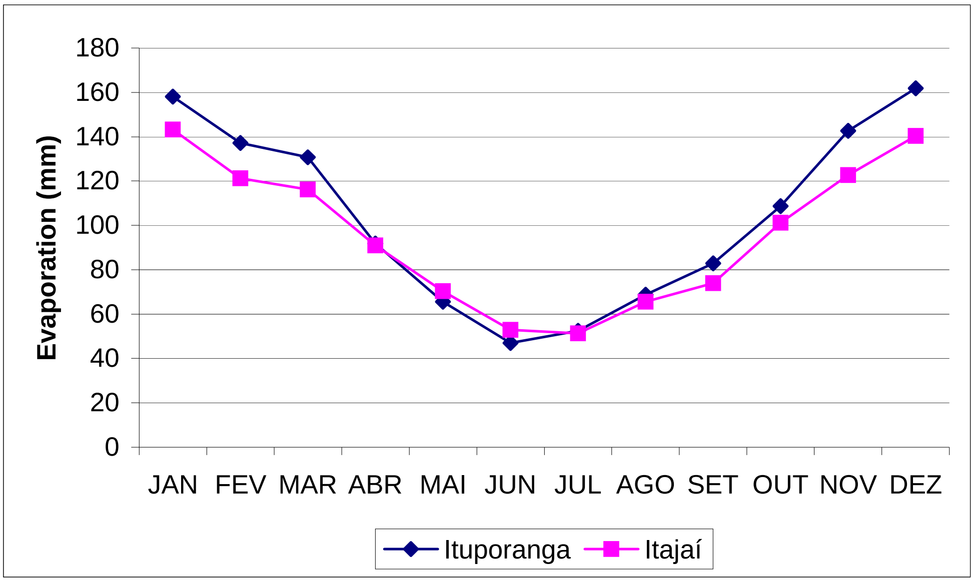
The Class A Pan evaporation observed in the mentioned stations is presented in the Table 3.6.1, except the Rio do Campo station where the observations are not enough for a representative mean. In Indail there is no observations on the Class A Pan.

Table 3.6.1 Mean Monthly and Annual Class A Pan Evaporation

Month	Rio do Campo	Ituporanga	Indaial	Itajaí
January	-	158,1	-	143,3
February	-	137,2	-	121,2
March	-	130,7	-	116,2
April	-	91,8	-	90,9
May	-	65,6	-	70,4
June	-	47,0	-	52,9
July	-	52,4	-	51,3
August	-	68,7	-	65,6
September	-	82,9	-	73,9
October	-	108,6	-	101,1
November	-	142,7	-	122,7
December	-	161,9	-	140,4
Annual	-	1.247,6	-	1.149,9

Source: JICA Survey Team

The monthly mean of the evaporation plot is presented in the Figure 3.6.1. The months which have a lowest evaporation are on the quarter (from May to August), according to the higher relative humidity.



Source: JICA Survey Team

Figure 3.6.1 Monthly mean evaporation of the A Pan

3.7 Insolation

The monthly mean of insolation observed in the mentioned stations is presented in the Table 3.7.1, except the Rio do Campo station where the observations are not enough for a representative mean.

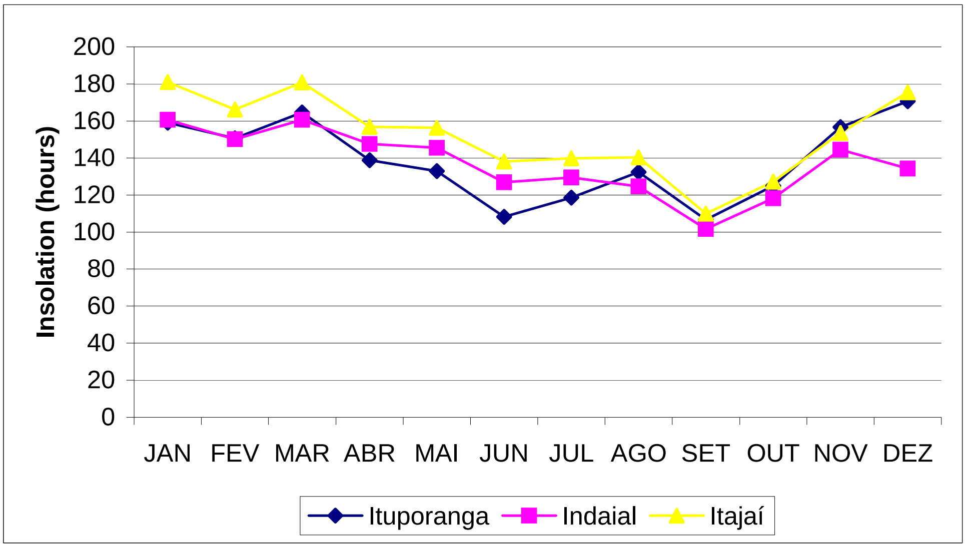
Table 3.7.1 Mean of Monthly and Annual Insolation (hours)

Month	Rio do Campo	Ituporanga	Indaial	Itajaí
January	-	159,1	160,6	181,1
February	-	150,7	150,2	166,2
March	-	164,6	160,7	180,8
April	-	138,7	147,5	156,8
May	-	132,8	145,4	156,4
June	-	108,2	126,9	138,1
July	-	118,6	129,5	139,8
August	-	132,4	124,6	140,3
September	-	106,7	101,6	109,9
October	-	124,9	118,2	127,1
November	-	156,7	144,5	153,6
December	-	170,6	134,3 *	175,5
Annual	-	1.664,0	1.644,0	1.825,6

* Value apparently inconsistent

Source: JICA Survey Team

The monthly mean of insolation plot is presented in the Figure 3.7.1 bellow. The obtained value for Indaial on December seems to be inconsistent. The summer months present a larger number of hours of sunshine, as expected. The insolation in the Itajaí River Basin decreases from the coast to the inland. Possible outliers values are due to different periods of data observation.



Source: JICA Survey Team

Figure 3.7.1 Monthly and Annual Mean of Insolation (Hours)

3.8 Annual Mean of Rainfall

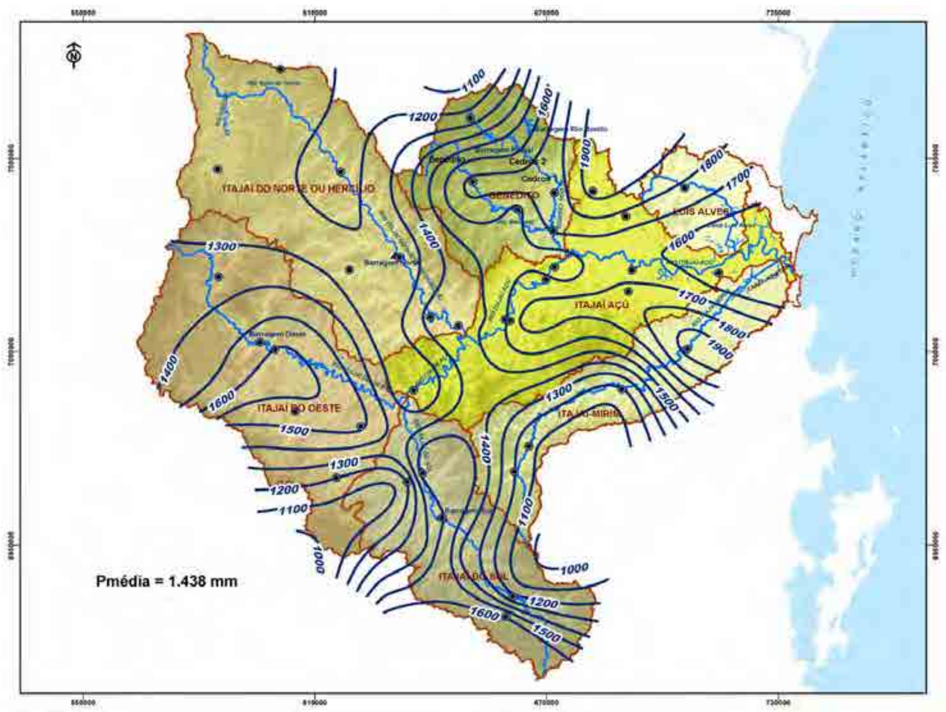
The isohyetal drawing map showed in Figure 3.8.1 was traced based on the annual mean of rainfall observed in 39 rainfall stations located in the Itajaí River Basin in the period of 1980 to 2009 (30 years). In the Table 3.8.1 the stations and the annual mean of rainfall are related.

Table 3.8.1 Annual Mean of Rainfall (mm) – 1980 to 2009

Rainfall Station	Code	Latitude	Longitude	Mean
Ilhota	02648001	-26:55:18	-48:50:21	1519
Luiz Alves	02648002	-26:43:27	-48:55:54	1777
Warnow	02649001	-26:56:37	-49:17:22	1629
Pomerode	02649002	-26:44:08	-49:10:13	1926
Benedito novo	02649003	-26:46:52	-49:21:54	1593
Timbó Novo	02649004	-26:49:47	-49:16:19	1705
Indaial	02649005	-26:54:49	-49:16:03	1536
Blumenau	02649007	-26:55:05	-49:03:55	1618
Arrozeira	02649008	-26:44:27	-49:16:14	1726
Garcia de Blumenau	02649009	-26:58:06	-49:04:27	1754
Itoupava central	02649010	-26:47:35	-49:05:00	1766
Doutor Pedrinho	02649017	-26:43:02	-49:28:59	1721
Witmarsum	02649053	-26:55:34	-49:48:09	1260
Barra do prata	02649058	-26:41:51	-49:49:41	1177
Barragem norte	02649061	-26:53:42	-49:40:20	1224
Barra do Avencal	02649065	-26:34:08	-49:29:30	1252
Rio do campo	02650014	-26:56:42	-50:08:36	1349
Iracema	02650022	-26:27:31	-49:59:11	1255
Nova Cultura	02650023	-26:41:35	-50:08:52	1243
Brusque	02748000	-27:06:02	-48:55:04	1926
Apiuna - Régua Nova	02749000	-27:02:17	-49:23:42	1578
Ibirama	02749001	-27:03:14	-49:31:00	1485
Ituporanga	02749002	-27:23:55	-49:36:21	1535
Taió	02749003	-27:06:47	-49:59:40	1601
Nova Bremen	02749005	-27:02:03	-49:35:23	1423
Pouso Redondo	02749006	-27:15:26	-49:56:27	1564
Lomba Alta	02749007	-27:43:50	-49:22:58	1590
Trombudo Central	02749013	-27:17:25	-49:46:08	1514
Neisse Central	02749016	-27:02:25	-49:22:53	1643
Sul Dam	02749017	-27:30:07	-49:33:11	1489
Vidal Ramos	02749033	-27:23:33	-49:21:56	1205
Saltinho	02749037	-27:41:00	-49:21:55	1225
Rio do sul	02749039	-27:12:20	-49:37:54	1205

Rainfall Station	Code	Latitude	Longitude	Mean
Agrolândia	02749041	-27:24:41	-49:49:53	1201
Ituporanga	02749043	-27:25:07	-49:38:46	1206
Botuverá	02749045	-27:11:48	-49:05:14	1193
Salseiro	02749046	-27:19:55	-49:19:42	1134
Dam	02750014	-27:05:50	-50:02:02	1548
Cabeceira Ribeirão Caetano	02750021	-27:08:28	-50:15:52	1401

Source: JICA Survey Team



Source: JICA / EPAGRI / CIRAM

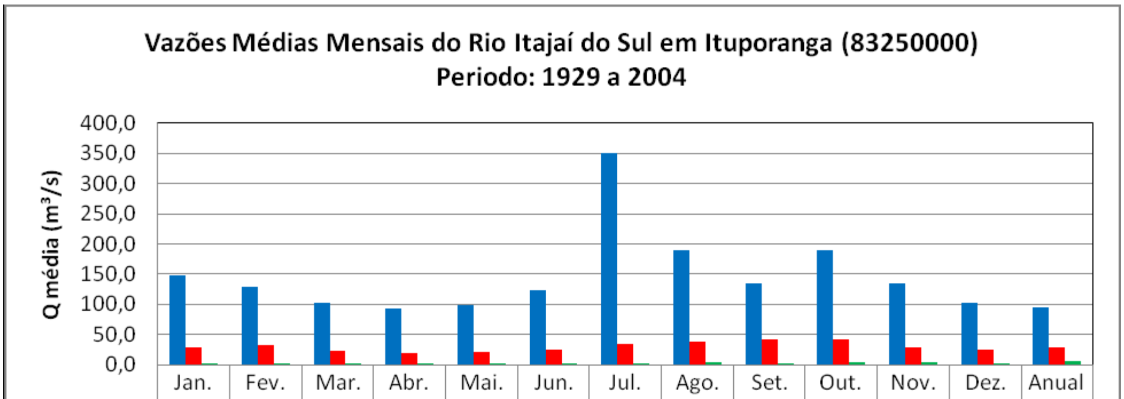
Figure 3.8.1 Annual mean of precipitation in the Itajaí River Basin

CHAPTER 4 HYDROLOGY

4.1 Monthly Mean of Discharge

The following Figures 4.1.1 to 4.1.8 present a brief of the monthly mean discharge and the seasonality of these discharges in many fluviometric stations located in the main rivers.

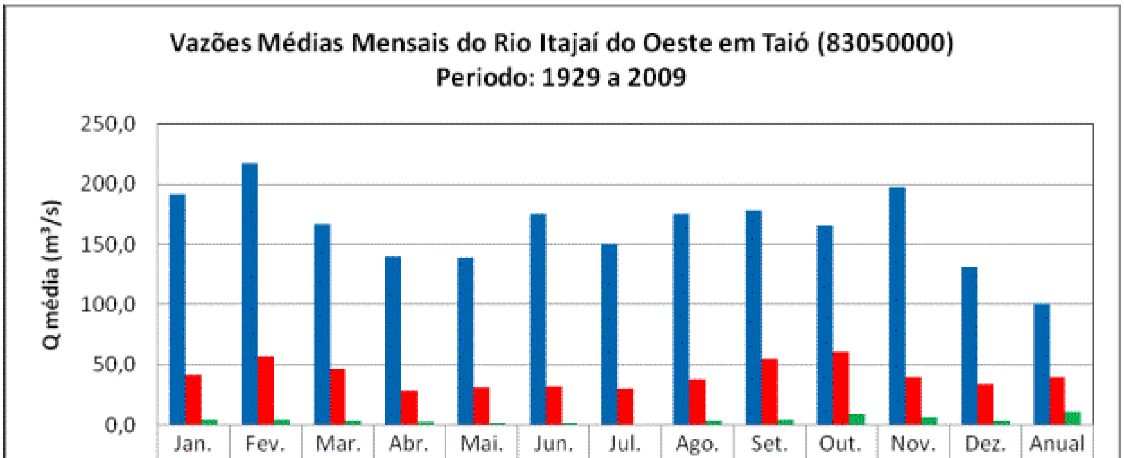
There is no only one dry season due to the occurrency of the rain in all the months of the year. Any month can be extremely humid on a specific year and extremely dry in another; July is the month that presents a notable contrast between these two characteristics.



	Jan.	Fev.	Mar.	Abr.	Mai.	Jun.	Jul.	Ago.	Set.	Out.	Nov.	Dez.	Anual
Máxima	148,5	128,2	101,8	92,8	99,0	123,9	350,3	190,2	134,2	190,1	133,7	102,2	95,6
Média	28,4	32,6	23,1	18,2	21,7	24,1	33,4	37,9	40,9	41,2	28,5	24,6	29,2
Minima	2,2	2,1	2,5	1,1	1,0	0,7	0,9	3,2	2,3	4,6	4,6	2,1	6,0

Source: JICA Survey Team

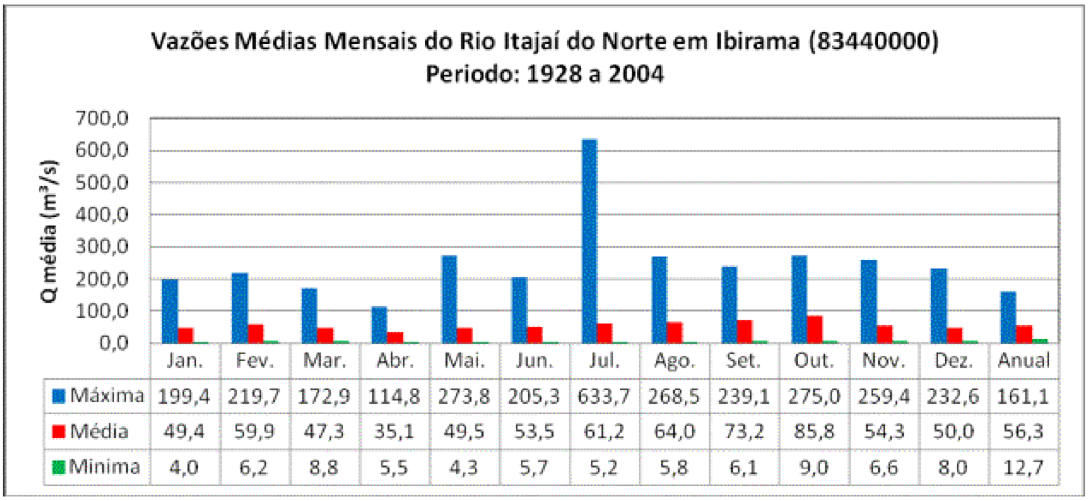
Figure 4.1.1 Monthly mean of discharge in the Itajaí do Sul River which is located in Ituporanga (83250000)



	Jan.	Fev.	Mar.	Abr.	Mai.	Jun.	Jul.	Ago.	Set.	Out.	Nov.	Dez.	Anual
Máxima	191,3	217,5	167,2	140,2	139,0	175,5	150,4	175,8	178,1	165,5	197,8	131,3	100,7
Média	41,8	56,7	46,3	28,0	31,5	32,4	30,6	37,6	55,0	60,8	40,2	34,2	39,5
Minima	4,4	4,7	3,7	2,7	2,0	1,5	1,1	3,4	4,1	9,3	6,2	3,1	11,2

Source: JICA Survey Team

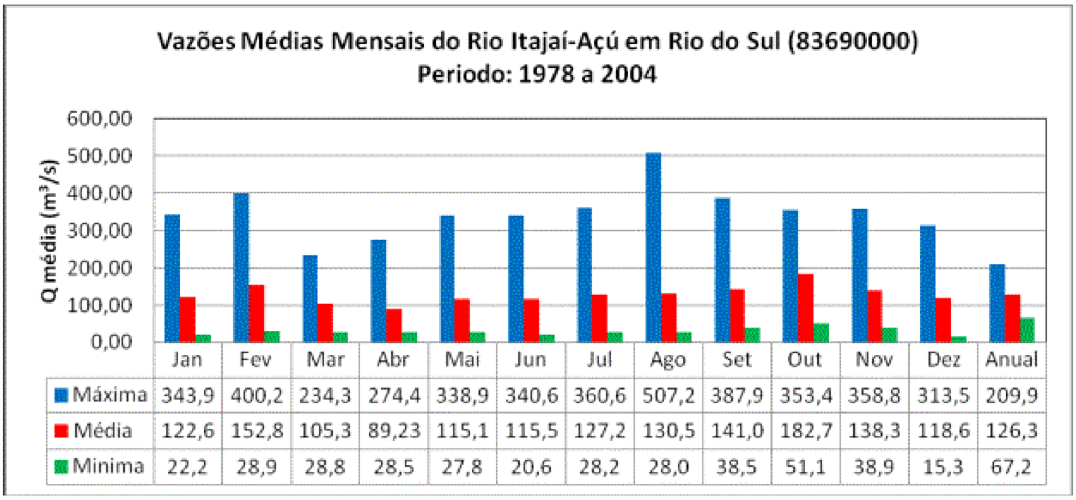
Figure 4.1.2 Monthly mean of discharge in the Itajaí do Oeste River which is located in Taió (83050000)



	Jan.	Fev.	Mar.	Abr.	Mai.	Jun.	Jul.	Ago.	Set.	Out.	Nov.	Dez.	Anual
Máxima	199,4	219,7	172,9	114,8	273,8	205,3	633,7	268,5	239,1	275,0	259,4	232,6	161,1
Média	49,4	59,9	47,3	35,1	49,5	53,5	61,2	64,0	73,2	85,8	54,3	50,0	56,3
Minima	4,0	6,2	8,8	5,5	4,3	5,7	5,2	5,8	6,1	9,0	6,6	8,0	12,7

Source: JICA Survey Team

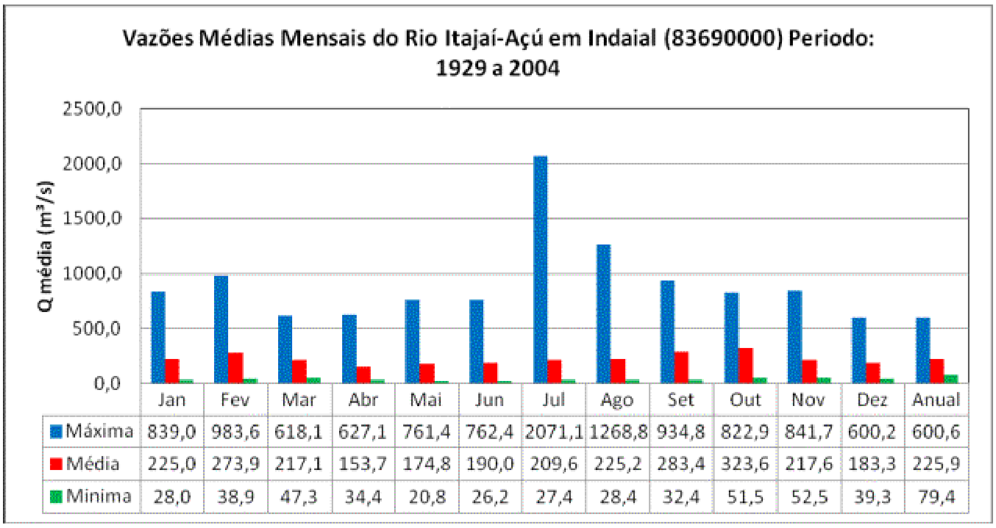
Figure 4.1.3 Monthly mean of discharge in the Itajaí do Norte River located in Ibirama (83440000)



	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Anual
Máxima	343,9	400,2	234,3	274,4	338,9	340,6	360,6	507,2	387,9	353,4	358,8	313,5	209,9
Média	122,6	152,8	105,3	89,23	115,1	115,5	127,2	130,5	141,0	182,7	138,3	118,6	126,3
Minima	22,2	28,9	28,8	28,5	27,8	20,6	28,2	28,0	38,5	51,1	38,9	15,3	67,2

Source: JICA Survey Team

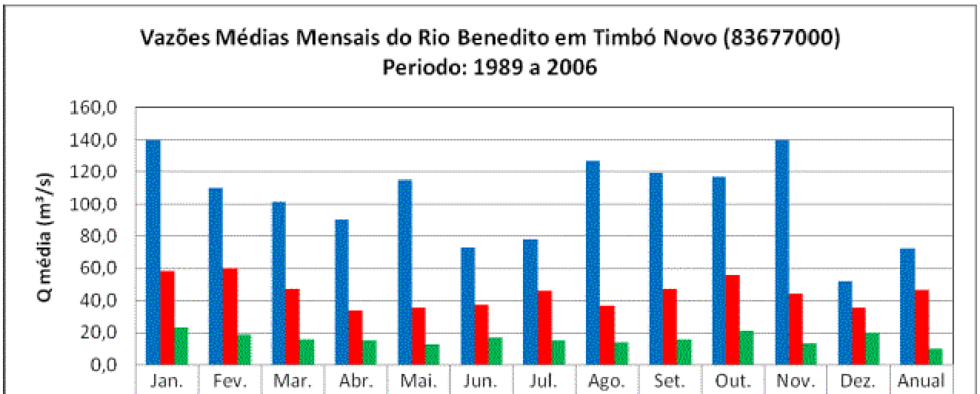
Figure 4.1.4 Monthly mean of discharge in the Itajaí which is located in Rio do Sul (83690000)



	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Anual
Máxima	839,0	983,6	618,1	627,1	761,4	762,4	2071,1	1268,8	934,8	822,9	841,7	600,2	600,6
Média	225,0	273,9	217,1	153,7	174,8	190,0	209,6	225,2	283,4	323,6	217,6	183,3	225,9
Minima	28,0	38,9	47,3	34,4	20,8	26,2	27,4	28,4	32,4	51,5	52,5	39,3	79,4

Source: JICA Survey Team

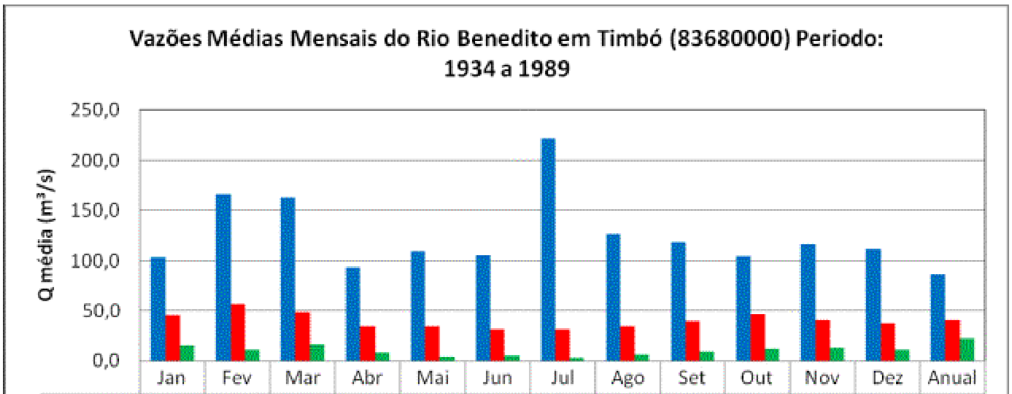
Figure 4.1.5 Monthly mean of discharge in the Itajaí River which is located in Ituporanga Vazões Médias Mensais do Rio Itajaí em Indaial (83690000)



	Jan.	Fev.	Mar.	Abr.	Mai.	Jun.	Jul.	Ago.	Set.	Out.	Nov.	Dez.	Anual
Máxima	139,7	110,3	101,4	90,1	114,9	73,1	78,3	126,8	119,2	116,6	139,4	52,3	72,4
Média	58,3	60,0	47,4	33,8	35,8	37,2	46,3	37,0	47,2	56,1	44,1	35,5	46,4
Minima	23,2	19,2	16,1	15,1	13,0	17,0	15,1	13,9	16,0	21,2	13,3	20,3	10,5

Source: JICA Survey Team

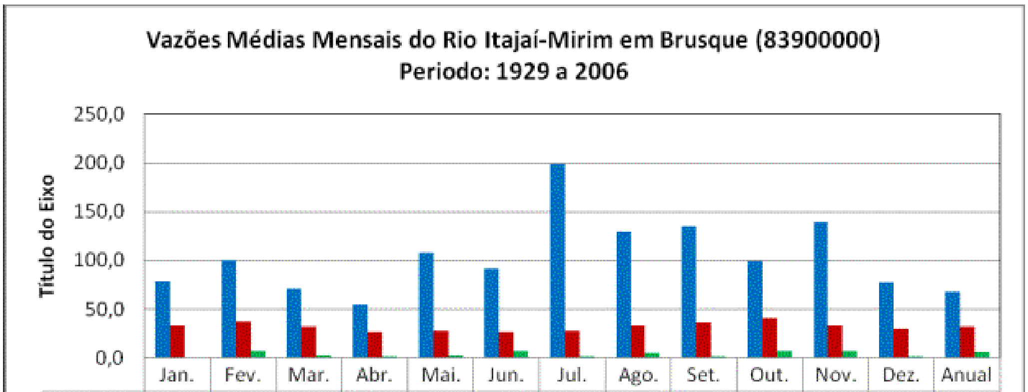
Figure 4.1.6 Monthly mean of discharge in the Benedito River which is located in Timbó Novo (83677000)



	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez	Anual
Máxima	103,0	166,0	163,0	93,7	109,0	105,0	222,0	127,0	119,0	104,0	117,0	111,0	86,7
Média	45,7	56,8	48,6	35,0	34,4	31,2	32,1	34,3	39,5	46,5	41,2	37,7	40,3
Minima	15,8	11,3	17,0	8,5	4,4	4,9	3,9	6,5	9,0	12,0	13,7	11,5	22,1

Source: JICA Survey Team

Figure 4.1.7 Monthly mean of discharge in the Benedito River which is located in Timbó (83680000)



	Jan.	Fev.	Mar.	Abr.	Mai.	Jun.	Jul.	Ago.	Set.	Out.	Nov.	Dez.	Anual
Máxima	78,4	100,4	70,7	55,0	107,7	91,8	199,1	129,3	134,6	99,2	139,0	77,2	68,0
Média	33,0	37,9	32,0	26,5	27,2	26,1	27,9	32,8	36,4	40,3	33,4	29,7	32,1
Minima	0,8	7,0	3,1	1,3	3,0	7,6	1,7	5,2	1,4	7,6	7,5	2,0	6,5

Source: JICA Survey Team

Figure 4.1.8 Monthly mean of discharge in the Itajaí-Mirim River which is located in Brusque (83900000)

4.2 Sediments

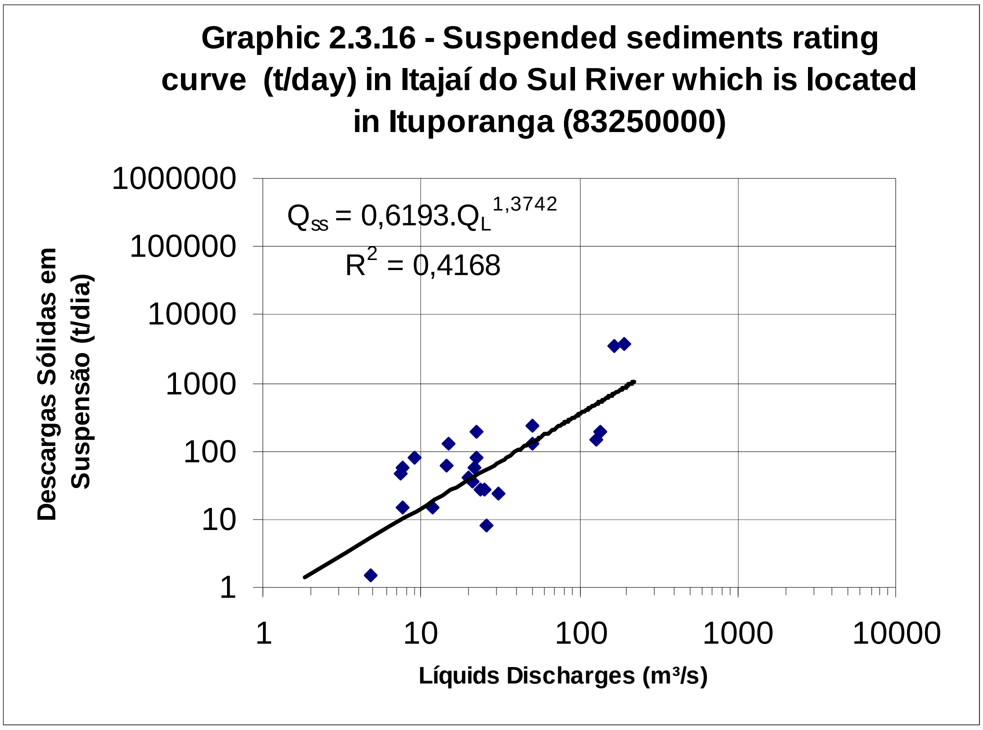
In the Itajaí River Basin there are only measurements of suspended sediment concentration, there is no bed sediments measurements. The sediment concentration measurements are implemented in the main rivers of the basin. These measurements were made by ANA (National Water Agency) and they are published on the internet (Hidro Web).

The solid discharges of the suspended sediments were calculated through the concentration (mg/l ou ppm) determined in laboratory using the following expression:

$$QSS = 0{,}0864 \times QL \times C$$

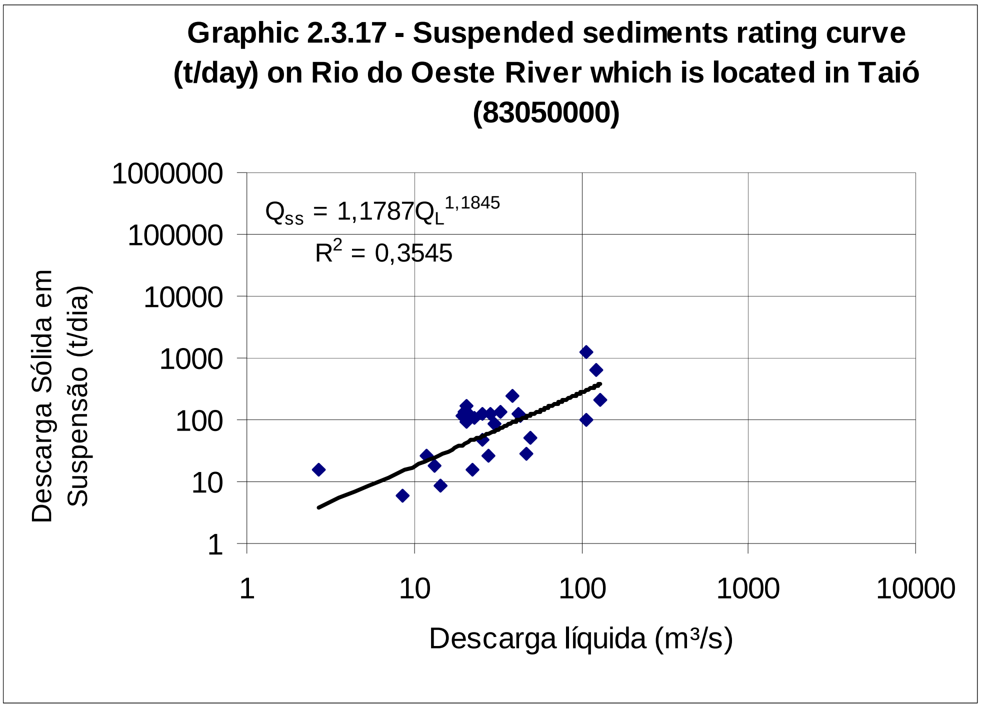
Where:
C = Concentration of sediment (mg/l ou ppm)
QL = Liquid discharge (m^3/s)
QSS = Solid suspended discharge (ton/dia)

After the solid suspended discharges had been obtained from each one of the considered stations the sediments rating curve for each one of them had been determined. This rating curve relates the suspended solid discharge to the liquid discharges measured in field survey by the suspended sediments collection. In the Figures 4.2.1 to 4.2.7 these curves are being presented:



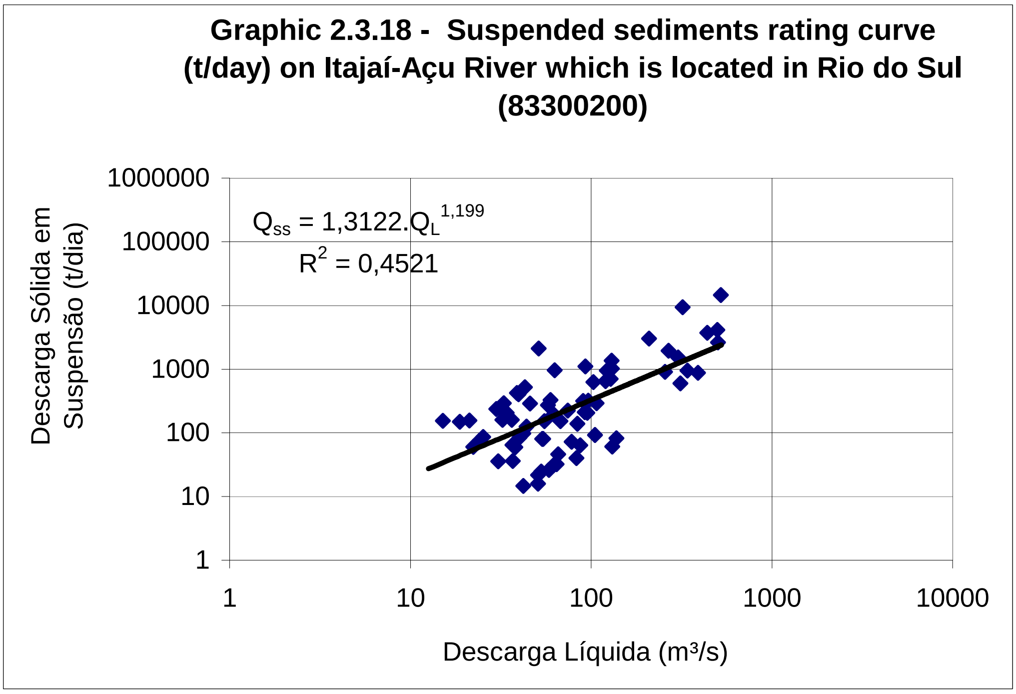
Source: JICA Survey Team

Figure 4.2.1 Suspended sediments rating curve (t/day) on Itajaí do Sul River which is located Ituporanga (83250000)



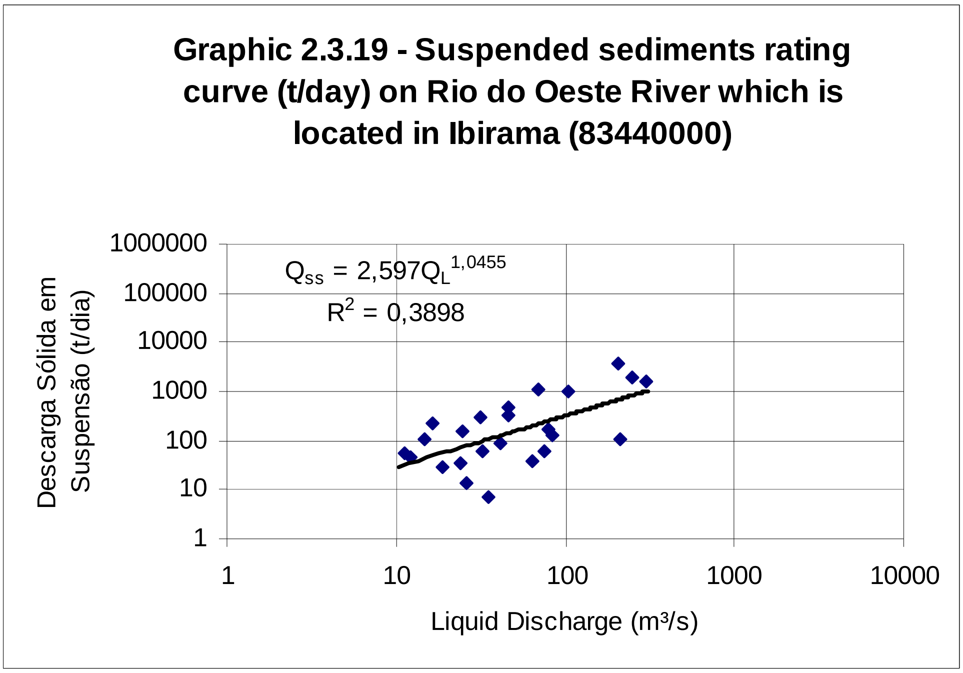
Source: JICA Survey Team

Figure 4.2.2 Suspended sediments rating curve (t/day) on Rio do Oeste River which is located in Taió (83050000)



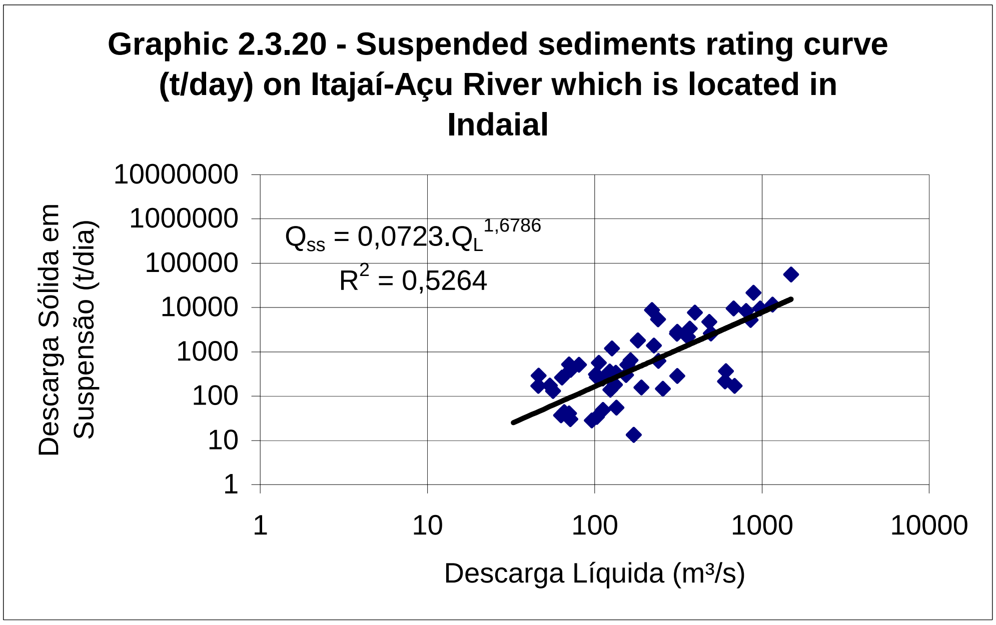
Source: JICA Survey Team

Figure 4.2.3 Suspended sediments rating curve (t/day) on Itajaí River which is located in Rio do Sul Novo (83300200)



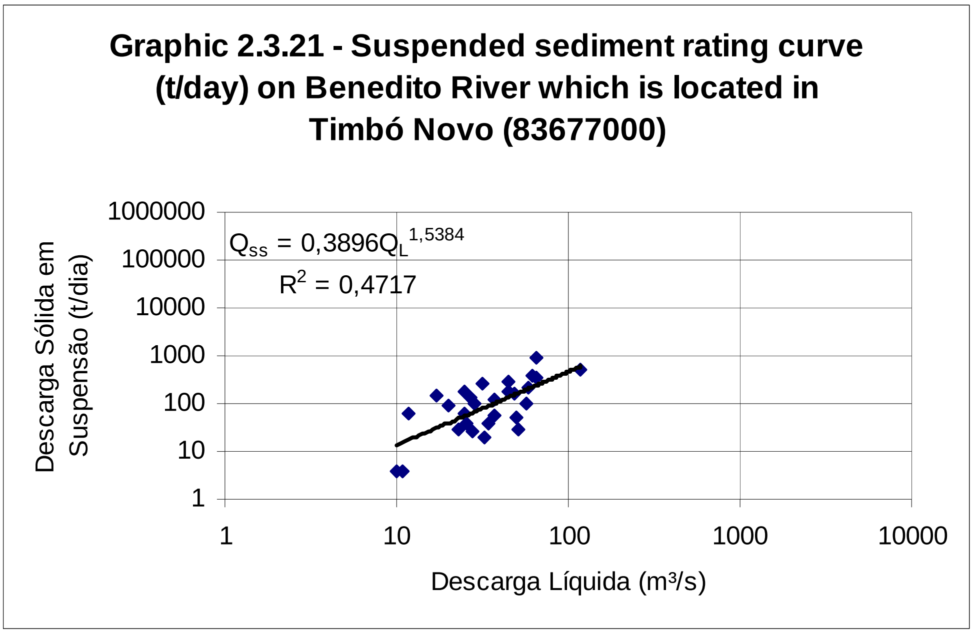
Source: JICA Survey Team

Figure 4.2.4 Suspended sediments rating curve (t/day) on Rio do Oeste River which is located in Ibirama (83440000)



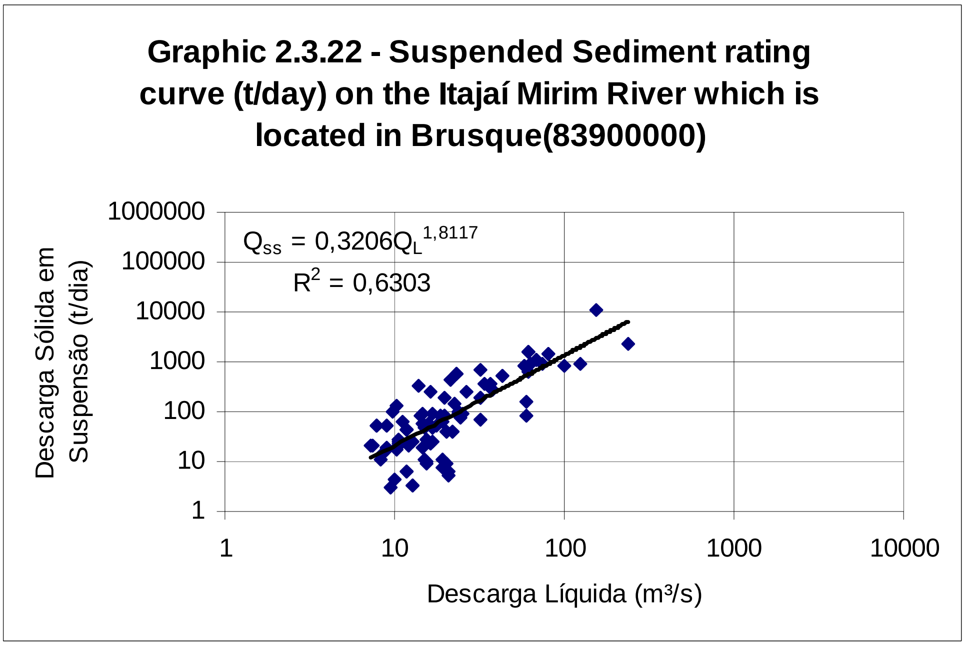
Source: JICA Survey Team

Figure 4.2.5 Suspended sediments rating curve (t/day) on Itajaí River which is located in Indaial



Source: JICA Survey Team

Figure 4.2.6 Suspended sediment rating curve (t/day) on Benedito River which is located in Timbó Novo (83677000)



Source: JICA Survey Team

Figure 4.2.7 Suspended sediment rating curve (t/dia) on Itajaí-Mirim River whih is located in Brusque (83900000)

In the Table 4.2.1 it is presented the suspended solid discharge brief for each station, which were obtained by the suspended sediment rating curve, mentioned above, and by the monthly mean of observed discharge. As there is no solid discharge derived the riverbed, this portion was estimated as 20% from the suspended solid discharge, in order to obtain the total solid discharge. The fact of the concetration measurements had happened in different time and in each station should be considerated. Likewise, the discharge observation period is also different in each hydrosedimentometric station.

Table 4.2.1 Suspended and Total Solid Discharge

Station	Code	River	Area (km²)	QSS Mean Anual Suspended Load (t/day)	Mean Annual Bed Load QBL=0,20 QSS (t/day)	Mean Annual Load (t/day)	Specific Sediment Load (t/day/km²)	Annual Specific Sediment Load (t/year/ km²)
Ituporanga	83250000	Itajaí do Sul	1,669.49	90.4	18.08	108.48	0.065	23.717
Taió	83050000	Itajaí do Oeste	1,575.00	105.11	21.022	126.132	0.08	29.231
Rio do Sul	83300200	Itajaí -Açú	5,100.00	463.65	92.73	556.38	0.109	39.819
Ibirama	83440000	Itajaí do Norte	3,314.00	183.04	36.608	219.648	0.066	24.192
Indaial	83690000	Itajaí	11,151.00	1044.17	208.834	1253.004	0.112	41.014
Timbó Novo	83677000	Benedito	1,342.00	174.62	34.924	209.544	0.156	56.992
Brusque	83900000	Itajaí-Mirim	1,240.00	260.43	52.086	312.516	0.252	91.991

Obs: The QBL was supposed to be 20% of the QSS

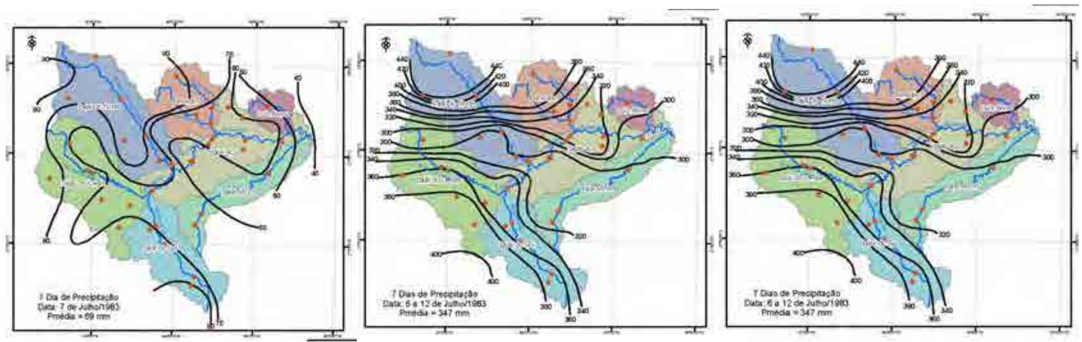
Source: JICA Survey Team

4.3 Flood Rainfall

After the building of the Sul and Norte dams (in the Itajaí do Sul and Itajaí do Norte rivers) occurred the largest flood registered in the Itajaí River Basin (July, 1983 and in August, 1984). In November, 2008, after a previously heavy rainy period some instense rainfall happened in the lower and mid-valley cities, especially in Itajaí, where a large Flood event happened. In Blumenau and other upper and mid-valley cities the flood level was large and caused several damage, but it did not achieve the 1983 and 1984 Flood event level. Many landslides, however, could be noticed such as the most serious event occurred in Ilhota where many lives were lost.

In April, 2010, after the beginning of this current survey, many intense rainfall happened in the Itajaí River Basin.

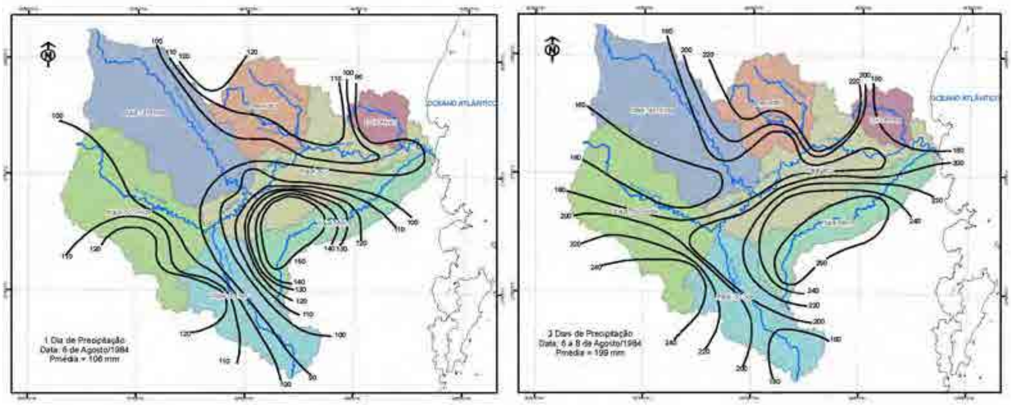
The Figure 4.3.1 presents the isohyetal rainfall in the Itajaí River Basin for a day, four days and seven days duration occurred in July, 1983 and the mean of rainfall in the basin for each of these durations.



Source: JICA Survey Team (Based on data from EPAGRI, CIRAM)

Figure 4.3.1 Rainfall (occurred in July, 1983) for 1, 4 and 7 days duration in the Itajaí-Açu River Basin

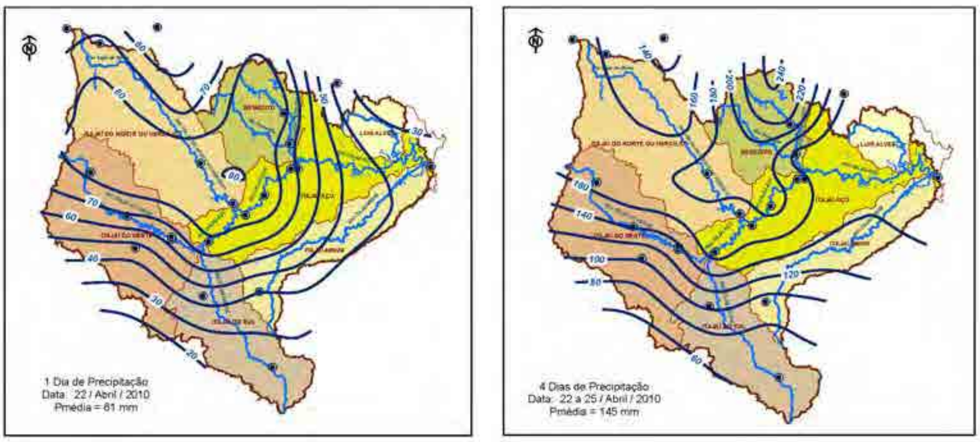
The Figure 4.3.2 presents the isohyetal rainfall in the Itajaí River Basin for a day and three days duration occurred in August,1984 and the mean of rainfall in the basin for each of these durations.



Source: JICA Survey Team (Based on data from EPAGRI, CIRAM)

Figure 4.3.2 Rainfall (occurred in August, 1984) for 1 and 3 days duration in the Itajaí River Basin

The Figure 4.3.3 presents the isohyetal rainfall in the Itajaí River Basin for a day and four days duration occurred in April, 2010 and the mean of rainfall in the basin for each of these durations.



Source: JICA Survey Team (Based on data from EPAGRI, CIRAM)

Figure 4.3.3 Rainfall (occurred in August, 1984) for 1 and 3 days duration in the Itajaí-Açu River Basin

The Table 4.3.1 presents the mean of rainfall in the Itajaí River Basin occurred in many days duration during the flood above mentioned.

Table 4.3.1 Flood Rainfall

Duration	Mean of Rainfall in the Basin (mm)		
	July, 1983	August,1984	April, 2010
1 day	69	106	61
3 days	-	199	-
4 days	228	-	145
7 days	347	-	-

Source: JICA Survey Team

The isohyetal rainfall that led to the floods of July, 1983 and August, 1984 were obtained from the JICA report, from January 1988: "Final Report on the Itajaí River Basin Flood Control Project – Part 1 – Master Plan Study – Supporting Report". These isohyetal presented in the report were scanned at this current stage of studies. The maximum rainfall values in the basin (for various durations presented in the table above) were also calculated at this stage of studies.

The rainfall observed at hourly intervals, for four days duration, occurred in the Itajaí River basin (August, 1984 and April,2010) were used for calibration of HEC-HMS rainfall-discharge model developed by the U.S. Army (U.S. Army - Corps of Engineers) and freely available on the INTERNET for download.

4.4 Maximum Annual Discharge

The Table 4.4.1 presents the maximum annual of mean daily discharges occurred in different fluviometric stations in the Itajaí River Basin. These discharges were updated until 2004 in the ANA (National Water Agency) website on the internet (hidroweb).

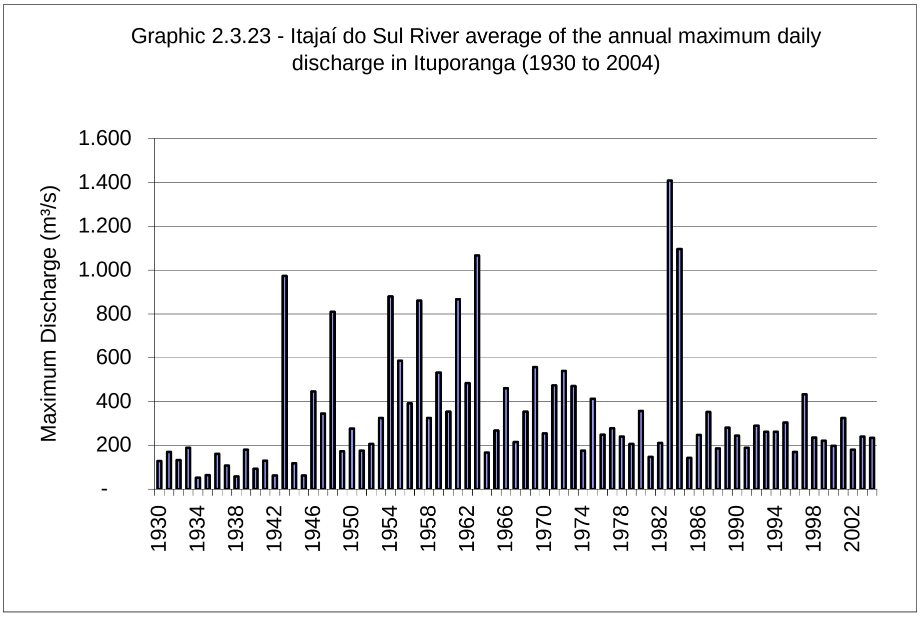
Table 4.4.1 Maximum Annual Mean of Daily Discharge (m³/s)

River	ITAJAÍ SUL		ITAJAÍ OESTE		ITAJAÍ NORTE		ITAJAÍ		ITAJAÍ MIRIM	
Station	ITUPORANGA		TAIÓ		IBIRAMA		INDAIAL		BRUSQUE	
ANA Code	83250000		83050000		83440000		83690000		83900000	
Year	Month	Q	Month	Q	Month	Q	Month	Q	Month	Q
1929	---	---	October	437	October	426	October	1.736	---	---
1930	February	129	August	247	February	339	August	1.362	January	181
1931	September	169	May	518	May	800	September	2.636	September	340
1932	May	133	May	482	April	628	May	1.887	May	356
1933	October	189	October	725	October	638	October	2.580	October	285
1934	February	53	February	388	February	532	April	1.439	February	247
1935	August	64	September	470	September	1.282	September	2.807	October	260
1936	August	161	June	270	August	528	August	1.935	August	352
1937	October	108	November	277	November	575	October	1.129	May	242
1938	February	58	June	308	June	729	June	1.713	June	182
1939	November	180	June	368	November	1.156	November	2.229	November	420
1940	August	94	March	261	August	240	August	1.226	October	269
1941	November	130	March	314	October	247	November	893	November	178
1942	March	63	February	201	February	545	February	1.376	February	198
1943	August	973	August	427	August	575	August	2.273	August	400
1944	March	118	March	280	January	206	March	574	January	168
1945	April	63	February	153	July	255	February	787	February	148
1946	August	446	February	397	February	659	February	1.667	February	229
1947	October	345	September	249	September	548	September	1.369	October	333
1948	August	809	May	501	May	894	May	2.673	May	398
1949	April	172	June	187	April	396	April	781	March	206
1950	October	276	October	428	October	551	October	2.282	October	253
1951	October	176	October	391	October	515	October	1.526	November	182
1952	October	206	September	321	October	354	September	1.206	October	214
1953	October	325	November	388	October	525	October	2.711	November	255
1954	October	879	October	592	October	770	October	3.990	October	555
1955	July	586	May	356	May	890	May	2.654	May	184
1956	September	391	January	249	January	235	September	1.017	September	181
1957	August	861	August	564	August	1.242	August	5.767	August	364
1958	November	324	March	430	March	502	March	1.504	March	283
1959	April	532	September	155	September	444	September	1.047	April	153
1960	August	354	October	365	November	444	August	1.266	February	321
1961	November	867	September	463	September	796	November	2.515	November	560
1962	May	484	September	328	September	545	September	1.592	March	195
1963	September	1.067	February	634	November	482	September	1.951	September	275
1964	October	167	May	189	May	334	May	771	October	102
1965	August	267	August	297	August	571	August	1.984	December	190
1966	February	461	February	480	February	785	February	2.204	February	226
1967	September	215	February	322	December	360	February	1.253	February	236
1968	December	354	December	212	December	260	September	728	December	80
1969	April	556	February	481	April	842	April	2.433	April	182
1970	October	254	June	221	July	408	July	1.273	July	127
1971	July	473	June	445	June	774	June	2.238	April	143
1972	August	539	August	428	August	927	August	2.344	August	420

River	ITAJAÍ SUL		ITAJAÍ OESTE		ITAJAÍ NORTE		ITAJAÍ		ITAJAÍ MIRIM	
Station	ITUPORANGA		TAIÓ		IBIRAMA		INDAIAL		BRUSQUE	
ANA Code	83250000		83050000		83440000		83690000		83900000	
Year	Month	Q	Month	Q	Month	Q	Month	Q	Month	Q
1973	August	470	August	279	June	1.161	August	3.062	August	279
1974	September	176	February	225	July	624	March	1.432	March	243
1975	September	412	October	375	October	1.186	October	2.533	October	301
1976	January	249	December	317	May	722	May	1.768	August	247
1977	November	278	August	362	October	712	August	1.870	August	416
1978	December	240	December	245	December	975	December	2.589	December	430
1979	October	206	July	257	May	886	October	2.186	October	215
1980	August	356	December	412	December	2.099	December	3.380	December	272
1981	January	148	January	217	December	447	January	1.341	October	284
1982	November	210	November	265	November	663	November	1.903	May	193
1983	July	1.408	August	483	July	2.442	July	5.078	July	484
1984	August	1.096	August	516	August	1.533	August	5.256	August	542
1985	July	143	November	253	April	280	April	819	November	99
1986	November	247	November	308	November	307	October	744	November	188
1987	May	352	January	297	May	656	May	1.562	May	134
1988	September	186	May	259	May	638	May	1.540	September	57
1989	May	280	September	301	September	785	November	1.721	January	145
1990	October	244	June	434	July	793	October	2.084	October	149
1991	October	189	December	257	August	453	October	1.141	November	113
1992	June	289	May	437	May	1.614	May	3.811	---	---
1993	July	261	September	375	September	548	September	1.807	---	---
1994	April	261	May	318	July	472	May	1.637	---	---
1995	January	304	January	363	July	375	January	1.783	---	---
1996	June	170	February	368	July	348	July	1.116	March	138
1997	February	432	November	382	October	578	February	2.406	February	432
1998	April	235	April	407	April	614	April	2.264	April	391
1999	October	221	July	414	July	565	July	1.919	October	165
2000	September	197	September	316	December	444	October	1.390	October	114
2001	October	325	September	498	October	850	October	3.133	October	378
2002	August	179	October	254	November	297	December	1.145	August	155
2003	December	239	February	167	October	204	December	755	---	---
2004	September	234	September	205	October	528	October	1.683	---	---

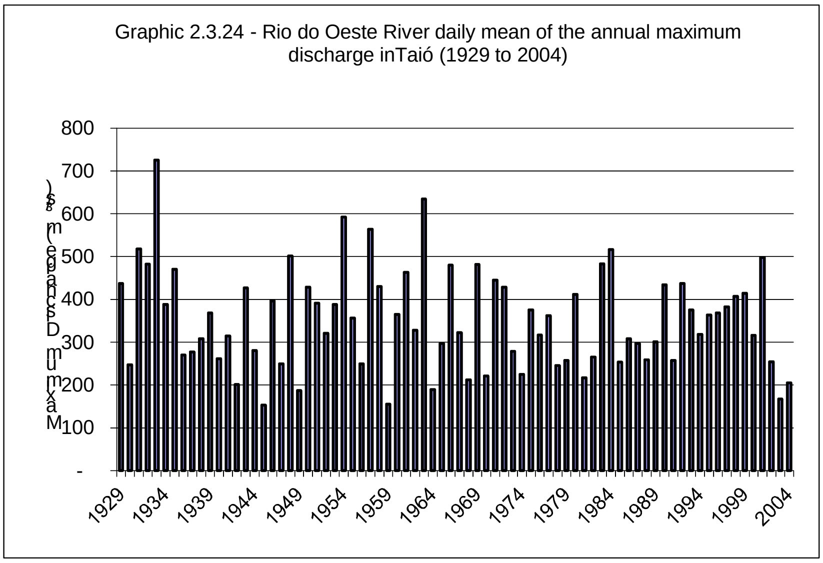
Source: JICA Survey Team

The Figures 4.41 to 4.45 presents the cronological plot of the annual maximum mean daily discharge in the considered stations.



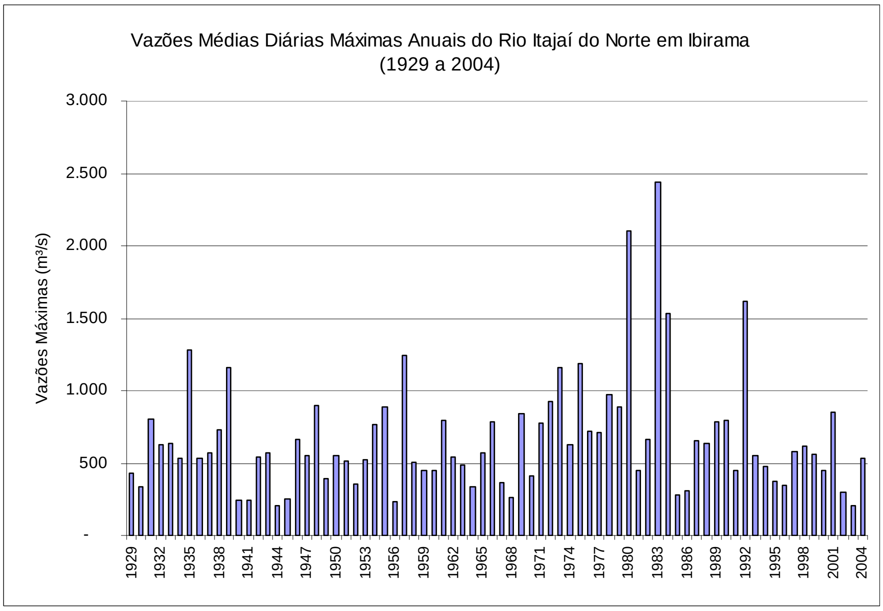
Source: JICA Survey Team

Figure 4.4.1 Itajaí do Sul River daily mean of the annual maximum discharge in Ituporanga



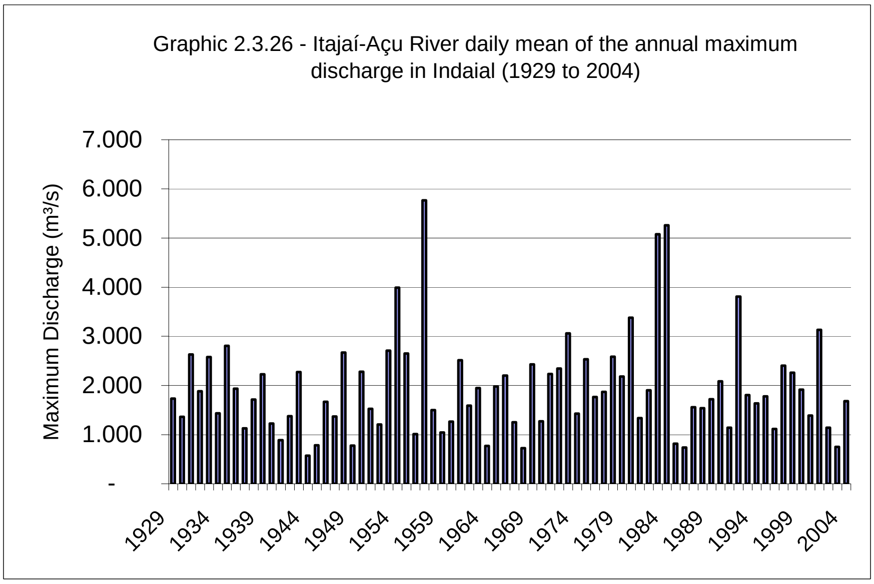
Source: JICA Survey Team

Figure 4.4.2 Itajaí do Oeste River daily mean of the annual maximum discharge in Taió



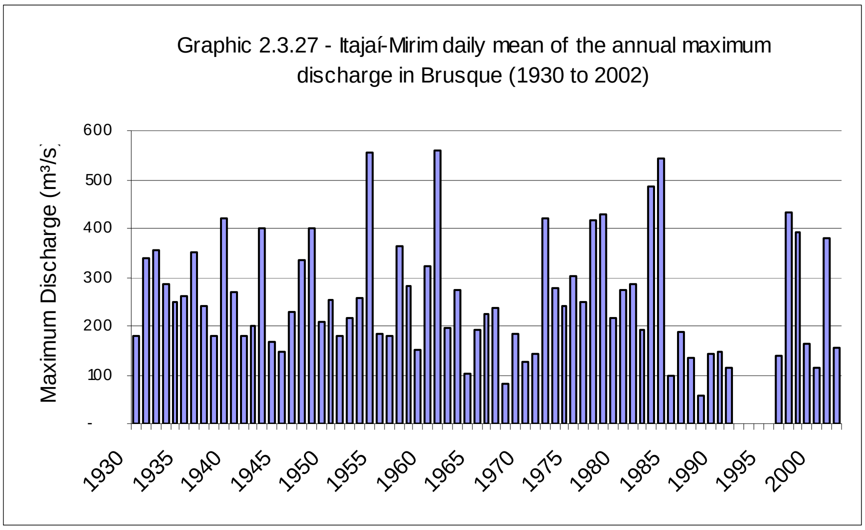
Source: JICA Survey Team

Figure 4.4.3 Itajaí do Norte River daily mean of the annual maximum discharge in Ibirama



Source: JICA Survey Team

Figure 4.4.4 Itajaí River daily mean of the annual maximum discharge in Indaial



Source: JICA Survey Team

Figure 4.4.5 Itajaí-Mirim River daily mean of the annual maximum discharge in Brusque

The flood on the basin can happen any time of the year, however the larger Flood events usually happen in the winter, on the months of July and August.

4.5 Flood Frequency Analysis for Sul Dam Heightening

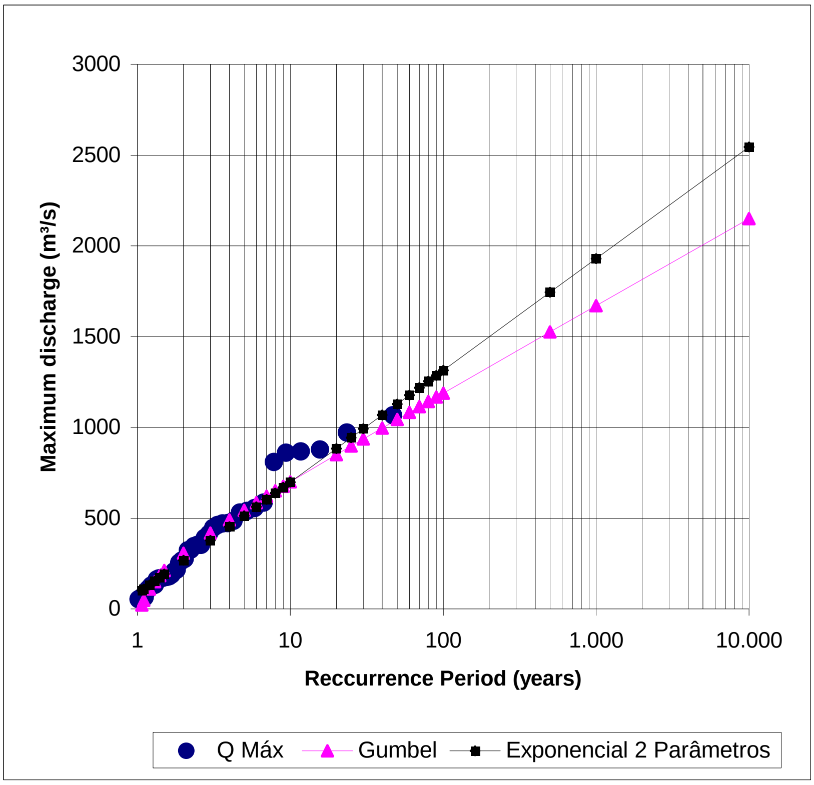
The hydraulic heightening of the Sul dam, located in the Itajaí do Sul river, aims to increase the capacity of the reservoir by the spillway crest heightening. In order to verify the new capacity of the spillway, many frequency flood studies based on the maximum annual mean daily discharge were carried out at the Ituporanga (83250000) station. Ituporanga station is located in the Itajaí do Sul River, its drainage area is about 1,645.41 km² , while the Sul dam covers an area of 1,273 Km². Due to the proximity of the areas and the fluviometric observations absence in the dam place, the resultants discharges of the fluviometric station for some recurrence intervals were transfered to the dam place by drainage area relation. Taking into account that the Sul dam was built in the year of 1976, two alternatives for maximum flood survey were considereted:

a) Historial range of maximum dicharges after 1975 were not considered;
b) Historical range mean of annual maximum discharges were considered.

As the “a” alternative leads to higher values and it is in favor of the safety, it was the chosen option.

Two probable distributions were adjusted to the daily mean of the annual maximum discharge of the Itupornaga (83250000) fluviometric station: Gumbel and 2 Paramenters Exponential, according to the methodology of the guide “Guia para Cálculo de Cheia de Projeto de Vertedores, ELETROBRÁS/CEPEL, Rio de Janeiro, 1987”. The Guidelines consider the 2 Parameters Exponential distribution as the most robust, but says it can be used Gumbel distribution if the asymmetry coefficient of the population is less than 1,5.

In the case of the sample, the skewness coefficient is 1,114. Even so it is recommended the 2 Parameters Exponential distribution, because its values takes to largest floods than Gumbel distribution, as shown in Figure 4.6.1. Besides the exponential leads to higher values, therefore it is in favor of the security.



Source: JICA Survey Team

Figure 4.5.1 Maximum Flood in Ituporanga (83250000) in Rio do Sul

The Table 4.5.1 below presents the maximum discharge in Ituporanga (83250000) and the site of the Sul dam for 1,000 and 10,000 years of recurrence period, which are commonly used in Brazil to design the hydraulic capacity of the spillways. In the case of Sul dam, due to the height of the dam and the size of the reservoir, the recurrence period of 10,000 years can be used.
As the daily mean of maximum annual discharge was used, the instantaneous peak of the Oeste dam place was calculated by the Füller method:

$$\mathbf{Qi = Q \times (1+2{,}66 \times A^{-0{,}3})}$$

Where:

Q_i = Instantaneous discharge (m³/s), Q = Daily mean of discharge (m³/s)

A = Drainage area (km²)

Table 4.5.1 Maximum Discharges for Sul Dam - Itajaí do Sul River

T(years)	Maximum discharge (m³/s)		2 Parameters Exponential
	Ituporanga	Barragem Sul	
	Daily mean	Daily mean	Instantaneous peak (Füller)
1,000	1,929	1,493	1,958
10,000	2,545	1,969	2,582

Remark 1: Sul dam was built in 1976
Remark 2: Data after 1975 were not considered
Source: JICA Survey Team

4.6 Flood Frequency Analysis for Oeste Dam Heightening

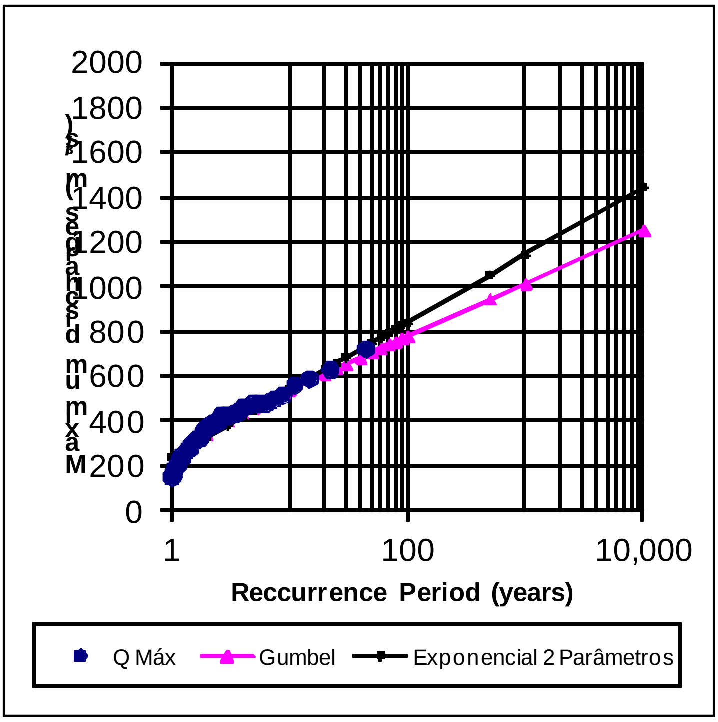
The hydraulic heightning of the Oeste dam, located in the Itajaí do Oeste river, aims to increase the capacity of the reservoir by the spillway crest heightening and also increase the capacity of the spillways background. In order to verify the new capacity of the spillway a frequency flood study based on the annual mean of maximum daily discharge were carried out on the Taió (83050000) station. This station is located in the Itajaí do Oeste River, its drainage area is about 1,570.13 Km², while the Oeste dam covers an area of 1,042 Km². Due to the proximity of the areas and the fluviometric observation absence in the dam place, the resultants discharges of the fluviometric station flood survey were transfered to the dam place by drainage area relation. Taking into account that the Oeste dam was built in the year of 1973, two alternatives for maximum flood frequency study were considereted:

a) Historial range of maximum dicharges after 1972 were not considered;

b) Historical range mean of annual maximum discharges were considered.

As the “a” alternative leads to higher values and it is in favor of the safety, it was the chosen option.

Two probability distributions were fitted to daily mean of maximum annual discharge on the Taió fluviometric station (83050000): Gumbel and 2 Parameters Exponential, according to the methodology of the "Guia para Cálculo de Cheia de Projeto de Vertedores, ELETROBRÁS/CEPEL, Rio de Janeiro, 1987". The Guidelines consider the 2 Parameters Exponential distribution as the most robust, but says it can be used Gumbel distribution if the asymmetry coefficient of the population is less than 1,5. In the case of the sample, the skewness coefficient is 0.469. Even so it is recommended the 2 Parameters Exponential distribution, because its values takes to largest floods than Gumbel distribution, as shown in Figure 4.6.1. Besides the exponential leads to higher values, therefore it is in favor of the safety.



Source: JICA Survey Team

Figure 4.6.1 – Maximum Flood in Taió (83050000) in Rio do Oeste

The Table 4.6.1 below presents the maximum discharge in Taió (83050000) and the site of the Oeste dam for 10,000 and 1,000 years of recurrence period, which are commonly used in Brazil to design the hydraulic capacity of the spillways. In the case of Oeste dam, due to the height of the dam and the size of the reservoir, the recurrence period of 1,000 years can be used.

As the daily mean of maximum annual discharge was used, the instantaneous peak of the Oeste dam place was calculated by the Füller method.

$$\mathbf{Qi = Q \times (1+2{,}66 \times A^{-0{,}3})}$$

Where:

Q_i = Instantaneous discharge (m³/s), Q = Daily mean of discharge (m³/s)

A = Drain area (km²)

Table 4.6.1 Maximum Discharge in the Oeste Dam – Itajaí do Oeste River

T(years)	**Maximum discharge (m³/s)**		**2 Parameters Exponential**
	Taio	Barragem Oeste	
	Daily mean	Daily mean	Instantaneous peak (Füller)
1,000	1,143	759	1,010
10,000	1,445	959	1,276

Observation 1: The Oeste dam was built in 1973
Observation 2: Data after 1972 were not considered
Source: JICA Survey Team

4.7 Recurrence Interval from July, 1983 and August, 1984 Floods in Blumenau

The flood contention plan in the Itajaí Basin will be formulated for 5, 10, 25 and 50 years of recurrence interval. These flood calculations was carried out through the transformation of the intense rainfall into discharges evaluated for these recurrence times assuming that the flood peaks have the same recurrence of rains.

The rain-flow transformations were effected through the model HEC-HMS (U.S. Army - Corps of Engineers) available for free download in INTERNET.

The evaluation of the maximum discharges for various reccurrence periods carried out by the observed discharge, besides being a reference, it has to verify the probability of floods in July, 1983 and August, 1984.

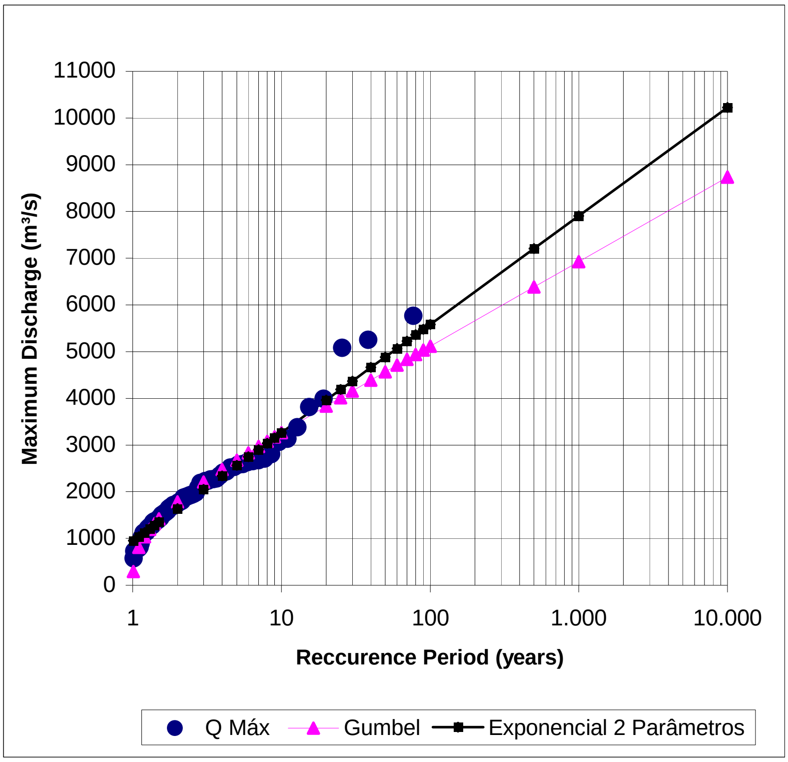
In order to evaluate the maximum floods recurrence period in Blumenau the daily mean of the maximum annual discharge observed in the Indaial rainfall station (83690000) in Itajaí –Açu River. In this section, the Itajaí drains an approximately 11,276 km² area.

There is a fluviometric station at Blumenau, however, the data from this station present a smaller observation period and do not present the same reliable data as Indaial (83690000) does.

The Itajaí drain area in Blumenau is approximately around 11,923 km². Therefore, in view of the small drainage area difference, it is reasonable to presume that the floods in July, 1983 and August, 1984 have the same recurrence time in both Indail (83690000) and Blumenau cities.

The methodoly described on the "Guia para Cálculo de Cheia de Projeto de Vertedores, ELETROBRÁS/CEPEL, Rio de Janeiro, 1987" was used in this frequency study . The Gumbel distribution probalities and 2 Parameters Exponential were adjusted to the maximum discharge of Indaial. The guide considers the 2 Parameters Exponential as the most efficient one, although the Gumbel distribution can be used if the skewness coefficient of the population is below than 1,5. In case of the Indaial (83690000) sample, the asymmetry coefficient is about 1.659, and in order to follow the guide, the 2 Parameters Exponential distribution was chosen.

In the Figure 4.7.1 it is presented the sample discharge plot, the Gumbel distribution and the 2 Parameters Exponential fittings.



Source: JICA Survey Team

Figure 4.7.1 Itajaí River Maximum flood in Indaial (83690000)

In the Table 4.7.1 it is presented the maximum discharge in Indaial (83690000), for a specific recurrence time. The maximum mean of discharges are daily, not the instantaneous discharge, therefore the instantaneous peak values are higher than those presented.

Table 4.7.1 Itajaí Maximum Discharge (m^3/s) in Indaial City (83690000)

T(years)	Gumbel	2 Parameters Exponential
2	1,784	1,640
5	2,676	2,564
10	3,266	3,263
20	3,832	3,962
25	4,012	4,187
50	4,565	4,886
100	5,114	5,585
500	6,383	7,208
1.000	6,928	7,906
10.000	8,739	10,228

Source: JICA Survey Team

In July, 1983 and August, 1984 the daily mean of maximum flood in Indaial (83690000) were about 5,078 m^3/s and 5,256 m^3/s. Therefore, it is possible to say that those floods are 100 years – reccurrence floods in Indaial (8369000) and also in Blumenau. In the Table 4.7.2 it is presented the maximum floods in Blumenau for some recurrence intervals, being this transferred from Indaial (83690000) by drainage area relation.

Q(Blumenau) = [A(Blumenau)/A(Indaial)] * Q(Indaial)
Q(Blumenau) = (11,923/11,276) * Q(Indaial)

Table 4.7.2 Itajaí River Maximum Discharges (m³/s) in Indaial (83690000)

T (years)	Gumbel	2 Parameters Exponential
2	1,886	1,734
5	2,830	2,711
10	3,453	3,450
20	4,052	4,189
25	4,242	4,427
50	4,827	5,166
100	5,407	5,905
500	6,749	7,622
1.000	7,326	8,360
10.000	9,240	10,815

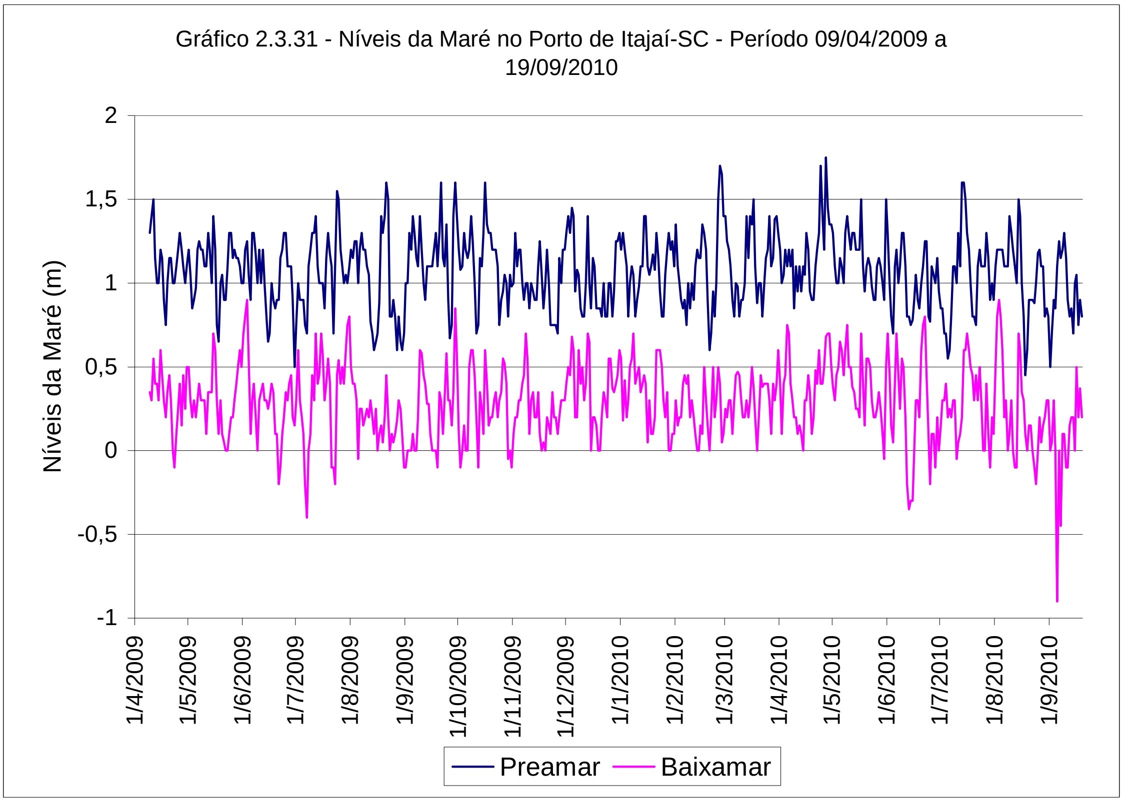
Source: JICA Survey Team

CHAPTER 5 TIDE LEVELS

The tide level were obtained from the "Associação dos Práticos do Porto de Itajaí". The largest high tide period observed was 1.75 meters on April 24th, 2010 and this value, the most critical of the sample, will be used in the calculations of the water levels profiles on various flood situations in order to define the flood plain.

It is noteworthy that the values are not measured in the same time, the number of tide level readings is variable on each day. The absolute maximum and minimum values for each day may not had been read properly, however more than 30 readings are usually carried out by day.

The Figure 5.1.1 presents the high tide and low tide daily levels in the mentioned period.



Source: JICA Survey Team

Figure 5.1.1 Tide level in Itajaí Port

CHAPTER 6 ITAJAÍ RIVER FLOOD AND INUNDATION FEATURES

6.1 Main Floods Records

The table 6.1.1 indicates the floods which occurred in the last years in the Itajaí Basin and the damages caused in each municipality. The Table 6.1.2 indicates the numbers of the victims and the prejudices in each flood. Then, the request measures for the protection against floods was summarized, taking into consideration the frequencies and the damage level.

- In the last years five floods were recorded which have caused relevant damage: July, 1983; August, 1984; May, 1992; October, 2001 and November, 2008.
- The most relevant damages caused by the flood happened in the municipality of Blumenau, and also were relatively large in the municipality of Itajaí, Gaspar and Rio do Sul. These four municipalities have high density and large number of industries, and they can be considered as cities ready for implementation of measures against floods.
- In relation to the other municipalities, there are more complaining against damage caused by flood in Taió and Timbó, implying that this municipality requires measures just like the other four cities mentioned above. In Timbó is necessary to examine the interference caused by hydroelectric dams (Rio Bonito and Pinhal dams) located by the upstream of the Cedros River. In the city of Taió prejudices are caused by the overflowing of the Oeste dam.
- The municipalities of Navegantes and Ilhota also had suffered reasonable damage, but the safety level in these cities will increase automatically with the measures that will be adopted in the major cities, such as Itajaí, Blumenau and Gaspar.
- By the other hand, the municipality of Brusque and Ituporanga suffered the damages in the large flood Return Periods, greater than or equal to 50 years, such as 1983, 1984 and 2008 (See Table 6.2.1), but in relation to the other municipalities, the current riverbed presents high safety level, decreasing the priority order of the measures.
- The upstream region of Blumenau until the junction with the North Itajaí River is an area where a large discharge level is presented. The cities located on this region, like Indaial and others, present low priority of measures because the damage caused by flood is lower.

Table 6.1.1 List of the Last Main Flood Events

Year	Month	Itajai Acu										Itajai Mirim		L.A.	Benedito			Itajai Do Norte		Itajai Do Oeste				Trombudo			Itajai Do Sul	
		Itajai	Navegan-tes	Ilhota	Gaspar	Blumenau	Pomerode	Indaial	Rodeio	Lontras	Rio Do Sul	Brusque	Guabiruma	Luiz Alves	Timbo	Benedito Novo	Rio Dos Cedros	Ibirama	Presidente Getulio	Taio	Lauren-tino	Rio Do Oeste	Rio Do Campo	Trombudo Central	Braco do Trombudo	Pouso Redondo	Itupoa-ranga	Alfredo Wagner
1980	10					□																						
1981	10												□															
1983	5					●																						
	7	●	○		○	●				○	●				○					◎		○		○			○	
	12					◎																						
1984	8	○			●	●						●								○				○			○	
1989	1				○																							
1990	1					△																						
	10					○																						
1991	11					◎							○															
1992	1					△																						
	5	●	○	◎	○	●		△			△				○													
1993	2	△																										○
1995	1					△						△																
1996	2																						△					
1997	1				◎	△																						
	2									△																		
	10										△																	
1999	7										△																	
2000	2														△													
2001	10	△			△	△		△	△	△	○				△				○		△			△				
2002	11																			△					△	△		
2005	9										□																	
2008	11	○	□	○	○	◎	△	□	△			○		△	△	△	△											
2009	10										□																	
2010	4	□									□				□					□								

Fonte:
1980 a 2004 ATLAS DE DESASTRES NATURAIS DO ESTADO DE SANTA CATARINA
2005 a 2009 Dados fornecidos pelo GTC (Relatório 1 do Plano de Prevenção de Desastres Naturais para a Bacia do Rio Itajaí)
2008 AVADANs enviados pelos municípios à Defesa Civil de Santa Catarina, nos dias 24 e 25 de novembro de 2008 (Relatório 1 do Plano de Prevenção de Desastres Naturais para a Bacia do Rio Itajaí)
MAPEAMENTO DAS INUNDAÇÕES – NOVEMBRO 2008
DESASTRE DE 2008 NO VALE DO ITAJAÍ
2010 Audiência pública (Municípios, cidades e vilas locais e suas populações)

Legendas
● Mais de 10.000 pessoas perderam suas casas
◎ 5.000 a 10.000 pessoas perderam suas casas
○ 1.000 a 5.000 pessoas perderam suas casas
△ Menos de 1.000 pessoas perderam suas casas
□ Sem dados

(orange) Cidade com alta prioridade da medida
(yellow) Cidade que necessita de medida
(white) Cidade com baixa necessidade da medida

Source: JICA Survey Team

Table 6.1.2 Main Damage Occurrences Caused by Flood

Year	Month	Water	Municipality	Victims	Death	Population	(%) of	Damage

		Level					Victims	(R$)
1980	10		Blumenau	S/R	1	157.258	-	
1981	10		Guabiruba		2	7.362		
1983	5	12.46	Blumenau	10.000	2	170.491	5,86	
	7	15.34	Blumenau	50.000	8		29,3	
	12		Blumenau	5.000	1		2,93	
	7		Gaspar	3.981	2	28.012	14,2	
	7		Itajaí	40.000	5	94.449	42,3	
	7		Ituporanga	1.820		18.149	10	
	7		Lontra	4.000		7.390	54,1	
	7		Navegantes	3.070		15.747	19,49	
	7		Rio do Oeste	2.820		7.280	38,7	
	7		Rio do Sul	25.000	5	38.616	64,74	
	7		Taio	5.079	1	18.809	27	
	7		Timbo	1.610		19.368	8,31	
	7		Trombudo Central	2.980		7.404		
1984	8	15.46	Blumenau	70.000		175.145	39,96	
	8		Brusque	20.000		46.558	42,95	
	8		Gaspar	10.000		28.863	34,64	
	8		Itajaí	1.000	2	97.273	1,02	
	8		Ituporanga	1.000		18.499	5,4	
	8		Taio	1.500		18.878	7,94	
			Trombudo Central	1.000		7.511		
1989	1		Gaspar	167		33.523	0,49	
1990	1		Blumenau	594			0,26	
	10		Blumenau	1.310	20	220.741	0,59	
1991	11	12.8	Blumenau	8.528	10	212.025	4,02	
	11		Guabiruba	1.038		9.905	10,47	
1992	1	10.62	Blumenau	21			0,01	
	5		Blumenau	35.000	2	216.422	16,17	
	5		Rio do Sul	800		46.827	1,7	
	5		Gaspar	2.830		36.516	7,75	
	5		Ilhota	5.580		9.548	58,44	
	5		Indaial	817		30.853	2,64	
	5		Itajaí	11.938		122.401	9,75	
	5		Navegante	4.780		24.204	19,74	
	5		Timbo	1.544		24.434	6,31	
1993	2		Itajaí	750		125.266	0,59	
	7		Alfredo Wagner	3.244		9.856		
1995	1		Blumenau	600		225.556	0,26	
	1		Brusque	520		62.328	0,83	
1996	2		Rio do Campo	196		6.576		
1997	1	9.44	Blumenau	353		231.401	0,15	
	2		Lontra	300		7.936	3,78	
	10		Rio do Sul	336		47.822	0,7	
	1		Gaspar	6.000		40.584	14,78	
1999	7		Rio do Sul	201		47.822	0,42	
2000	2		Timbo	150		26.497	0,56	1.473.000
2001	10		Rio do Sul	2.885	1	47.822	6,03	2.071.076
	10		Presidente Getulio	2.100		11.523	18,22	4.648.600
	10		Gaspar	469		40.584	1,15	549.000
	10	11.02	Blumenau	400		231.401	0,12	2.999.300
	10		Itajaí	383		134.942	0,28	2.385.381
	10		Timbo	350		26.497	1,32	57.000
	10		Rodeio	175		9.623	1,81	1.252.200
	10		Indaial	144		35.400	0,4	524.083
	10		Lontras	144		7.936	1,81	786.300
	10		Laurentino	120		4.532		732.490
	10		Trombudo Central	120		5.895		244.500
2002	11		Taio	257		15.997	1,6	1.730.302
	11		Pouso Redondo	450		11.778	3,82	1.233.946
	12		Braco do Trombudo	120		3.531	3,39	1.325.000

Source: Natural Disasters Atlas of Santa Catarina State

6.2 Scale of Major Flood

6.2.1 Return Period of the Rain that Caused the Major Flood events

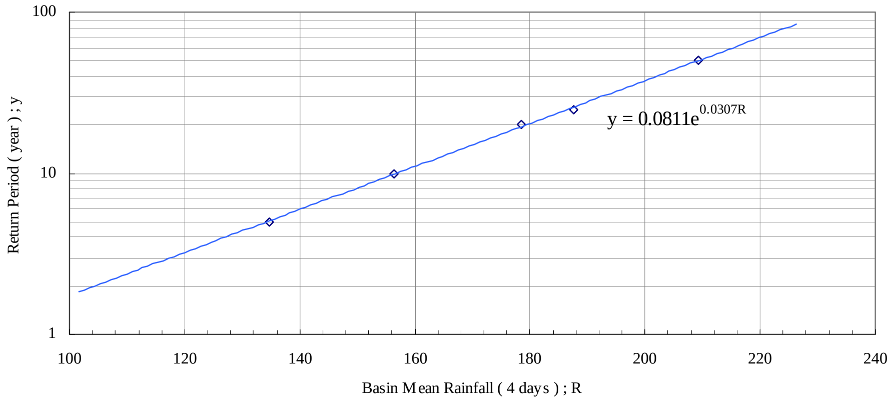
The Return Period of the rain that caused the major Flood events were calculated from the weighted mean of rainfall intensities of the 4 consecutive days' duration in the basin, and the results are indicated on the Table 6.2.1 (See details on the item 7). The rainfalls that caused the 1983 and 1984 floods, the ones that promoved large losses, have Return Period of 76 and 66 years, respectively, succeced by the rainfall occurred in the 1992 Flood event whose Return Period is equivalente to 33 years. Rainfalls that caused other Flood events have Return Period around 5 to 10 years.

The rainfall that provoked the 2008 Flood event, taking into consideration the balance of the 4 days duration in the basin, has a Return Period of approximately 5 years. Due to the spice distribuction, the torrential rainfalls were located at the lower valley, decreasing considerably from the coast to the inland.

Table 6.2.1 Main Flood Events Return Period

Date of flood occurrence	Rainfall volum for 4 days (mean of the entire basin)	Return period (year)	Status of damages
31.10.1961	139,3 mm	6	—
26.09.1963	149,0 mm	8	—
25.08.1972	165,7 mm	13	—
19.12.1980	147,3 mm	7	—
06.07.1983	222,8 mm	76	Great damage in the cities of Itajaí and Blumenau. Great damage in the cities of Lontras and Rio do Sul. Medium and large damage proportion in the cities of Timbó, Taió, Rio do Sul and Ituporanga.
05.08.1984	218,4 mm	66	Great damage in the cities of Itajaí, Gaspar and Blumenau. Great damage Brusque. Medium damage proportion in the cities of Taió and Ituporanga.
28.05.1992	195,7 mm	33	Great damage in the cities of Itajaí and Blumenau. Relatively minor damage in the city of Rio do Sul. Mid-size damage in the city of Timbó.
31.01.1997	133,7 mm	5	Relatively large damage in the city of Gaspar. Minor damage in the city of Blumenau.
02.07.1999	150,3 mm	8	Minor damage in the city of Rio do Sul.
29.09.2001	146,8 mm	7	Minor damage in the cities of Itajaí, Gaspar, Blumenau, Indaial e Lontras. Medium damage proportion in the city of Rio do Sul. Minor damage in the cities of Timbó and Taió.
18.05.2005	144,3 mm	7	No significant damage.
21.11.2008	135,1 mm	5	There were unprecedented torrential rains in the downstream region, causing major damage. However, because it is localized torrential rains, in the middle of the basin it is computed with less return period.
23.04.2010	130,3 mm	4	There are no official data. In the field survey there were reports of minor damage in the cities of Rio do Sul, Timbo and Taió

*The calculation of the Return Period of rainfall causing floods is based on the correlation formula showed below.
Source: JICA Survey Team



Source: JICA Survey Team

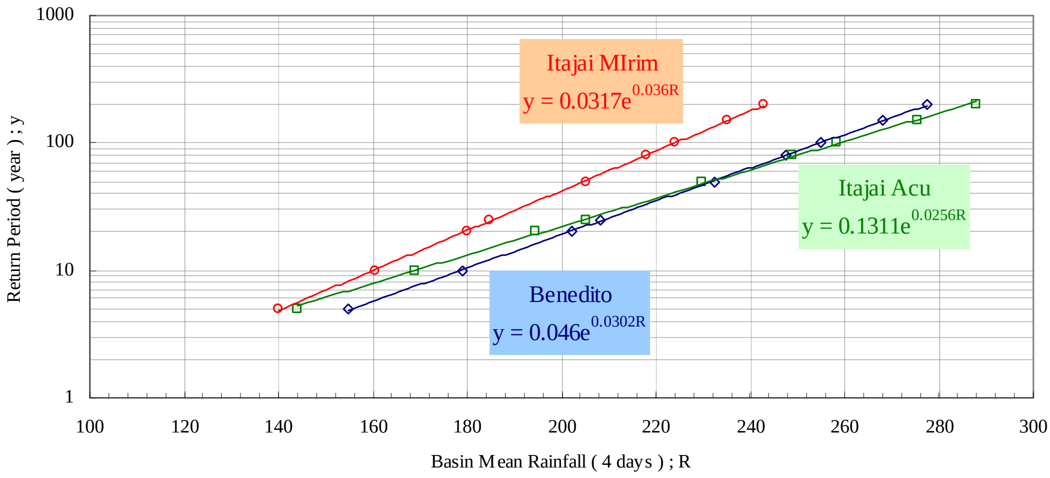
6.2.2 Return Period of the 2008 Flood Event

Just like showed in Table 6.2.2, the intensities of the rainfalls in 4 consecutive days were low in the Itajaí Oeste, Sul and Norte basin. But, the rainfalls on the Benedito River and Itajaí Açu River are equivalent to 30 and 60 years of Return Period, respectively. The intensity of the rain in Itajaí-Mirim Basin is equivalent to 10 years.

Table 6.2.2 Return Period of 4 Consecutive Intense Rainfall Days and Observed Rainfall (November 21th to 24th) From Each Sub-basin in the 2008 Flood Event

Sub-basin		Itajaí Do Oeste	Itajaí Do Sul	Itajaí Do Norte	Benedito	Itajaí Acu	Itajaí do Mirim
4 consecutive days in the 2008 Flood event		**49**	**36**	**31**	**214**	**236**	**160**
Rainfall intensity	5 anos	153	141	140	155	144	140
	10 anos	175	161	160	179	169	161
	20 anos	196	181	179	202	194	180
	25 anos	202	186	184	208	205	185
	50 anos	224	207	204	232	230	205
	80 anos	238	220	217	248	249	218
	100 anos	244	226	223	255	258	224
	150 anos	256	237	233	268	276	235
	200 anos	265	245	241	277	288	243
Return Period (years)		-	-	-	**30**	**60**	**10**

* The return time calculation of each flood was based in the Correlation Formule presented in the figure bellow.
Source: JICA Survey Team



Source: JICA Survey Team

In terms of runoff the results of the torrential rainfall analysis are as follows;

- The torrential rainfall concentration on the Itajaí basin (main river), especially by the downstream of the Indaial City and the greatest rainfall volum occurred in Blumenau City, reached in 4 days (November 21th – 24th) the mark of 576mm.
- The rainfalls are concentrated specially in November, 23 th and 24 th reaching the mark of 494, 4 mm in 2 days and 251 mm in November 25th, this being the biggest rainfall in 1 day.

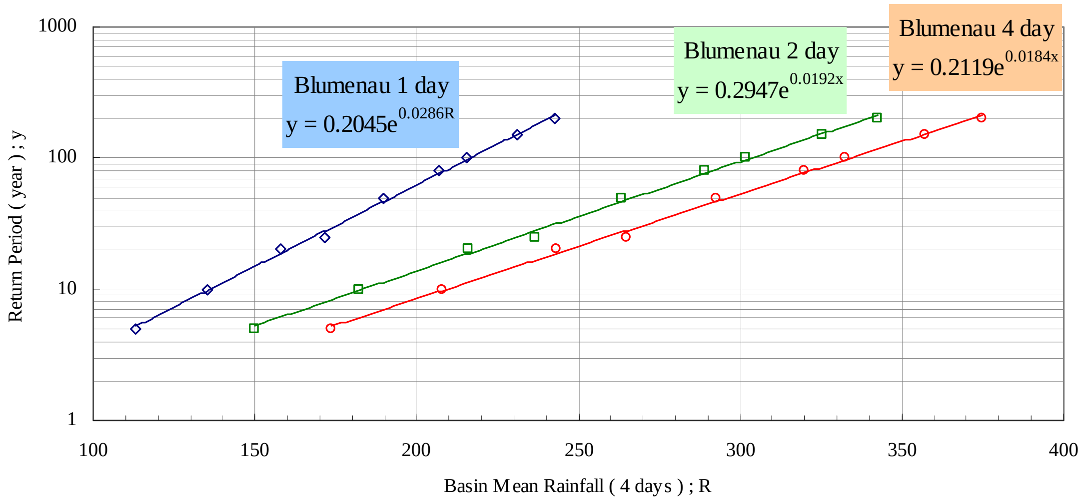
In the rainfall Return Period intensity evaluation in Blumenau City, the intensity of the 1 day raining was equivalent to the 270 years of Return Period. The following Table 6.2.3 indicates the probable rainfall intensity.

Table 6.2.3 Return Periods of the Intense Rainfall from 1 to 4 days in Blumenau and Observed Values in the 2008 Flood Event

		Blumenau daily rainfall	Blumenau 2 days rainfall	Blumenau 4 days rainfall
Rainfall in the 2008 Flood event		**251**	**494**	**575**
Intensity of probable rainfall	5 years	113	150	173
	10 years	135	182	208
	20 years	158	216	243
	25 years	171	236	265
	50 years	189	263	293
	80 years	207	289	320
	100 years	215	301	333
	150 years	231	325	357
	200 years	242	342	375
Return Perido (years)		**270**	-	-

*The calculation of the return period from each flood is based on the correlation formule as shown in the figure bellow.

Source: JICA Survey Team



Source: JICA Survey Team

6.3 Main Flood Events Features

Among the main flood mentioned before, the flood (1983, 1984, 2008 and 2010 events) features that possess enough rainfall or discharge data were evaluated on this chapter.

6.3.1 1983 Flood Event

The 1983 Flood event had torrentials rainfalls during the period of 8 days, from de July 5th to 12th, the higher intensity occurred between the 6th to 9th days. The mean of rainfall intensity from 4 consecutive days in all the whole basin was approximately 210mm and it was distributed in all sub-basin around 200mm.

Table 6.3.1 Daily Rainfall Record in July 1983 Flood Event

Sub-basin	Station	Time								Total (4 days)	Total (8 days)
		7/5	7/6	7/7	7/8	7/9	7/10	7/11	7/12		
Itajaí-Açú	Luiz	0,0	39,2	50,4	48,4	62,2	38,4	20,2	20,2	200,2	279.0
	Planalsucar	0,0	58,0	47,0	46,0	53,0	39,0	12,0	12,0	204,0	267.0
	Pomerode	0,1	41,0	60,2	67,0	70,0	49,2	7,5	7,5	238,2	302.5
	Blumenau	0,0	54,4	62,8	43,8	54,4	38,2	30,4	30,4	215,4	314.4
	Garcia De Blumenau	0,0	54,0	63,6	43,8	54,4	38,2	30,4	30,4	215,8	314.8
	Apiuna Regua Nova	0,0	62,0	58,8	49,0	31,4	29,9	25,2	25,2	201,2	281.5
	Neisse Central	0,0	60,0	56,0	53,0	25,0	30,0	25,0	25,0	194,0	274.0
	Rio Do Sul	0,0	59,5	70,2	52,5	54,0	50,0	33,0	33,0	236,2	352.2
	Mean of the Sub-bacia	0,0	53,5	58,6	50,4	50,6	39,1	23,0	23,0	213,1	298.2
Benedito	Benedito Novo	0,0	68,9	63,6	36,2	32,2	35,5	16,2	16,2	200,9	268.8
	Timbo Novo	0,0	58,2	65,1	39,0	40,0	12,5	18,5	18,5	202,3	251.8
	Arrozeira	0,0	68,0	62,6	52,0	75,4	38,2	0,0	0,0	258,0	296.2
	Doutor Pedrinho	0,0	57,2	78,2	68,2	75,6	44,0	20,0	20,0	279,2	363.2
	Mean of the Sub-bacia	0,0	63,1	67,4	48,9	55,8	32,6	13,7	13,7	235,1	295.0
Itajaí Do Norte	Witmarsum	0,0	47,0	86,8	53,2	40,2	26,4	21,8	21,8	227,2	297.2
	Barra Do Prata	0,0	52,4	83,6	69,2	73,4	45,6	32,2	32,2	278,6	388.6
	Barragem Norte	0,0	57,6	65,4	59,2	44,4	24,8	24,2	24,2	226,6	299.8
	Ibirama	0,0	52,2	58,3	47,0	31,5	34,0	16,5	16,5	189,0	256.0
	Iracema	0,0	44,1	93,2	84,0	103,6	64,5	16,4	16,4	324,9	422.2
	Nova Bremen	0,0	58,1	58,9	47,1	38,2	38,3	23,4	23,4	202,3	287.4

Sub-basin	Station	Time								Total (4 days)	Total (8 days)
		7/5	7/6	7/7	7/8	7/9	7/10	7/11	7/12		
	Mean of the Sub-basin	0,0	51,9	74,4	60,0	55,2	38,9	22,4	22,4	241,4	325.2
Itajaí Do Oeste	Taio	0,0	63,4	71,4	67,8	34,0	63,8	28,0	28,0	236,6	356.4
	Rio Do Campo	52,0	80,8	68,6	41,4	33,8	21,4	33,4	33,4	224,6	364.8
	Pouso Redondo	0,0	50,4	66,3	49,4	73,0	60,4	39,4	39,4	239,1	378.3
	Trombudo Central	0,4	43,0	62,2	58,5	60,8	61,8	40,6	40,6	224,5	367.9
	Agrolandia	0,0	52,8	73,0	54,2	49,0	50,6	45,0	45,0	229,0	369.6
	Barragem Oeste	0,0	63,0	74,0	66,6	34,0	63,8	28,0	28,0	237,6	357.4
	Mean of the Sub-basin	8,7	58,9	69,3	56,3	47,4	53,6	35,7	35,7	231,9	365.7
Itajaí Do Sul	Lomba Alta	0,0	41,2	63,8	42,8	32,6	44,4	74,0	74,0	180,4	372.8
	Saltinho	0,0	46,7	61,6	45,0	26,3	45,3	73,4	73,4	179,6	371.7
	Ituporanga	0,0	47,9	61,8	42,6	36,8	56,4	59,6	59,6	189,1	364.7
	Barragem Sul	0,0	40,8	76,3	51,6	42,4	47,6	43,2	43,2	211,1	345.1
	Ituporanga	35,0	45,0	43,0	49,0	41,0	65,0	46,0	46,0	178,0	370.0
	Mean of the Sub-basin	7,0	44,3	61,3	46,2	35,8	51,7	59,2	59,2	187,6	364.9
Itajaí Mirim	Vidal Ramos	27,4	36,5	34,6	31,7	42,3	38,5	27,4	27,4	145,1	265.8
	Mean of the Sub-basin	27,4	36,5	34,6	31,7	42,3	38,5	27,4	27,4	145,1	265.8
Total Mean of the Sub-basin		7.2	51,4	60,9	48,9	47,9	42,4	30,2	30,2	209,0	319,1

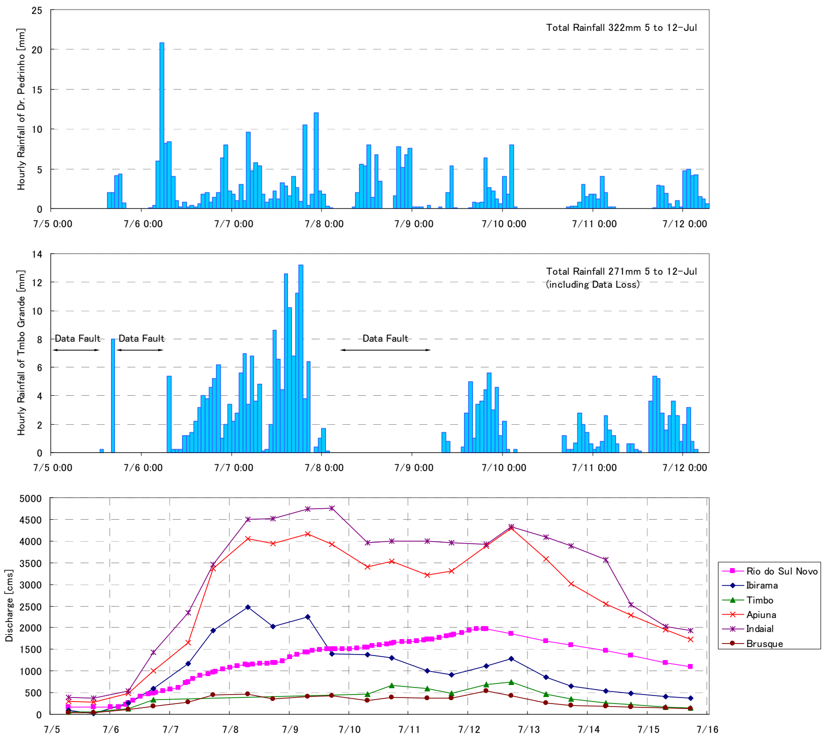
Source: ANA Measurements reformulated by JICA Survey Team

In the 1983 Flood there was only hourly rainfall data (however, in Timbó Novo there are gaps not recorded in July 8th to 9th) in two locations: Doutor Pedrinho and Timbó Grande (both located in Benedito River Basin). The discharge records (converted values from the streamflow levels) exist in 6 locations. It is noteworthy that these data are basically recorded twice a day (7 a.m and 7 p.m), but in the Rio do Sul case, they are recorded in 1 to 3 hours.

The Figure 6.3.1 indicates the hourly rainfall and discharge data from both locations.

- The rainfall had more intensity in the first half of the flood period (Days 6th and 7th), when the maximum hourly rainfall reached 21mm/h in Doutor Pedrinho, and the other hours around 15mm/h.
- The peak of the discharge occurred between July 8th and 9th, lagged by more than one day of the rainfall peak. There was only a delay on the peak in Rio do Sul e its cause was unknown, due to the lack of the hourly data, but it seems that a retention had happened on the Sul and Oeste dams.

The maximum discharge was 4.760 m³/s which happened in Indaial. In Rio do Sul and Ibirama the discharges was about 2000 to 2500 m³/s and about 500 to 1000 m³/s in Brusque.



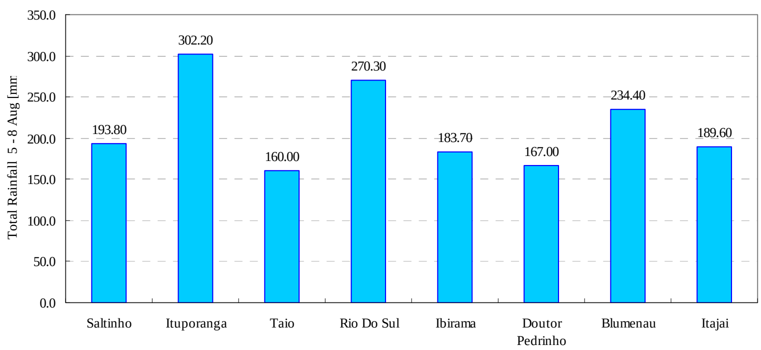
Source: Final Report on The Itajaí River Basin Flood Control Project Part II Data Book, JICA, 1988

Figure 6.3.1 Rainfall and discharge Curve in the 1983 Flood event

6.3.2 1984 Flood Event

There are records of hourly rainfall in eight station about the flood that occurred in August (1984). The Figure 6.3.2 indicates a consecutive rainfall in the four days.

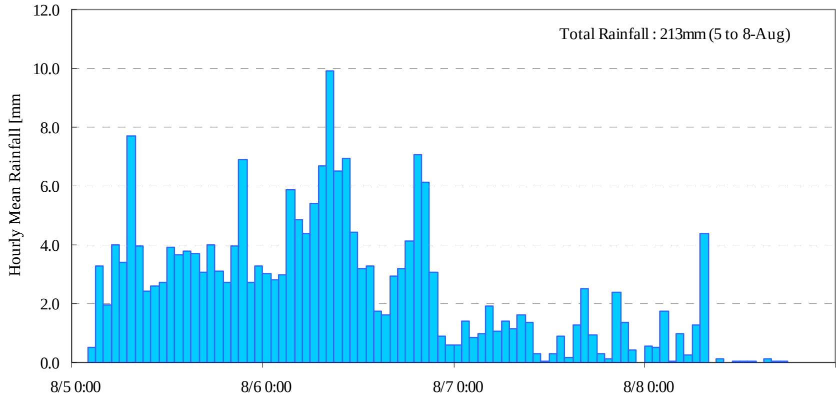
In the 1984 Flood event rained in four consecutive days, from August 5th to 8th, the rainfall recorded in the stations ranged from 160mm to 300mm. The higher rainfall level was about 300mm in Ituporanga and the rainfall was relatively high in Rio do Sul and Blumenau. Generally, there were more rain in the central and southwest regions and propensity for lower rain in northwest, north and east regions.



Source: Final Report on The Itajaí River Basin Flood Control Project Part II Data Book, JICA, 1988, reformulated by JICA Survey Team (the missing measurements were completed according to the Table 6.1.7).

Figure 6.3.2 Rainfall total distribution in the 1984 Flood event

The Figure 6.3.3 indicates the hourly rainfall distribution in four days (mean of the basin is 213mm). The rainfall focused in Agust 5th and 6th and the recorded peak was 10mm/h at midday in the second day (maximum per station was 18mm). From Agust 7th the rainfall was decreasing to the ratio of 1 to 2 mm per hour.

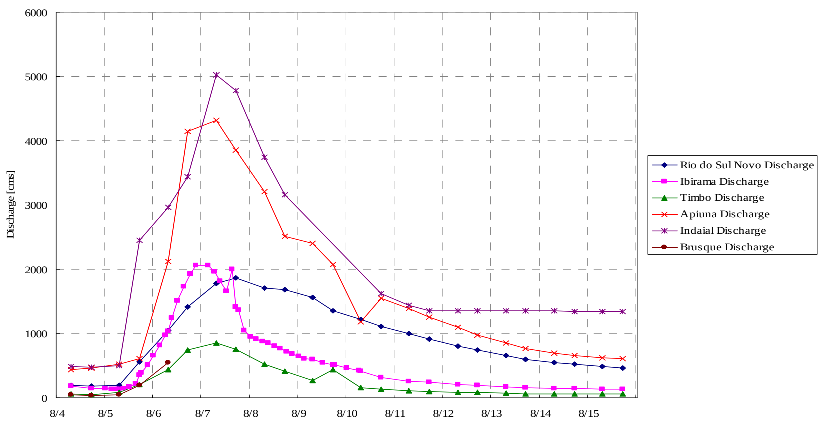


Source: Final Report on The Itajaí River Basin Flood Control Project Part II Data Book, JICA, 1988, reformulated by JICA Survey Team

Figure 6.3.3 Hourly rainfall distribution in the 1984 Flood event

In the Figure 6.3.4 it is indicated the river discharges (converted values from water stages). There are water stages data in 6 locations, basically 2 daily readings carried out, but in Ibirama there are records from 1 to 3 hours.

- The discharges peaks in the 1984 flood (peak values among twice a day data) were: 5.000m³/s in Indaial and 4,300 m³/s in Apiúna, reaching the peak at 7 a.m in Agust 7th. Then, there is a lack of approximately 20 hours in relation to the rainfall peak.
- In the 1894 Flood event there was a delay in the peak occurrence in Rio do Sul in relation to the others, highlighting the interference of the dam.The discharge peak in each station was around 4,000m³/s in Apiúna, 2,000m³/s in Rio do Sul and Ibirama and 1,000m³/s in Timbó.



Source: Final Report on The Itajaí River Basin Flood Control Project Part II Data Book, JICA, 1988, reformulated by JICA Survey Team

Figure 6.3.4 Discharge records in each station on the 1984 Flood event

6.3.3 2008 Flood Event

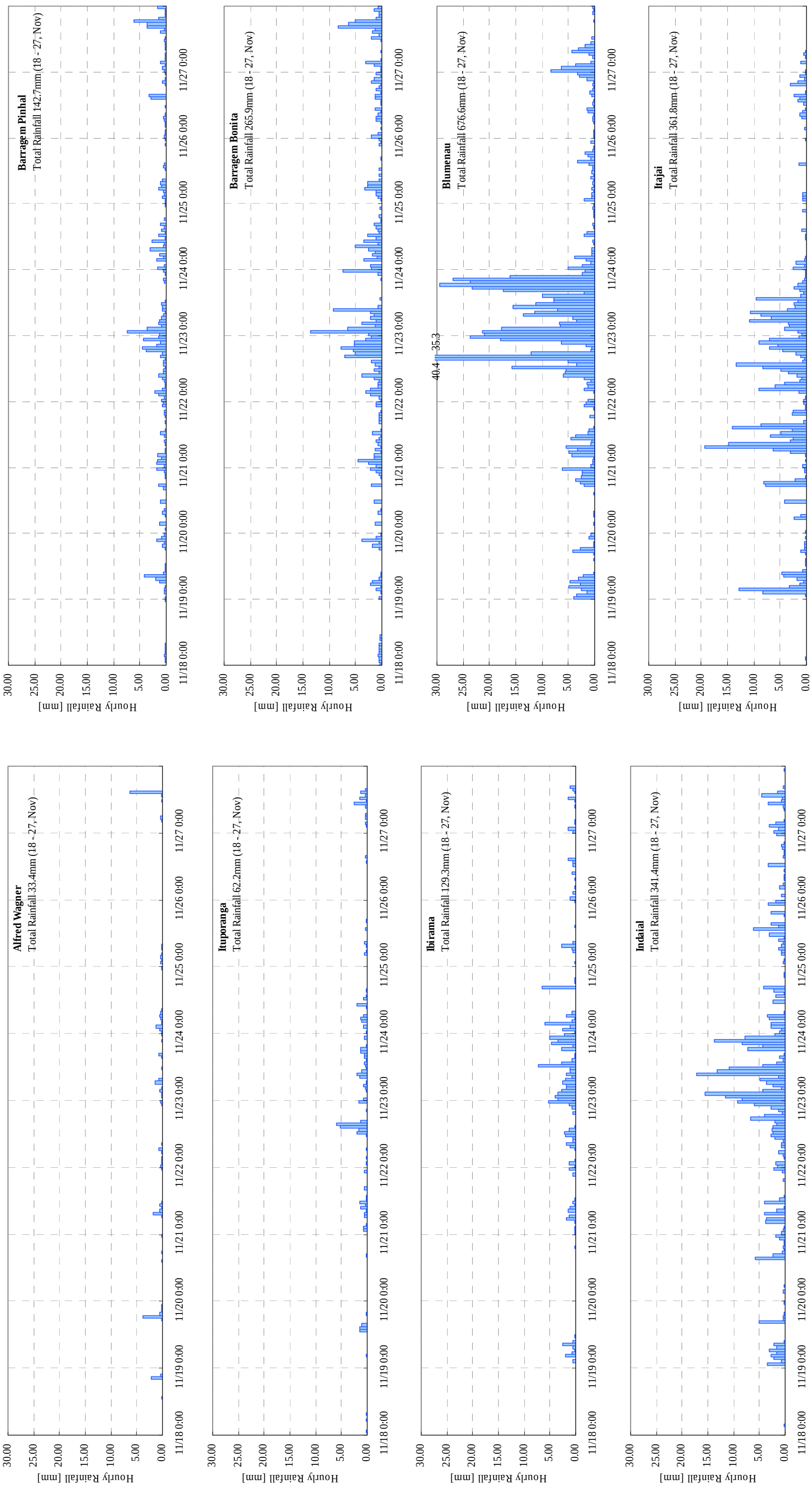
In the 2008 Flood event it started raining around November 18 th, and then it remained until November 27 th. The most of the rainfall happened during 4 days, among November 21th to 24th, reaching the mean of mark of 120,9mm in four days. However, as mentioned before, this flood focused in the downstream of the basin, reaching 266mm on the Itajaí (Lower Valley), 214mm on the Benedito river basin and 160mm on the Itajaí-Mirim river basin.

Hourly rainfall data were indicated on the Figure 6.3.5 and in the Table 6.3.2. The larger hourly rainfall recorded was 40,4mm/h in Agust 22 th in Blumenau.

Table 6.3.2 Daily Rainfall in the 2008 Flood Event

Sub basin	Station	Date										**Total (4 days)**	**Total (11 days)**
		11/18	11/19	11/20	11/21	11/22	11/23	11/24	11/25	11/26	11/27		
Itajaí Acu	Pomerode	2.5	9.8	11.4	41.5	34.3	114.3	62.3	15.3	11.2	25.5	**252.4**	**328.1**
	Blumenau	0.2	30.8	13.9	38.0	43.3	243.5	250.9	10.5	9.6	20.8	**575.7**	**661.5**
	Apiuna Regua Nova	0.7	14.3	4.8	3.6	10.6	55.5	83.1	8.3	9.7	8.9	**152.8**	**199.5**
	Neisse Central	0.5	15.6	0.5	3.7	0.0	65.5	66.5	8.3	11.0	6.5	**135.7**	**178.1**
	Rio Do Sul	1.0	2.4	0.5	1.6	8.6	17.4	35.9	1.6	2.6	1.8	**63.5**	**73.4**
	Mean of the Sub-basin				17.7	19.4	99.2	99.7				**236.0**	**288.1**
Benedito	Arrozeira	1.4	11.7	8.3	36.6	28.9	125.2	72.7	7.8	12.9	32.6	**263.4**	**338.1**
	Timbo Novo	1.4	15.8	14.5	11.0	21.6	184.9	63.4	55.2	36.9	29.4	**280.9**	**434.1**
	Doutor Pedrinho	1.4	8.2	9.0	28.8	11.1	36.0	22.1	0.0	31.0	6.8	**98.0**	**154.4**
	Mean of the Sub-basin				25.5	20.5	115.4	52.7				**214.1**	**308.9**
Itajaí Do Norte	Witmarsum	0.9	0.0	1.0	4.9	13.1	11.2	9.7	4.8	1.6	0.0	**38.9**	**47.2**
	Barra Do Prata	0.0	0.0	4.0	0.0	3.2	0.0	2.7	0.0	0.0	0.0	**5.9**	**9.9**
	Barragem Norte	0.0	0.0	0.0	0.0	4.4	7.8	20.0	0.0	0.0	7.0	**32.2**	**39.2**
	Iracema	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**3.4**
	Nova Cultura	0.0	2.3	2.0	1.8	0.9	2.1	0.0	18.0	2.3	0.0	**4.8**	**29.4**
	Ibirama	0.0	0.0	0.0	0.0	10.0	55.0	40.0	9.0	4.0	0.0	**105.0**	**118.0**
	Mean of the Sub-basin				1.1	5.3	12.7	12.1				**31.1**	**41.2**
Itajaí Do Oeste	Taio	0.0	5.0	5.5	10.0	18.1	24.7	8.9	6.3	1.7	0.0	**61.7**	**80.2**
	Pouso Redondo	1.0	3.3	7.7	8.0	26.1	15.8	20.8	2.1	2.3	4.0	**70.7**	**91.1**
	Trombudo Central	1.2	0.2	1.3	1.6	7.4	15.2	11.5	1.0	0.7	1.5	**35.7**	**41.6**
	Barragem Oeste	0.4	2.1	2.9	0.0	24.7	14.2	6.6	8.7	1.4	3.5	**45.5**	**64.5**
	C. Ribeirão Caetano	56.6	15.8	6.6	3.0	2.1	0.6	36.2	14.4	20.5	1.4	**41.9**	**157.2**
	Agrolandia	0.0	0.0	0.0	11.0	8.2	10.0	6.0	2.0	1.8	0.0	**35.2**	**39.0**
	Mean of the Sub-basin				5.6	14.4	13.4	15.0				**48.5**	**78.9**
Itajaí Do Sul	Ituporanga	0.5	2.9	2.7	2.1	4.0	8.9	11.0	1.6	2.3	2.5	**26.0**	**38.5**
	Lomba Alta	0.2	0.0	7.4	5.1	12.0	19.6	7.8	4.6	3.2	0.9	**44.5**	**60.8**
	Barragem Sul	0.0	0.3	7.2	0.5	18.7	13.5	7.6	1.8	0.2	1.4	**40.3**	**51.2**
	Saltinho	0.0	1.8	7.3	0.0	12.8	13.8	5.4	0.0	0.0	0.0	**32.0**	**41.1**
	Mean of the Sub-basin				1.9	11.9	14.0	8.0				**35.7**	**47.9**
Itajaí Mirim	Salseiro	0.6	12.6	6.8	6.6	6.6	53.6	24.7	6.7	2.4	3.9	**91.5**	**124.5**
	Botuvera	0.0	5.1	15.5	26.5	35.9	165.2	106.5	22.5	6.0	15.7	**334.1**	**398.9**
	Vidal Ramos	0.0	24.9	7.4	28.5	7.0	9.4	8.9	25.4	6.0	5.0	**53.8**	**122.5**
	Mean of the Sub-basin				20.5	16.5	76.1	46.7				**159.8**	**215.3**
Total Mean of the Basin					12.1	14.7	55.1	39.0				**120.9**	**120.9**

Source: ANA measurements reshaped by JICA Survey Team



Source: Alfred Wagner, UFSC, Ituporanga, INMET, Ibirama, Celesc and ANA, Indaial, INMET

Figure 6.3.5 Hourly rainfall distribution by each station in 2008 Flood event

Related to the 2008 Flood event, the rainfall data indicated on the report "Desastre de 2008 no vale do Itajaí" is as following:

Blumenau	H=11.5m	Q=4200m^3/s
Timbó	H=8.0m	Q=710m^3/s
Indaial	H=6.0m	Q=3100m^3/s

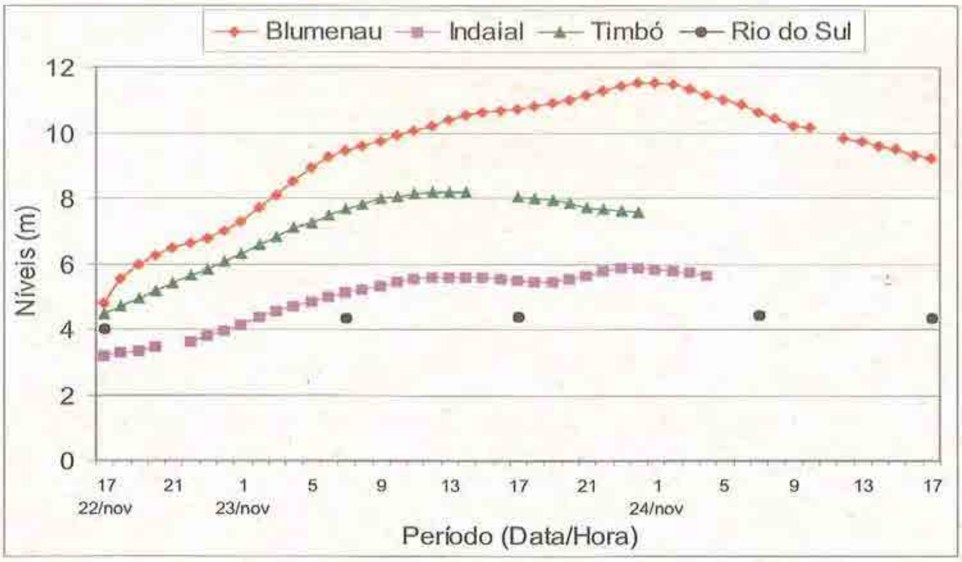
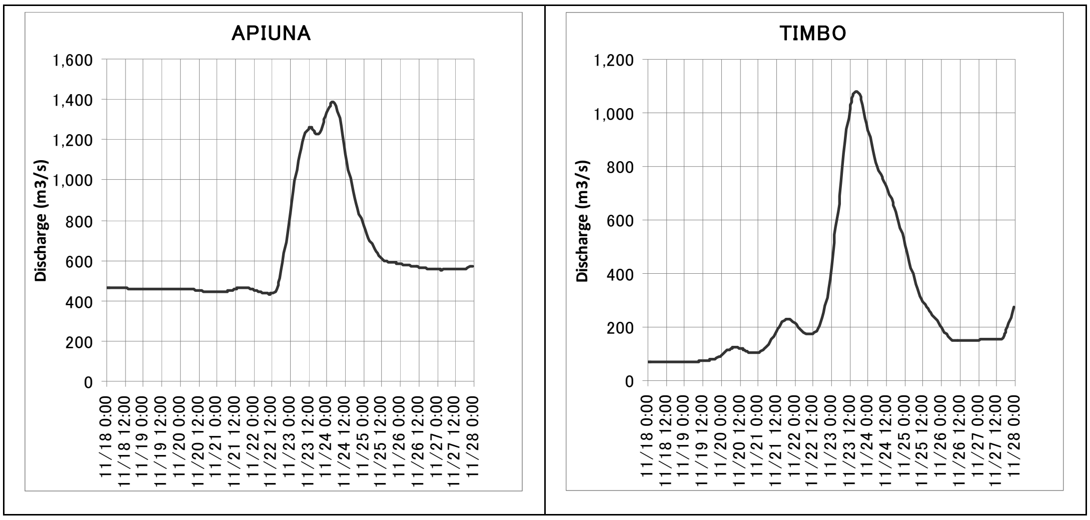


Figura 2 - Evolução temporal dos níveis em Rio do Sul, Timbó, Indaial e Blumenau entre 22 e 24/11/2008. Fonte: CEOPS/IPA/FURB.

Source: Disaster of 2008 in the valley of Itajaí

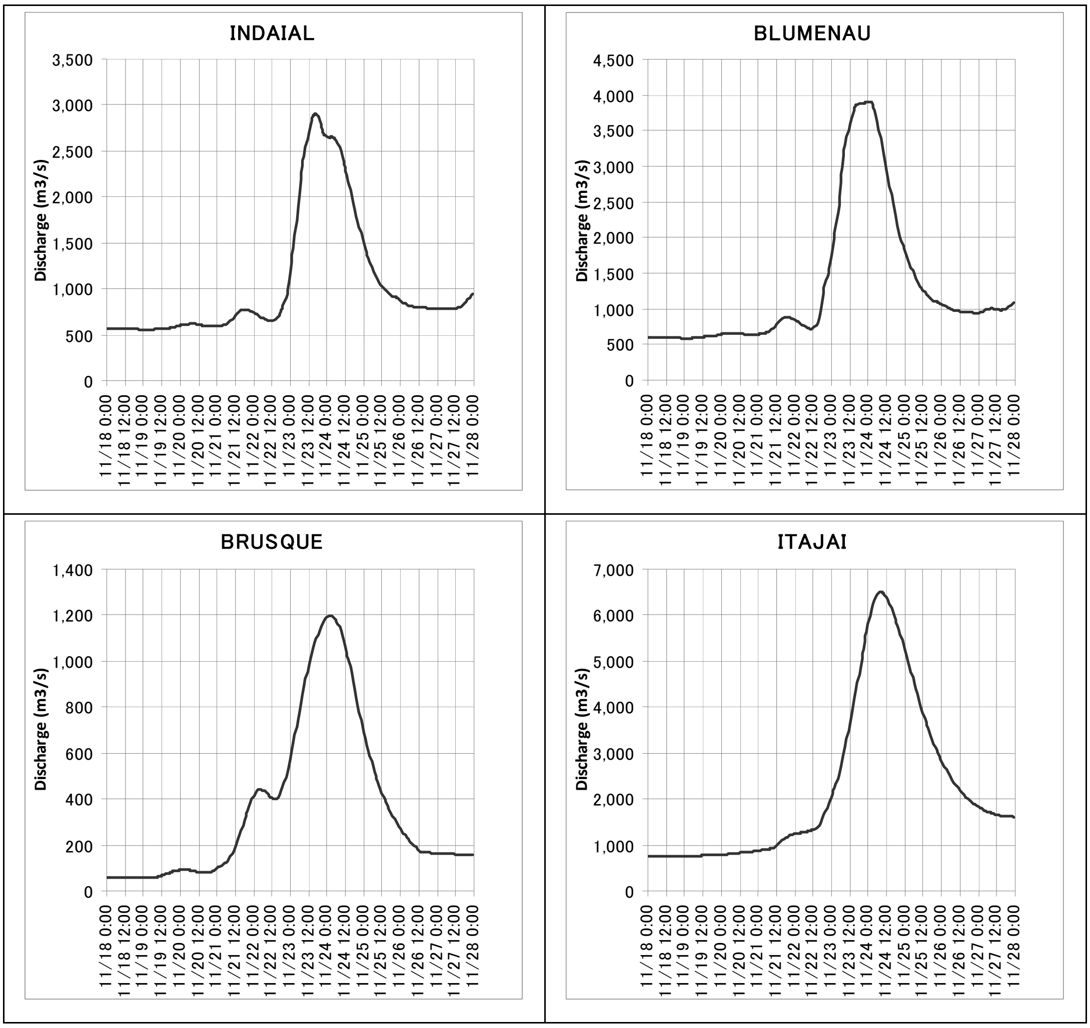
Figure 6.3.6 Rainfall Level records on the 2008 Flood event

The Figure 6.3.7 shows the 2008 flood simulation about the result hydrograph (See details in the 7 item model). Due to the focused rainfall distribution and the scarcity of simulated rainfall recorded information it is difficult to calibrate the rainfall, but the discharge were calculated around 4000m³/s in Blumenau, 1200m³/s in Brusque and around 100m³/s in Timbó. The discharge was estimated around 6500m³/s in Itajaí, but due to the large flood occurrences, the discharge is believed to be lower.



Source: JICA Survey Team

Figure 6.3.7 Outflow calculation results in 2008 Flood event (1/2)



Source: JICA Survey Team

Figure 6.3.7 Outflow calculation results in 2008 Flood event (2/2)

6.3.4 2010 Flood Event

In the 2010 Flood event the intense rainfall started in April 21th and continued until 26th. Rainfall data from this flood were recorded in 18 stations. However, different agencies carried out the measurements in many places; and, due to the unreliability or high number of missing measurements in some stations, data source and organization manners were adopted and showed in the following Table 6.3.3.

Table 6.3.3 Data Source and Organization Manners

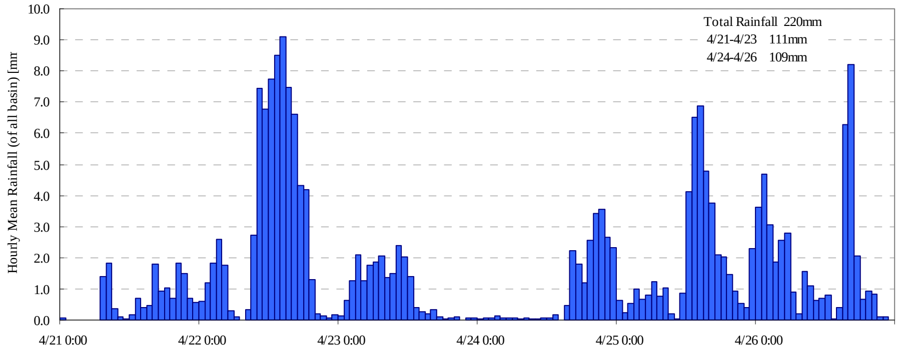
Sub Basin	Station	Source	Data Reability and Failure Data Interpolation	Interpolation Equation
Rio Itajaí do Sul	Alfredo Wagner	FURB	Good correlation with Ituporanga, no reability problems. Missing measurements were supplemented by the Ituporanga INMET data.	y = 0.7425x + 0.1077
	Ituporanga	INMET, FURB, ANA	The correlation between INMET and FURB is good, implying that the reliabilities are also good. Thus, the missing measurements were complemented with INMET based on FURB.	y = 1.0021x - 0.00687
Rio Itajaí do Oeste	Rio do Campo	INMET	Correlation was observed with Dam West, and they are reliable. Missing measurements complemented with Dam West.	y = 0.7593x + 0.6886
	Oeste dam	ANA	Good and reliable correlation with Taió (FURB). Missing measurements complemented with the same.	y = 1.2405x + 0.0829
	Pouso Redondo	FURB	Some correlation with Taió and Rio do Oeste are reliable; The data is reset because of missing measurements.	-
	Taió	FURB, ANA	Good and reliable correlation between FURB and ANA with similar values. FURB data was used with minor missing measurements, the missing ones were	y = 0.7737x + 0.1200

Sub Basin	Station	Source	Data Reability and Failure Data Interpolation	Interpolation Equation
			supplied with ANA data.	
	Rio do Oeste	Salto Pilão, FURB	Good correlation between Salto Pilão and FURB, but Salto Pilão values are approximately the double. By the other hand, the correlations between Taió and FURB are not good enough, but the rainfall volumes are virtually the same. Thus, the decision was consider the FURB as the superior one. The missing measurements were supplied by Salto Pilão with larger correlation.	y = 0.5189x - 0.0159
Rio Itajaí do Norte	Boiteux dam	Salto Pilão	Some correlation with Ibirama are reliable. The missing measurements were supplied with Ibirama.	y = 1.4989x + 0.5459
	Ibirama	Celesc e ANA, FURB	Good correlation between FURB and Celesc, similar and reliable values. The missing measurements were supplied with ANA, based on FURB.	y = 0.9013x + 0.0383
Itajaí by the upstream	Rio do Sul	FURB, ANA	Good and reliable correlation between FURB and Salto Pilão. The missing measurements were supplied with ANA, based on FURB with minor flood missing measurements.	y = 1.1004x - 0.0096
	Apiúna	Salto Pilão, FURB	Good correlation between FURB and Salto Pilão, but the last one presents a trend to be larger. The priority is FURB because of its accordance with other stations. The missing measurements were supplied with Salto Pilão.	y = 0.6311x + 0.1298
	Indaial	INMET, Celesc e ANA	Due to the different values from Celesc to the other trends in the first half of the flood, it was based on the INMET. There are no missing measurements, the complementation was unnecessary.	-
Benedito	Pinhal dam	Celesc	The rainfall is not detected mainly in the second half. There are many missing measurements. Being close to the Bonito Station, despised the Pinhal.	-
	Rio Bonito dam	Celesc	Some correlations in Timbó are low. However, there is no problem because there are no missing measurements. The missing measurements were supplied with Timbó.	y = 0.6111x + 0.8844
	Timbó	FURB	Correlation with Indaial, and values are consistent. Thus, the measurements were complemented with Indaial missing measurements.	y = 0.8860x + 0.1164
Itajaí by the downstream	Blumenau	Celesc	Correlation with Indaial, and values are consistent. Thus, the measurements were complemented with Indaial missing.	y = 0.6532x + 0.3515
	Itajaí	Cepsul Ibama, Pesquisador Robert	There are correlations in both. There is no problem on the values which are similar. Average values for both, due to there are no missing measurements.	-
Itajaí Mirim	Salseiro	ANA	Many missing measurements, which are important as data since the rainfall characteristic is different about Brusque. Missing measurements complemented with Ituporanga that showed reasonable correction.	y = 1.4944x + 0.1234
	Brusque	ANA	No metering station nearby, but is relatively high the correction with Indaial (Itajaí is low, Blumenau with high number of missing measurements, discarded). Missing measurements complemented with Indaial, because the values are also consistent.	y = 1.0431x + 0.0793

Source: JICA Survey Team

The Figure 6.3.2 indicates the hourly rainfall distribution and rainfall level (by each station) in the 2010 Flood event.

- The 2010 Flood event had two peaks: Between the days 21th and 23th and between 24th and 26th. The rainfall volume was practically the same in both times.
- The maximum value of the hourly rainfall in the basin was around 9 mm/h. The values remained on the level of 10 to 30 mm/h; like in Brusque (30mm/h) and Boiteux dam (28mm/h).
- The total rainfall was rised specially in the Boiteux (Itajaí do Norte Basin – total rainfall: 400mm), in Rio do Campo and Oeste Dam in the Itajaí do Oeste Basin, and in Rio Bonito Dam in the Benedito Basin. The rainfall seems to be larger in the north and northeast regions.
- By the other hand, the rainfall was relatively weaker in the Itajaí do Sul Basin, as Alfredo Wagner and Ituporanga.

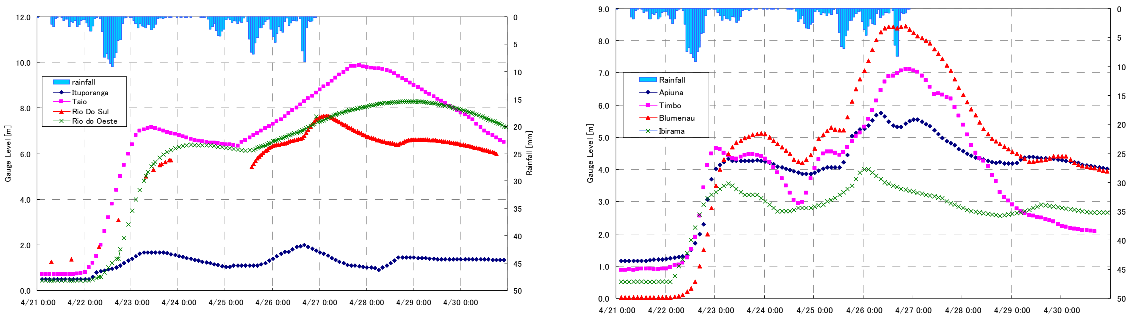


Source: JICA Survey Team

Figure 6.3.8 Mean of hourly rainfall in the 2010 Flood event (mid-valley)

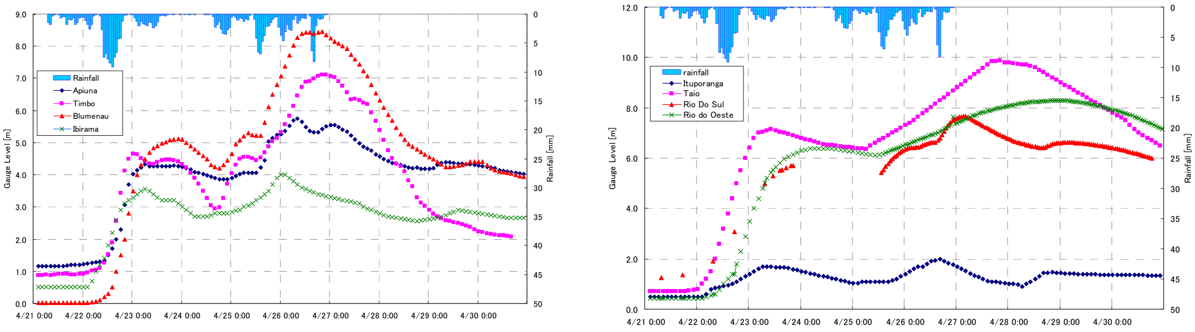
The river level data were obtained in 7 locations. In the Figure 6.3.9 were indicated the river level recorded and in the Figure 6.3.10, the discharge convertion results made by the relation discharge-level.

- The peak discharge at Rio do Sul was approximately 850m³/s. According to the researches made in Rio do Sul , *in loco*, part of the city overflowed.
- The peak occurrence in Taió was delayed because of the dam. The Oeste dam overflowed on this event. A flood close to the prefecture happened in Taió City
- Discharge variation on the opening of the Sul Dam gates occurred in Ituporanga. The Sul Dam did not overflow, fulfilling its role as regulator of flooding, and there was no flood in that city.
- The discharge peak was approximately 800 m³/s in Ibirama. The Norte Dam fulfiled its role as regulator of flooding, and there was no flood in that city.
- The peak discharge at Timbó was approximately 600m³/s. According to the municipality information part of this city overflowed.
- The discharge peak in Blumenau was approximately 2,600m³/s.



Source: Rainfall data measured by JICA Survey Team

Figure 6.3.9 River Level record in the 2010 Flood event



Source: Rainfall data measured and converted in discharge by JICA Survey Team

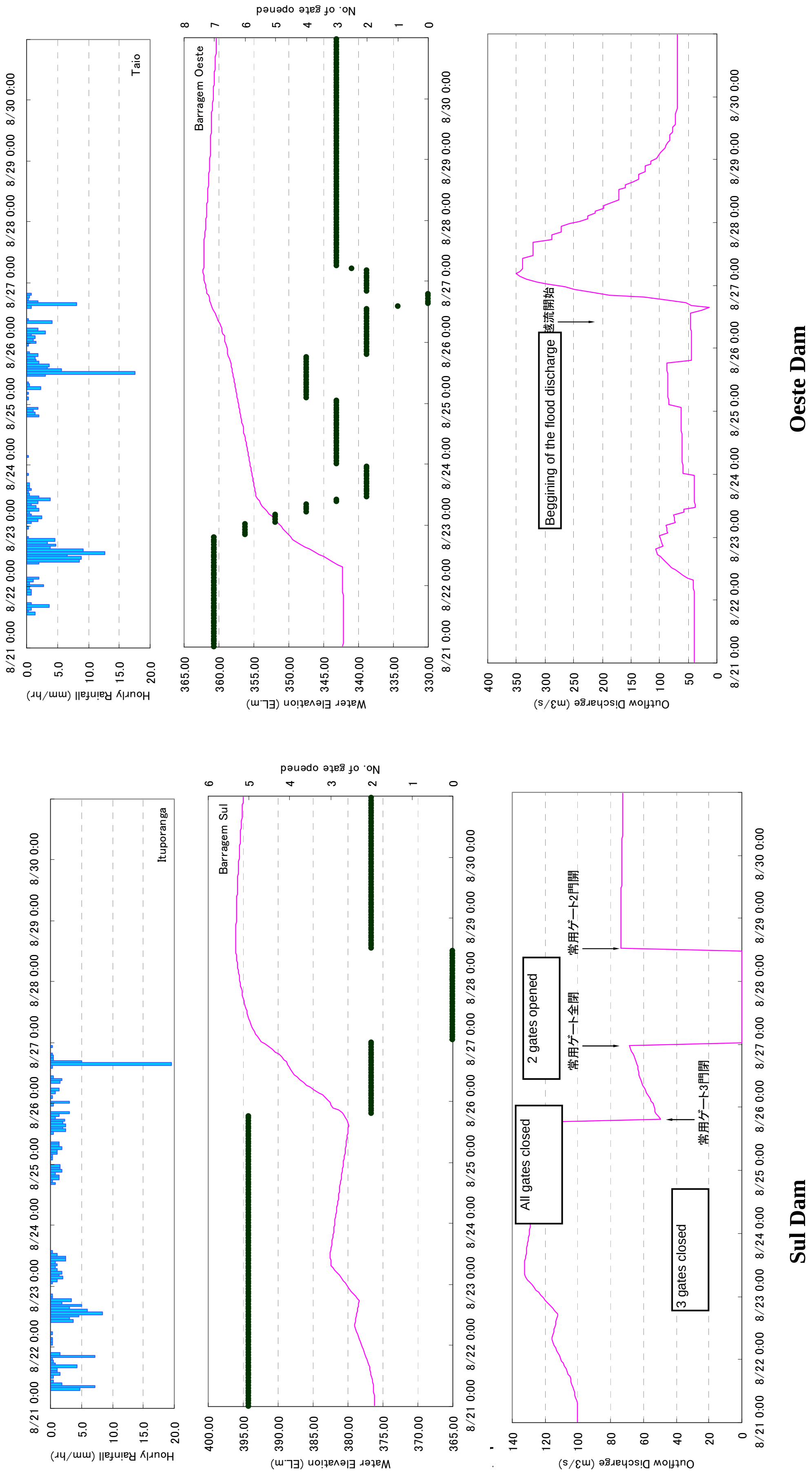
Figure 6.3.10 2010 Flood Discharges

The operational situation of the Sul and Oeste dams in the 2010 Flood event are indicated in the Figure 6.3.11.

The Oeste dam started the gates closing in the 22th day, in the first period of the flood; and in the 23th day closed 5 gates, keeping open 2 others. As the rain got lighter, the dam opened the gates again, letting 4 gates opened in the 25th day. However, it restarted to rain pouring and all the gates were closed in the middle of the day 26th. Consequently, the reservoir began filling on the afternoon of the day 26th, starting the overflow. The overflow discharge reached the peak in the morning of the day 27th, but by that time the rain had ceased.

On the other hand, the Sul dam began closing the gates on the 25th afternoon, closing them completely in 27th. However, the river level reached the overflow maximum quota EL. 396.1 m, leaving approximately 3m to the overflow elevation (EL 399m).

In both operations the dam guidelines were not followed as mentioned in the Annex B.



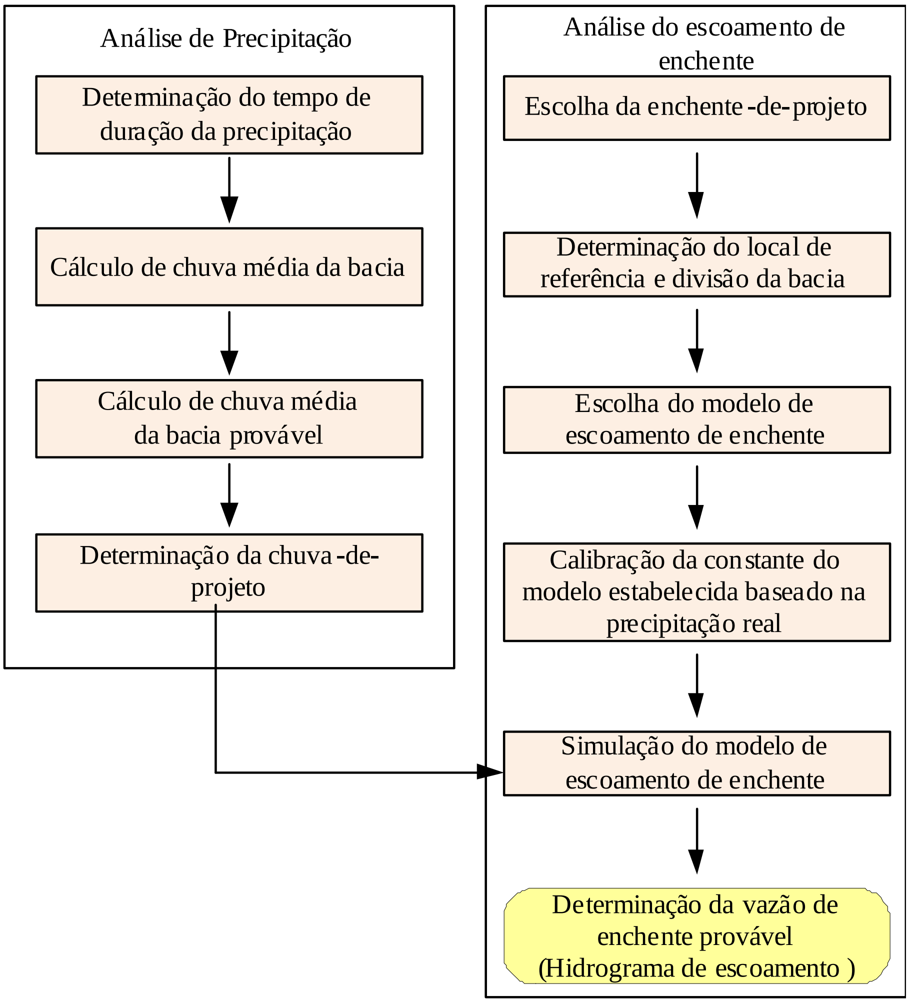
Source: Obtained by the Rio do Oeste Home Page and the Rio do Sul municipality (the original data are from DEINFRA), volume discharge calculated by JICA Survey Team

Figure 6.3.11 Operational situation of both Oeste and Sul dams in the 2010 Flood event

CHAPTER 7 FLOOD OUTFLOW ANALYSIS

7.1 Synthesis

According to the explanation in the Annex D, there are difficults to define the security level against floods, which is a adequacy planning measure. Then, the calculated flood discharge to 5, 10, 25, 50 years of Return Period project. The flood discharge will be calculated by outflow analysis based on the rainfall design, the bellow figure contains the analysis flow.



Source: Equipe de Estudos da JICA

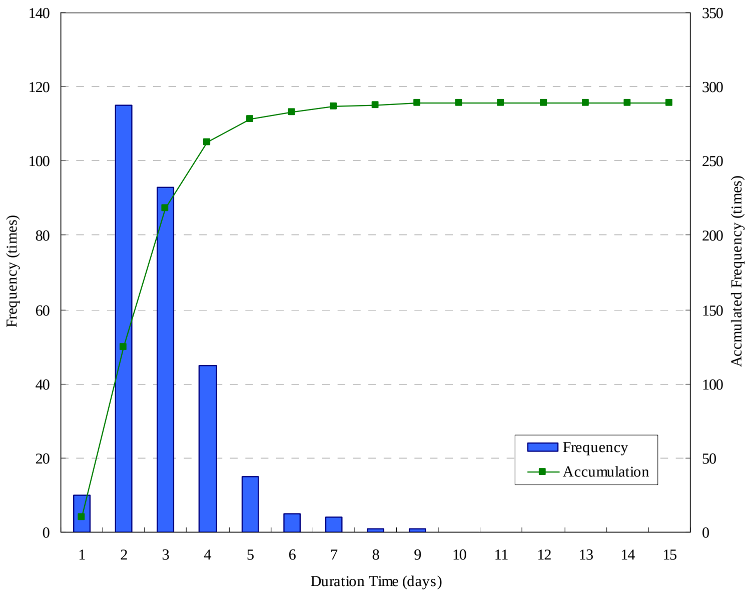
Figure 7.1.1 Flood discharge calculation flowchart

7.2 Rainfall Design Rainfall Analysis

7.2.1 Duration Time

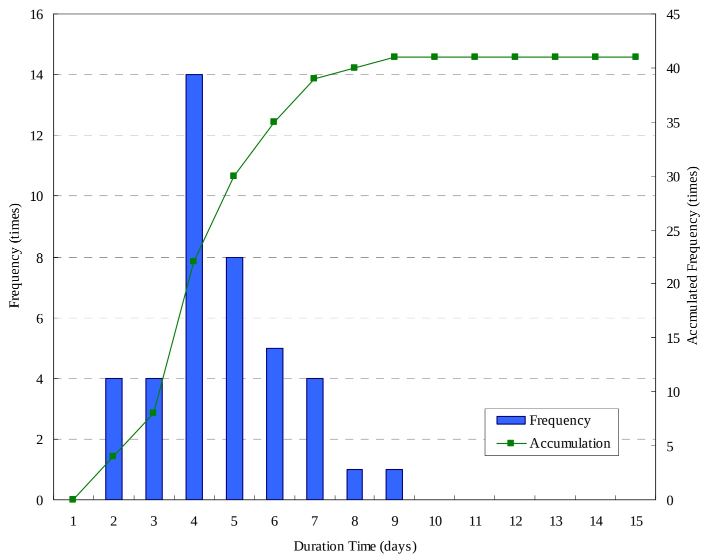
When calculating the rainfall design, there are some points that should be considerated, such as the rainfall features and the flood outflow way due to determine the rainfall design time duration. There are cases that the rainfall time duration is indicated by hours; however, in the Rio Itajaí Basin the rainfall time duration during the flood (time when the flood arrives at the downstream) is larger than the first day. As the daily rainfall data are more reliable (only part of the recorded data are hourly rates) the time unit used is considerated as daily.

The Figures 7.2.1 and 7.2.2 ilustrate the distribution of total rainfall during frequency which is bigger than 50mm and 100mm, respectively. The total rainfall time bigger than 50mm is from 5 to 6 days, maximum. The rainfall time duration bigger than 100mm is from 5 to 6 days, maximum, but the biggest frequency corresponds to 4 days. Thus, rainfall design time duration was established as 4 days.



Souce: JICA Survey Team

Figure 7.2.1 Total rainfall of the frequency distribution duration bigger than 50mm



Souce: JICA Survey Team

Figure 7.2.2 Total rainfall of the frequency distribution duration bigger than 100 mm

7.2.2 Mean of Rainfall Calculation on the Basin

For determinating the rainfall design (4 days duration), firstly the mean of the basin rainfall was calculated using the daily rainfall data recorded on the Itajaí River Basin stations. The calculation methodology is described bellow.

- As basis for the calculation, selected daily rainfall data recorded by ANA since1950 and on were used, because of its reliability.
- The Thiessen method was used for determing the mean of rainfall in the basin. The stations that lack daily records were neglected in the calculation (then, when the daily measurement is neglected, the ponderation of the coefficient and Thiessen changes.)

To indentify the rain trend, it was calculated the mean of rainfall in the whole Itajaí River Basin and the mean of rainfall in each sub-basin of the main tributaries rivers (See Figure 2.3.1 – ANA Rainfall Station Localization Map).

7.2.3 Rainfall Design Determination

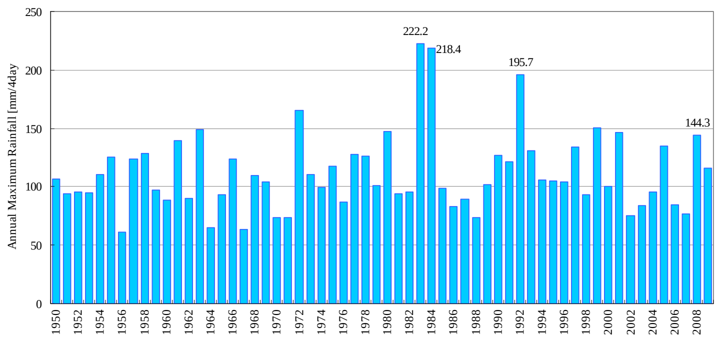
The rainfall design was determinated based on the rainfall highest rates from 4 days since 1950. Furthermore, it was calculated according to the following guidelines for the whole basin and for each sub-basin of the main tributaries.

- The extreme value distribution (Gumbel distribution), which has a high degree of compatibility with the short-term hydrological phenomenon; also its variants, extreme value distribution and generic (GEV) and exponential distribution maximum value (SQRT-ET) were considered as a distribution model.
- It was used the SLSC as an indicator more consistent and the jackknife error standard estimated as an indicator of stability, where the SLSC is less than 0.04 into the distribution, following the model of distribution that minimizes jackknife error.

(1) Rainfall Design for the Whole Itajaí Basin

1) Mean of Rainfall in the Basin

The maximum rainfall of 4 days for each year was extracted by the Thiessen method (which was determined by the mean of rainfall in the whole Itajaí River Basin). As illustrated on the Figure 7.2.3, the biggest rainfall of 4 days happened in 1983, 222,2 mm rate, the rate of 1984, 218.4mm was the second biggest, and 1992 was 195.7mm. In the 2008 Flood event, which has caused serious damages, the rainfall was focused in some regions; so, the mean of the basin rates was 144,3 which is considered a average size Flood event.



Source: JICA Survey Team (Based on data from the ANA station)

Figure 7.2.3 Maximum daily rainfall of each year in the whole Itajaí River Basin (1950 - 2009)

2) Rainfall Design

The mean of the whole Itajaí River Basin complies to the exponential distribution of maximum value (extreme value). The rainfall design of 5 return years is 134,7mm; 10 return years is 156,3 mm; 25 return years is 178,5 mm and 50 return years is 209,2 mm. The 1983 and 1984 Flood event are equivalent to 30 return years flood. The 2008 Flood event, considering the whole basin, is equivalent to the 5 and 10 return years.

Table 7.2.1 Results of the Rainfall Design Calculation for the Whole Itajaí River Basin

Toda Bacia

Função distribuição de probabilidade		Distribuição exponencial	Distribuição de Gumbel	Distribuição raiz quadrada exponencial	Distribuição genérica de valores extremos	Distribuição de Pearson tipo III	Distribuição log-normal parâmetro 3	Distribuição log-normal parâmetro 3	Distribuição log-normal parâmetro 2
Estimação de parâmetros		Método momento L	Método momento L	Máxima verossimilhança	Método momento L	Método momento L	Método Iwai	Método Ishihara/Takase	Método momento L
Abreviação		Exp	Gumbel	SqrtEt	Gev	LogP3	Iwai	Ishitaka	LN2LM
Valor hidrológico provável (estimação de parâmetros em todas as amostras)	1/2	100.8	106.3	104.8	105.1	105.2	–	–	–
	1/3	115.2	120	118.5	118.4	118.8	–	–	–
	1/5	133.2	135.2	134.7	133.9	134.3	–	–	–
	1/10	157.7	154.3	156.3	154.2	154.6	–	–	–
	1/20	182.2	172.7	178.5	174.6	174.8	–	–	–
	1/30	196.5	183.2	191.9	186.8	186.7	–	–	–
	1/50	214.6	196.4	209.2	202.6	202.1	–	–	–
	1/80	231.2	208.5	225.7	217.4	216.7	–	–	–
	1/100	239.1	214.2	233.7	224.7	223.8	–	–	–
	1/150	253.4	224.6	248.5	238	236.8	–	–	–
	1/200	263.6	232	259.3	247.7	246.3	–	–	–
Coeficiente de correlação		0.942	0.996	0.996	0.997	0.996	–	–	–
SLSC		0.04	0.035	0.026	0.027	0.025	–	–	–
Método Jackknife 1/50	Valor estimado	214.6	196.4	210.5	202.5	201.6	–	–	–
	Erro estimado	16.8	14.4	14.1	21.9	20.3	–	–	–
Método aplicado				?					

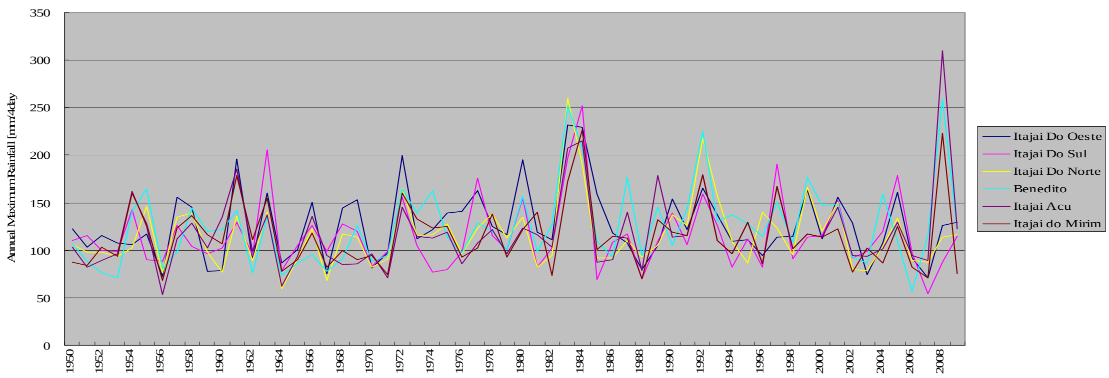
Source: JICA Survey Team

(2) Rainfall Design for the Tributaries Rivers

1) Mean of Rainfall in the Basin

The Figure 7.2.4 and the Table 7.2.2 ilustrates the mean of rainfall in each sub-basin of tributaries rivers.

- In the large 1983, 1984 and 1992 Flood events the maximum rainfall of 4 days occurred in the same period. By the other hand, in the 2008 Flood event, in the Itajaí River Basin, Benedito River Sub-basin and Itajaí Mirim River the largest Flood event occurred in the month of November; in the High Valley, the rainfall rate was low and the rainfall of four days occurred in different periods.
- In the 1983 and 1984 Flood events the rainfall rates were around 200/250 mm in the whole basin; but, in 2008 rainfall with different rates occurred in the whole basin; in the biggest basin, Itajaí River Basin, the rate was higher than 300 mm.



Source: JICA Survey Team

Figure 7.2.4 Mean of Rainfall in the main tributaries rivers of the basin (1950-2009)

Table 7.2.2 Mean of Rainfall for Each Sub-basin of the Tributaries (1950 – 2009)

	Itajai Do Oeste		Itajai Do Sul		Itajai Do Norte		Benedito		Itajai Acu		Itajai do Mirim	
1950	3/1	122.9	3/1	110.6	3/1	105.8	3/1	106.8	3/1	103.3	3/1	87.1
1951	10/15	102.9	10/14	115.2	10/15	98.1	10/15	88.4	10/18	82.6	10/15	84.1
1952	1/23	115.3	1/23	99.8	9/3	97.9	9/2	76.3	1/23	89.7	1/23	103.5
1953	10/28	108.0	10/28	98.7	10/28	93.3	11/11	70.8	10/28	96.6	10/28	93.5
1954	10/19	105.5	10/18	142.7	10/19	102.5	3/31	140.5	3/31	161.7	3/31	159.9
1955	5/17	117.3	7/4	90.4	5/17	145.8	5/17	164.8	5/17	124.8	5/17	127.6
1956	1/16	72.2	1/29	88.7	1/22	76.1	1/21	80.7	5/5	53.5	9/18	68.3
1957	8/16	155.8	7/30	125.7	8/16	135.1	8/16	97.6	8/16	112.2	7/30	123.2
1958	3/14	145.2	8/6	104.2	3/13	139.3	2/18	143.9	3/13	128.8	3/13	136.6
1959	2/20	78.0	4/23	96.3	8/30	97.6	8/30	119.6	8/30	102.5	8/30	116.6
1960	11/10	78.6	7/31	102.1	7/31	76.7	11/26	121.5	11/27	134.6	1/31	106.7
1961	9/9	196.3	10/31	129.5	9/9	135.5	10/31	141.6	10/31	185.5	10/31	178.2
1962	9/19	90.0	9/17	95.2	9/19	89.6	9/19	76.0	9/19	99.1	9/18	111.4
1963	9/26	160.5	9/25	205.7	9/26	140.3	9/26	135.4	9/26	137.6	9/26	155.3
1964	1/31	86.6	4/28	78.5	2/16	59.3	4/28	73.4	4/28	61.9	4/28	78.0
1965	8/18	100.8	8/17	104.7	8/18	91.3	8/18	86.6	4/28	93.7	8/18	90.4
1966	2/9	150.8	2/12	126.0	2/9	122.1	2/9	95.6	2/9	135.7	2/9	118.0
1967	8/21	75.2	9/20	98.5	2/23	67.8	2/10	77.5	2/23	94.7	2/10	82.1
1968	12/21	144.0	12/22	128.1	12/22	117.5	10/27	91.2	12/22	84.9	12/22	100.1
1969	2/16	153.2	2/16	120.2	2/17	114.1	11/13	126.3	2/27	85.8	6/15	90.5
1970	12/10	81.6	1/1	83.0	12/24	81.9	12/22	88.7	1/1	96.1	2/2	94.4
1971	1/9	97.0	7/2	99.3	6/5	90.7	10/10	94.3	5/5	70.9	5/5	74.2
1972	8/25	199.5	8/25	155.8	8/25	165.5	8/25	164.3	8/25	144.8	8/25	159.9
1973	8/11	111.6	7/19	105.1	8/26	115.4	8/25	139.5	8/26	114.8	7/19	132.7
1974	2/17	121.2	8/31	77.0	7/22	116.2	7/22	162.5	7/21	113.1	3/21	123.2
1975	9/30	139.2	9/30	79.9	9/30	127.6	9/30	113.4	9/30	119.2	1/6	125.1
1976	11/29	141.0	11/29	98.2	11/29	96.3	5/26	96.7	5/25	85.9	5/26	92.4
1977	8/15	163.1	8/15	175.9	8/15	123.3	1/17	128.5	8/15	107.6	8/15	102.2
1978	12/25	124.9	12/23	115.9	12/25	138.3	12/23	120.3	12/23	121.8	12/23	138.1
1979	5/7	116.1	5/7	100.7	5/7	112.7	10/6	100.8	4/3	96.3	5/7	92.9
1980	12/19	195.4	12/19	155.3	12/19	135.2	12/19	156.8	12/19	123.1	12/19	121.4
1981	12/20	118.7	12/20	81.9	12/21	81.8	3/27	99.2	10/27	116.5	10/27	140.1
1982	11/3	111.2	11/3	102.4	11/3	94.1	2/4	127.0	2/2	103.4	10/5	73.3
1983	7/6	231.6	7/7	197.3	7/6	260.0	7/6	252.0	7/6	207.4	7/6	172.4
1984	8/5	229.0	8/5	251.6	8/5	191.0	8/5	207.8	8/5	215.2	8/5	226.8
1985	2/12	158.8	2/12	69.2	2/13	92.2	4/5	109.4	2/12	87.9	11/20	100.2
1986	11/3	118.0	11/3	108.4	4/4	92.0	9/18	93.0	9/19	90.4	10/9	114.6
1987	1/11	107.8	5/12	117.2	6/13	109.9	2/13	176.4	2/14	140.3	2/14	113.1
1988	5/21	80.0	9/20	69.8	5/21	93.0	5/21	94.7	9/19	79.1	9/20	69.6
1989	5/3	105.2	5/3	109.0	9/11	105.1	1/4	145.0	1/5	178.7	1/6	132.2
1990	5/30	154.1	2/10	139.2	5/29	137.0	7/18	105.4	7/18	113.4	5/30	118.8
1991	6/20	121.6	6/20	106.1	6/20	126.1	6/20	143.8	1/23	115.2	1/23	115.2
1992	5/27	165.5	5/28	159.3	5/28	217.8	5/28	224.8	5/28	179.7	5/28	179.7
1993	9/21	137.8	7/2	126.0	9/21	157.6	9/21	130.2	9/21	110.2	9/21	110.2
1994	5/10	109.6	6/19	82.1	5/10	108.9	5/10	137.3	5/10	96.4	5/10	96.4
1995	1/10	110.8	1/10	111.7	1/10	86.6	7/5	127.8	1/7	129.7	1/7	129.7
1996	6/17	94.6	1/14	81.9	6/17	140.3	6/17	114.5	6/17	85.5	6/17	85.5
1997	1/30	113.7	1/30	191.1	10/6	123.3	1/20	150.3	1/31	167.2	1/31	167.2
1998	4/26	115.0	4/27	90.8	1/31	95.5	8/13	108.3	4/26	101.7	4/26	101.7
1999	7/2	163.4	7/2	113.4	7/2	166.2	7/2	176.5	7/2	117.5	7/2	117.5
2000	9/12	112.1	9/12	115.4	9/12	119.9	2/14	146.8	2/14	113.4	2/14	113.4
2001	9/28	156.1	9/29	152.0	9/29	150.9	9/29	148.6	9/29	145.2	9/29	122.5
2002	11/27	128.6	4/18	91.5	7/31	79.5	7/31	92.9	1/10	94.6	4/1	76.6
2003	12/12	74.5	12/12	99.2	12/11	78.9	12/12	86.6	3/2	93.8	12/12	102.5
2004	9/12	107.8	9/12	119.7	10/22	104.3	10/22	159.1	10/23	101.5	9/12	86.5
2005	5/18	160.8	5/18	178.2	5/18	134.1	8/30	109.8	5/18	129.4	8/30	125.1
2006	11/18	92.2	1/23	97.3	11/17	89.1	9/30	57.1	11/18	94.4	11/18	82.1
2007	11/1	71.1	11/1	54.3	12/5	87.2	12/4	115.5	11/2	89.0	11/1	70.7
2008	10/16	126.4	10/16	87.7	10/15	113.6	11/21	258.7	11/21	309.3	11/21	222.7
2009	9/28	129.3	9/28	114.2	9/28	116.3	9/28	121.8	9/28	122.3	4/23	75.0

Source: JICA Survey Team

2) Rainfall design

The Table 7.2.3 ilustrates the rainfall design in the Itajaí river and its tributaries.

- The rainfall design is relatively large in the Itajaí do Oeste Basin, Bendito basin and Itajaí Basin
- The Itajaí do Sul, Itajaí Mirim (both located in the south region) Rainfall Volume and Itajaí do Norte basin are relatively small.
- The rainfall design of the whole basin is relatively small, because of the focused pouring rainfall are balanced and the level is lower.

Table 7.2.3 Itajaí River Rainfall Design and its Tributaries

	1/5	1/10	1/20	1/25	1/50
Total da Bacia	134.7	156.3	178.5	187.7	209.2
Itajai do Oeste	153.1	175.2	196.3	201.7	223.8
Itajai do Sul	140.8	161.4	181.1	186.1	206.7
Itajai do Norte	140.4	160.3	179.3	184.1	204
Benedito	154.8	179	202.3	208.1	232.4
Itajaí-açu	144.1	168.9	194.4	205.2	229.9
Itajai Mirim	140.1	160.5	179.9	184.8	205.2

Source: JICA Survey Team

7.3 Choice of the Flood Design

The flood that will be used for Flood Plan evaluation (based on the recurrence time) will be choosen from the flood group obtained of the outflow calculation using the hyetograph of precipitation for the extended real rain project. In order to formulate flood prevention measures for different modalities of rainfall (different hyetograph) the ideal would be choosing several types of floods.

In the Main Plan was formulated a plan for 5 return years (mean of rainfall volume in 4 days in the whole basin = 135mm) until 50 return years (mean of rainfall volume in four day in the whole basin = 209mm); therefore, the four days precipitation was considered as 130mm to 220mm. The Table 7.3.1 bellow show the extract flood; the hourly data available needed for the outflow analysis refers to six passed floods (1972, 1980,1984,2005 and 2010); the rainfall rates were based on these six floods were. In relation to the1984 and 2010 Flood events, there are rainfall and discharge data measured in differents stations; thus, they will be used on the elaboration of the outflow analysis model (gauge of the rainfall-discharge model: HEC-HMS).

Table 7.3.1 Flood for the purpose of the Survey

Flood Occurrence Time	**Rainfall volume for 4 days (mean of all the basin)**	**Choise**	**Choice of flood / Reason for disposal**
31/10/1961	139,3 mm		There is no record of hourly data of rainfall / discharge
26/09/1963	149,0 mm		There is no record of hourly data of rainfall / discharge
25/08/1972	**165,7 mm**	○	**There are hourly records of rainfall (1 station)**
19/12/1980	**147,3 mm**	○	**There are hourly records of rainfall (2 stations)**
06/07/1983	**222,8 mm**	○	**There are hourly records of rainfall (2 stations)**
05/08/1984	**218,4 mm**	¤	**Discharge and hourly data are consistent**
28/05/1992	195,7 mm		There is no record of hourly data of rainfall
31/01/1997	133,7 mm		There is no record of hourly data of rainfall
02/07/1999	150,3 mm		There is no record of hourly data of rainfall / discharge
29/09/2001	146,8 mm		There are hourly records od rainfall
18/05/2005	**144,3 mm**	○	**There are hourly records of rainfall (8 stations)**
21/11/2008	135,1 mm		The rainfall is extremely biased
23/04/2010	**130,3 mm**	¤	**Discharge data and Hourly Rainfall are complete**

¤ Choosen for the outflow analysis calibration and flood plan. ○ Choosen for flood plan
Source: JICA Survey Team

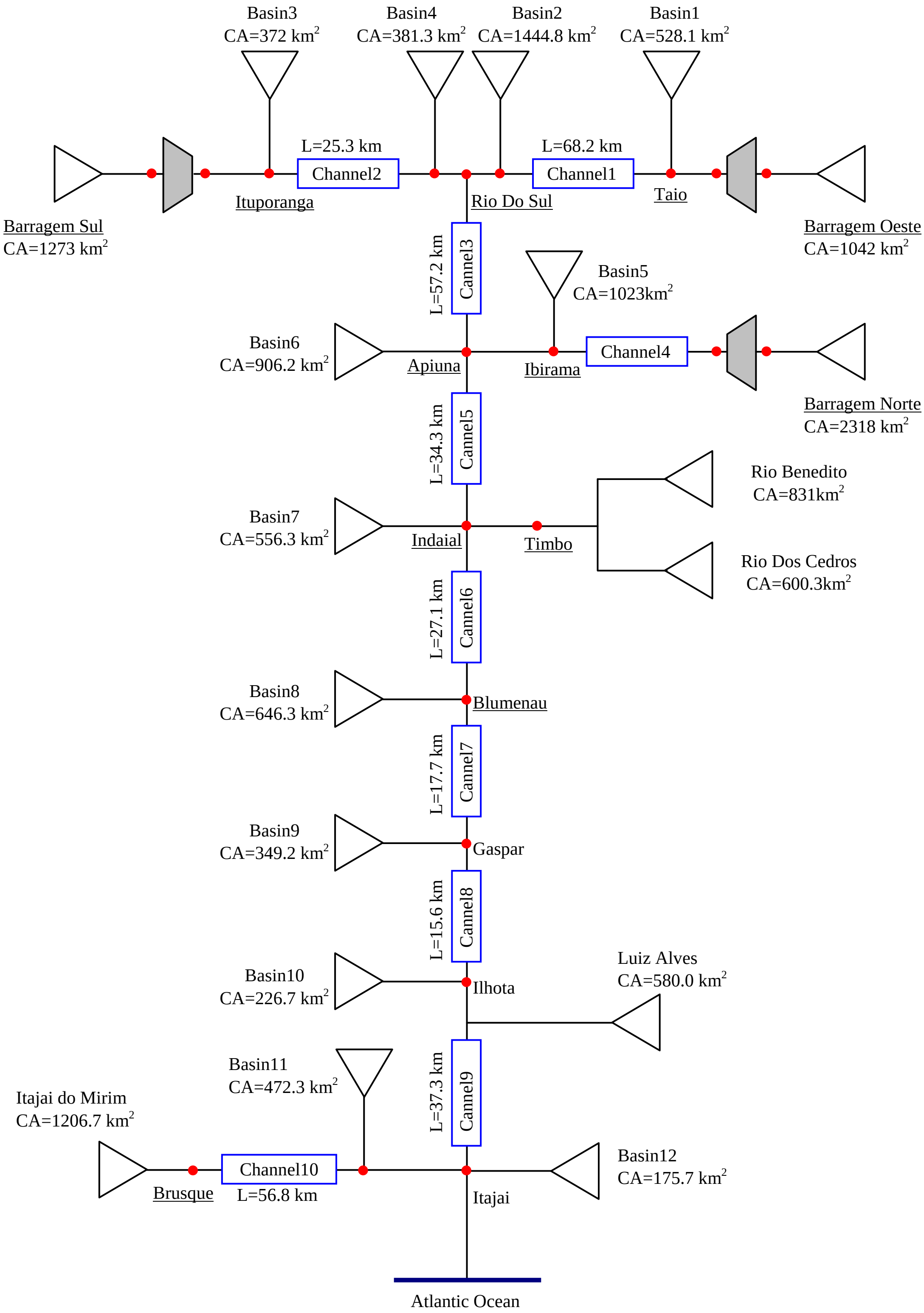
7.4 Analysis and Calibration Model

7.4.1 Division of the Basin

The basin division model for the purpose of outflow analysis, according to the illustrated on the Table 7.4.1 bellow, was elaborated taking into consideration: i) Main tributaries and ii) Determination of the necessary place or the cross section for the discharge calculation. The stretch between those determined places were connected to the chanel model. The Itajaí River Basin is presented on the the Figure7.4.1 (Outflow model).

Table 7.4.1 Main Tributaries and Discharge Calculation Place Which Were Considered in the Basin Division

Name of the Tributary river	Place	Basin Area (km2)	Distância de foz /encontro dos rios (km2)	Motivo da escolha do lugar para cálculo da vazão
C.A=3.014,9 km2	Barragem Oeste	1.042,0	81,4	Volume de contenção e descarga, e plano de reforma da barragem
	Taio	1.570,1	68,2	Medidas contra enchentes de Taió: calibração com os valores de medição
	Antes do encontro com Rio principal	3.014,9	0,0	Medidas contra enchentes da cidade de Rio do Sul (antes do encontro dos Rios)
Itajaí do Sul C.A=2.026,7 km2	Barragem Sul	1.273,0	43,4	Volume de contenção e descarga, e plano de reforma da barragem.
	Ituporanga	1.645,4	25,3	Calibração com os valores de medição (o problema de enchentes é insignificante)
	Antes do encontro com Rio principal	2.026,7	0,0	Medidas contra enchentes da cidade de Rio do Sul (antes do encontro dos Rios)
Itajaí do Norte C.A=3.353,8 km2	Barragem Norte	2.318,0	48,1	Volume de contenção e descarga da barragem (não há necessidade de reforma)
	Ibirama	3.341,0	4,0	Calibração com os valores de medição (o problema de enchente é insignificante)
Rio Benedito Rio Dos Cedros C.A=1.500,3 km2	Antes do encontro com Rio principal	831,1 600,3	0,0 0,0	Medidas de enchentes da cidade de Timbó (antes do encontro dos Rios)
	Timbó	1,431.3	10.5	Cidade de
Luis Alves C.A=580.0km2	Antes do encontro com Rio Principal	580,0	0,0	Há possibilidade de avaliar lagos de retardamento como medida contra enchentes da cidade de Itajaí
Itajaí Mirim 1,678.9 km2	Brusque	1.206,6	56,8	Calibração com os valores de medição (o problema de enchentes é insignificante)
	Antes do encontro com Rio principal	1.678,9	0,0	Medidas contra enchentes da cidade de Itajaí (Inundação do Rio Itajaí Mirim)
Itajaí C.A=14,933.2 km2 (Toda a Bacia, incluindo as bacias dos rios tributários)	Rio do Sul	5.041,6	189,2	Calibração com os valores de medição e medidas de enchentes de Rio do Sul
	Apiúna	9.288,8	132,0	Calibração com os valores de medição (o problema de enchentes é insignificante)
	Indaial	11.276,4	97,7	Calibração com os valores de medição (o problema de enchentes é insignificante)
	Blumenau	11.922,7	70,6	Calibração com os valores de medição e medidas de enchentes de Blumenau
	Gaspar	12.271,9	52,9	Medidas de enchentes de Gaspar
	Ilhota	12.498,6	37,3	Medidas contra enchentes de Ilhota: há possibilidade de avaliar planície de retardamento e outras medidas para prevenção de enchentes de Itajaí



Souce: JICA Survey Team

Figure 7.4.1 Itajaí River Basin division (outflow analysis model)

7.4.2 Analysis Methodoly

(1) Software used on the analysis

The *software* that will be used on the outflow analysis should have versatility; the program HEC-HMS (which belongs to the HEC family and was developed by the USA Army, and it is largely used in Brazil) will be used in the outflow analysis.

(2) Determination of effective rainfall

The effective rainfall height will be the total rainwater height, discounted the losses caused by seepage, evapo-transpiration, etc. The rainwater losses height will be subdivided into initial loss rate and constant loss rate. Therefore, the rainfall height with the initial loss (Ia) is not considered straightly in the outflow, from the time that the volume overcome the Ia, there will be a constant loss (fc), every hour, considered in the rainfall height (pt),

$$pet = \begin{cases} 0 & if \quad \sum p_i < I_a \\ pt - fc & if \quad \sum p_i > I_a \ and \quad p_t > f_c \\ 0 & if \quad \sum p_i > I_a \ and \quad p_t < f_c \end{cases}$$

I_a（Initial Loss） :

According to the historical data, the initial loss value proposed is in accordance with the table bellow.

Table 7.4.2 Initial Loss Ia

Loss of Surface		
Inicial Loss (área agrícola)		
Cultivo	Altura Pie	Intercepção polegada
Corn	6	0,03
Cotton	4	0,33
Tabaco	4	0,07
Cereais	3	0,16
Pastagem	1	0,08
Alfafa	1	0,11
desde Linsley, Kohler, and Paulhus 1975)		
Área Floresta (desde Viessman et al. 1977) 10-20% total de precipitação, maxima 0.5 polegada		
Armazenamento de Detenção (desde Horton 1935)		
Área agrícola (Depende de tempo de arado)		0,5 – 1,5
Florestas/Pastagens		0,5 – 1,5 polegada
Perda Total Superficial		
Urban Area Área Aberta		0,1 – 0,5 polegada
Área Impermeável		0,1 – 0,2 polegada

Source: EM 1110-2-1417 Engineering and Design - Flood-Runoff Analysis

The biggest part of the Itajaí Basin is covered by forests, fields and agriculture, the urban area occupies a significant part. The quantity of initial losses in the agricultural areas, forests and fields, according to the Detention Storage (from Horton, 1935) from the table above, is from 0,5 to 1,5 inches (12,7 to 38,1mm). Additionally, according to the value for Forest Area (from Viessman et al. 19744), also from the above table, it is defined as being 10% to 20% from the total of the rainfall height (maximum 0,5 inches = 12,7 mm), existing different versions among the researchers. In this analysis, it will be defined the initial loss as being 20 mm, based in the above information and it will be adjusted through the real flood calibration, according to the necessity.

Constant Loss Rates f_c

According to the historical data, the constant loss rate is proposed as shows the Table 7.4.3 bellow.

Table 7.4.3 Soils group SCS and Infiltration Rate (loss) (SCS, 1986; Skaggs and Khaleel, 1982)

Soils Group	Description	Loss Rate Range (inch/h)
A	Deep Sand, Deep loss, added mud	0,30-0,45
B	Moderate Loss, Sandy Mud	0,15-0,30
C	Clay, mud moderately sandy, soil with organic content, soil with high clay content	0,05-0,15
D	Highly moist soil, heavy clay and soil salinity	0,00-0,05

Source: SCS, 1986; Skaggs and Khaleel, 1982

In the mountain region of the Itajaí Basin there are stones, mud, metamorphic rocks derived from the fine sand which are distributed in relatively thick layers throughout the region. Moreover, the alluvial deposits downstream are clays that were transported from the upstream and are grounded in thick layers.

Therefore, the constant loss value corresponds to the soil group B or C from the Table above, close to the value of 0,15 inches/m³ (8mm/h); or corresponds to the Soil Group D, with the value of 0,05 inches (1,27mm/h), supposing that the ground is wet. In this study, the constant loss will be defined as being 2,0mm/h by the analysis from the table above. The adjustments will be done using real flood calibration, according to the necessity. Beyond the loss above, the waterproof area rate as being 5%.

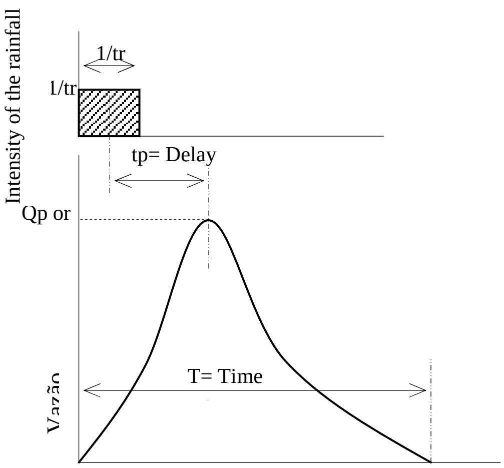
(3) Direct outflow model

The Snyder (Snyder's UH Model) unit hidrogram method will be used for the direct outflow model.

The Snyder method elaborates the effective rainfall unit hidrogram versus the normal duration TR, based in the elements: discharge peak, basic length and delay time.

The usual effective rainfall duration is established according to the delay time formule bellow.

$$t_r = \frac{t_p}{5.5}$$



In addition, the delay time tp , discharge peak (compared discharge qp) and the basic length tb are obtained as bellow.

$$t_p = C \cdot C_t \left(L \cdot L_c\right)^{0.3}$$

$$q_p = \frac{C \cdot C_p}{t_p}$$

$$t_b = 3 + \frac{t_p}{8}$$

L is the output length until the river bank from the main river; Lc is the output length of the basin until the closest point to the basin centroid; the unit of convertion factor C is 0,75 in the Unit SI, this means 1,0 in the english system for units. Furthermore, the C_t parameter will be obtained through calibration, but in general it uses a value between 1,8 to 2,0.

The convertion factor C related to the discharge peak is 2,75 in the unit SI and 640 in english units. The peak coeficient C_p will be obtained through calibration, but in general this value is between 0,4 to 0,8. The defined standards in the calibration are Ct and Cp. In the current analyses, the initial value will be adopted as: Ct= 1,9 and Cp= 0,6; these values will be adjusted through the real flood calibration, according to necessity.

However, the rainfall duration t_R for any other time from the standard duration t_r will be obtained by the delay time equation t_{pR}, compared discharge peak q_{pR} and the basic length $t_{bR.}$

$$t_{pR} = t_p + 0.25(t_R - t_r)$$

$$q_{pR} = \frac{640C_p}{t_{pR}}$$

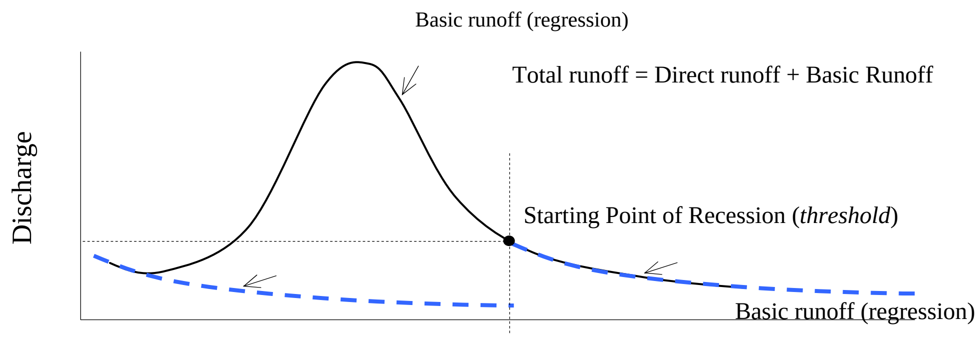
$$t_{bR} = 3 + \frac{t_{pR}}{8}$$

(4) Basic Outflow Volume Establishment

For the basic outflow volume the *Exponential Regression Model* will be used; the initial discharge value (*Initial baseflow)* Q_0 and the Regression rate k will be calculated throught the equation bellow.

$$Q_t = Q_0 k^t$$

As the basic outflow should be calculated before and after the flood, both situations should establish the beggining (*threshold*) (after the flood peak and, when the flood discharge reduce until the recession point (*threshold*)) and implement the exponential regression (similar to the initial basic flow). The initial rate (*threshold*) will be represented by the flow peak (*ratio-to-peak*).



Initial Discharge: Q_0

The initial flow Q_0 is different for each flood (seasonality or proximity to the flood); in the 2010 Flood event was 0~5m³/s/100 km² (However, in Timbó it was more than 2m³/s/100 Km²) and in the 1984 Flood event it was 4~5m³/s/100 Km² (However, in Brusque it was less than 0,5m³/s/100 Km²). In the calibration the measurements above will be used, but in the Flood design calculation it will be estimated 5m³/s/100 Km², predicting the safety margin.

Constant of Regression k

For the constant of regression k, according to the existing literature, the values illustrated in the Table 7.4.4 are suggested. The applicable extent in the chart bellow is less than 300~16,000 Km². The larger the dimension of the basin, the constant value will trend to the bigger extent. The Itajaí River Basin basin dimension is close to the superior extent limit of expansion, therefore, the constant of reduction will be the superior limit value of the extent from the Table 7.4.4 bellow. Furthermore, the basic discharge will be structured according to the groundwater or the interflow outflow.

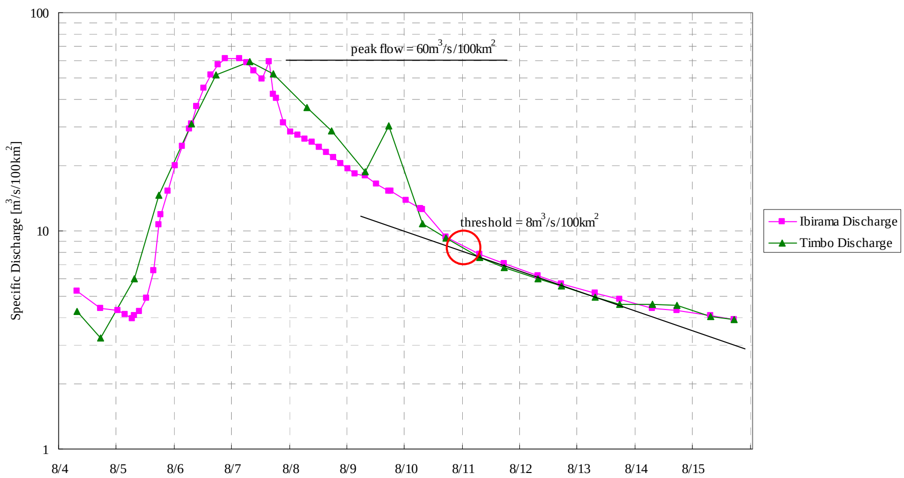
Table 7.4.4 Proposed Value for the Constant of Regression k

Flow component	Recession constant, daily
Groundwater	0,95
Interflow	0,8-0,9
Surface runoff	0,3-0,8

Source: Pilgrim and Cordery 1992

<u>Relation between the discharge peak and recession peak (ratio-to-peak)</u>

The exponential regression curve from the relation between the discharge peak and the recession point was analysed after the flood, based in the 1984 discharge data, in Ibirama and Timbó, places where there is no dam influences. According to the Figure 7.4.2, supposing that the exponential regression time (represented as a straight line in the logarithmic scale, and this compared discharge is around 8 m³/s/100 Km²). The compared discharge in the peak time is 60 m³/s/100km²; so, the relation 8/60=0,14. Therefore, in the current analysis the relation between the discharge peak and the recession point was established as 0,14.



Source: Equipe de Estudos da JICA

Figure 7.4.2 Compared discharge from the 1984 Flood event (Ibirama e Timbó)

(5) River Channel Model (flood propagation model)

If the HEC-HMS was used as river channel model for flood propagation it would be possible choosing among 5 calculation methods, according to the relation bellow:

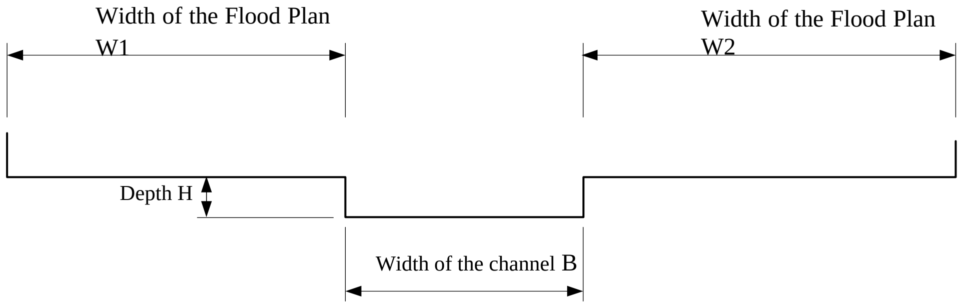
(1) Lag
(2) Muskingum
(3) Modified Plus
(4) Kinematic Wave
(5) Muskingum Cunge

There is a delay in the outflow due to the effect of the natural flood plan contention from the Itajaí River bank. Therefore, the Muskingum-Cunge method (which enables the physical reproduction of this contention effect as channel model) will be adopted . The Muskingum Cunge is a method based on the wave propagation which is close to the continuous expression of the open channel one-dimentional movement equation.

Continuous Equation $$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L$$

Movement Equation $$S_f = S_0 - \frac{\partial y}{\partial x}$$ (Wave Propagation)

In the current analysis, the modeling for each strech of the river channel will be implemented, according to the figure 7.4.3. Using the river cross section data in which the survey was performed previously (measurements at ANA's stations data) establishing: representative width of the channel = B, Depth = H and plan width = W. The input data in the Muskingum Cunge model are showed in the Table 7.4.5 bellow.



Source: JICA Survey Team

Figure 7.4.3 Modeling of the channel form

Table 7.4.5 Input Data in Muskingum Cunge Method

River Channel	Stretch	Channel Shape			Tilt of the Riverbed	Roughness coefficient	
		Width of the Riverbed	Depth	Width Plain		Channel	Flood Plain
Channel 1	Taió/Rio do Sul	30	12.000	600	0.0003	0.035	0.050
Channel 2	Ituporanga/Rio do Sul	25	8.500	55	0.0010	0.035	0.050
Channel 3	Rio do Sul/Apiuna	60	12.000	600	0.0003	0.035	0.050
Channel 4	B.Norte/Ibirama	45	12.000	60	0.0042	0.035	0.050
Channel 5	Apiuna/Indaial	90	19.000	40	0.0010	0.035	0.050
Channel 6	Indaial/Blumenau	90	19.000	40	0.0020	0.035	0.050
Channel 7	Blumenau/Gaspar	90	14.000	330	0.0001	0.035	0.050
Channel 8	Gaspar/Ilhota	100	17.000	600	0.0001	0.035	0.050
Channel 9	Ilhota/Itajai	180	8.000	600	0.0001	0.035	0.050
Channel 10	Brusque/Itajaí	20	11.000	600	0.0004	0.035	0.050

Source: JICA Survey Team

(6) Contention of Dam Model

Along with the program HEC-HMS, the flood modeling for dam facilities will be carried out. In the Itajaí River Basin there are three exclusive dams for flood control: Oeste Dam, Sul Dam and Norte Dam.

The data referring to the discharge features (H-Q) and H-V of the each dam reservoir are not available, according to the DEINFRA information (that manages the dams of the Santa Catarina State) (Old drawings in paper about the dams were accessed and the curves H-Q and H-V were extracted). The dam control data that have been recorded only on the reservoir level and the opening and closing situation of the gates (there is a improvement possibility in the dam management).

As there is a necessity of the H-Q rating curve from the dam and H-V curve from the reservoir these curves were elaborated adjusting the constant curve scale in the drawings in paper, based on the generic discharge formule, according to the Table 7.4.6 bellow.

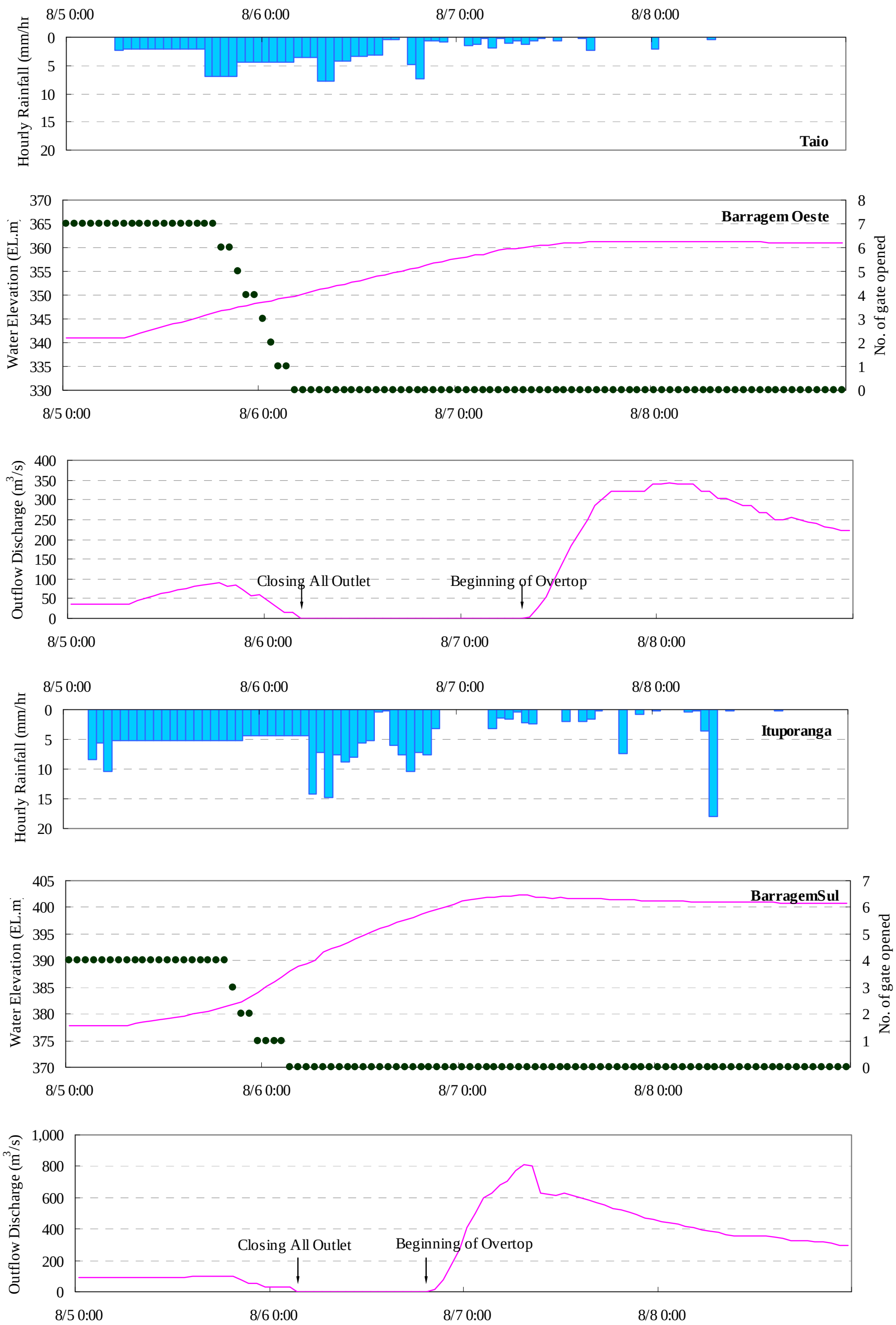
Table 7.4.6 H-Q e H-V Curve Equation

		H-Q、H-V	
Generic Expression		Usual	$Q = C \cdot n \cdot A\sqrt{2g(H - H_0)}$
		Unusual	$Q = C \cdot B \cdot H^{1.5}$
		Reservoir capacity	$V = a(H - b)^2$
Adjustament	Oeste Dam	Usual	$Q = 0.6667 \times 7 \times 1.7663\sqrt{2g(H - 340.05)}$
		Unusual	$Q = 2.1658 \times 100 \times (H - 360)^{1.5}$
		Reservoir capacity	$V = 0.18192 \times (H - 338.64)^2 \times 10^6$
	Sul Dam	Usual	$Q = 0.8901 \times 5 \times 1.7663\sqrt{2g(H - 368)}$
		Unusual	$Q = 2.0758 \times 65 \times (H - 399)^{1.5}$
		Reservoir capacity	$V = 0.17033 \times (H - 375.57)^2 \times 10^6$
	Norte Dam	Usual	$Q = 74H - 19092$ (H=EL.258m～EL.259m)
			$Q = 3.8H - 910.2$ (H=EL.259m～EL.264m)
			$Q = 92H - 24195$ (H=EL.264m～EL.265m)
			$Q = 0.89513 \times 2 \times 6.76\sqrt{2g(H - 253)}$ (H=EL.265m～)
		Unusual	$Q = 2.0506 \times 100 \times (H - 295)^{1.5}$
		Reservoir capacity	$V = 0.17825 \times (H - 250.69)^2 \times 10^6$

Executado por: CNEC	Bacia do rio Itajai subsidios para o plano integrado de aproveitamento e controle dos recursos hidricos Obras existentes de controle de cheias Barregem Sul, Oeste, Norte (em Construção)	CAEEB	MME DNAEE	APROV. DNAEE
				No.3.1 (Sul) No.3.2 (Oeste) No.3.3 (Norte)

Source: JICA Survey Team

The information about the dam operation referring to the 1984 Flood event was organized based on the H-Q curves elaboreted by the team, according to the following Figure 7.4.4.



Source: JICA Survey Team
Remark: The water level data, discharge volume and gate operation that were not record were implemented by the prior and posterior data.

Figure 7.4.4 Dam operation during the 1984 Flood event (the discharge volume was estimated based in the H-Q elaborated curve)

7.4.3 Results of the Constant Calibration of the Model

Among the constants of the outflow analysis model explained until now,

- The values of the basic discharge constants (Initial discharge Q0, attenuation constant K and the peak rate) were established according to the measurement values.
- However, for the parameters relationed to the effective rainfall (Initial loss Ia, Constant Loss fc) and the parameters related to the straight outflow model (Ct, Cp from the Schneider Unit Hydrograph) were considered the generic values; so, a calibration is necessary for helping the real flood.
- Using the real discharge volume in the dam on the calibration phase would be the correct action. However as there is no record from these data, the obtained discharge value was introduced according to the water level calculated by the H-Q curve equation.

The model constant of the initial value was ordered on the Table 7.4.7. The calibration result is showed bellow.

<u>Calibration results from the 1984 Flood event (Table 7.4.7 and Figure 7.4.6)</u>

- After the analysis using the initial parameters, the rise time of the flood was reproduced satisfactorily.
- The reproduction discharge peak and total outflow volume on the Itajaí do Norte River Basin and Benedito River Basin were less than the real flood and relatively large in other basins.
- The initial loss was not modified; the constant loss rate value on the Itajaí do Norte River Basin and Benedito River Basin was reduced and a modification relatively significant was carried out in other basins. The Itajaí do Norte and Benedito Rivers Basins present relatively steep terrain and the weathering is lower. Therefore, from the physical point of view, this modification is adequated.
- After the sensitivity analysis, Ct e Cp did not influence the outflow wave. Therefore, the decision was do not change the parameters.
- The calculation showed that the peak time was relatively faster than in the Timbó real Flood event and relatively slower in Bruque; Therefore, the maximum values were changed from Ct (Benedito River Basin) to the generic value, and the Itajaí-Mirim Basin to the maximum value (at the same time, the Cp was changed due to the adjustment from the peak discharge).
- Accordingly, the 1984 Flood event was reproduced satisfactorily.

<u>Calibration results of the 2010 Flood event (Table 7.4.8 e Table 7.4.9, Figure 7.4.7)</u>

- 2010 Flood event was calibrated based on the calibration results from the 1984 Flood event.
- In the 2010 Flood event there was two peaks flood, the effective rainfall and the basic discharges are different. So, the calibration was carried out in two phases.
- The rainfall at the first phase of the occurred 2010 Flood event was less; therefore, the initial loss value was increased and the constant loss rate (Initial Loss、Constant Loss Rate) and a lesser basic discharge value was established.
- The flood from the second phase suffers the impact of the previous phase; therefore, the loss value was reduced and a larger value for the basic discharge was established.
- The results of the 2010 Flood reproduction is not good enough if it was compared to the 1984 Flood event. Mainly, Rio do Sul's upstream flood reproduction results, from the both first and second phases are not good enough.

- The possible reason for bad results on the flood initial reproduction should be the following: The large loss value was established because of the little rainfall on the flood initial phase; There is a possibility of a fast outflow on the surface due to the the underground infiltration difficulty in the interflow. This kind of interflow is difficult to reproduce on the Unique Model.
- The possible reason for bad results on the flood initial reproduction should be the following: the large difference on the discharge volum between the Oeste and Sul dams. Furthermore, there is a possibility of mistake on the reservoir level data of both dams or a mistake on the water data level by the downstream of the dams.

Table 7.4.7 Initial Value from the Constant Model of the Basin (before calibration)

Tipo	Nome	Área de Drenagem	perda			Transformação					Vazão básica			
			Perda Inicial*	**Taxa Constante****	Impermea-bilidade	L	Lc	**Parâmetro Ct*****	Standard Lag	**Peaking Coefficient Cp******	Descarga inicial específico*****	Descarga Inicial	Recessão constante	Pico de recessão (Ratio to peak)
		km^2	**mm**	**mm/h**	%	km	km	-	hr	-	$m^3/s/100km^2$	m^3/s	-	-
Sub-bacia	Barragem Oeste	1.042.0	**20**	**2**	5	55	28	**1.9**	12.9	**0.6**	5	52	0.95	0.14
	Bacia 1	528.1	**20**	**2**	5	40	15	**1.9**	9.7	**0.6**	5	26	0.95	0.14
	Bacia 2	1.444.8	**20**	**2**	5	68	34	**1.9**	14.6	**0.6**	5	72	0.95	0.14
	Barragem Sul	1.273.0	**20**	**2**	5	62	31	**1.9**	13.8	**0.6**	5	64	0.95	0.14
	Bacia 3	372.0	**20**	**2**	5	25	13	**1.9**	8.1	**0.6**	5	19	0.95	0.14
	Bacia 4	381.3	**20**	**2**	5	25	13	**1.9**	8.1	**0.6**	5	19	0.95	0.14
	Barragem Norte	2.318.0	**20**	**2**	5	102	51	**1.9**	18.6	**0.6**	5	116	0.95	0.14
	Bacia 5	1.023.0	**20**	**2**	5	44	22	**1.9**	11.2	**0.6**	5	51	0.95	0.14
	Bacia 6	906.2	**20**	**2**	5	57	29	**1.9**	13.2	**0.6**	5	45	0.95	0.14
	Rio Benedito	831.0	**20**	**2**	5	74	37	**1.9**	15.3	**0.6**	5	42	0.95	0.14
	Rio dos Cedros	600.3	**20**	**2**	5	70	35	**1.9**	14.8	**0.6**	5	30	0.95	0.14
	Bacia 7	556.3	**20**	**2**	5	34	17	**1.9**	9.6	**0.6**	5	28	0.95	0.14
	Bacia 8	646.3	**20**	**2**	5	27	14	**1.9**	8.5	**0.6**	5	32	0.95	0.14
	Bacia 9	349.2	**20**	**2**	5	20	10	**1.9**	7.0	**0.6**	5	17	0.95	0.14
	Bacia 10	226.7	**20**	**2**	5	20	10	**1.9**	7.0	**0.6**	5	11	0.95	0.14
	Luis Alves	580.0	**20**	**2**	5	81	40	**1.9**	16.1	**0.6**	5	29	0.95	0.14
	Itajaí Mirim	1.206.6	**20**	**2**	5	133	67	**1.9**	21.8	**0.6**	5	60	0.95	0.14
	Bacia 11	472.3	**20**	**2**	5	57	29	**1.9**	13.2	**0.6**	5	24	0.95	0.14
	Bacia 12	175.7	**20**	**2**	5	30	15	**1.9**	8.9	**0.6**	5	9	0.95	0.14

*** A perda inicial deve ser entorno de 0,5 a 1,5 polegadas, confome tabela 3.5.7, então iremos ajustar dentro da faixa a esquerda durante a calibração**

**** A perda deve ser entre 0.0 e 0.3 polegada (0.0～7.6mm）, conforme tabela 3.5.8, então iremos ajustar dentro da faixa a esquerda durante a calibração.**

***** Ct normalmente é entorno de 1.8～2.0, então iremos calibrar dentro dessa faixa.**

****** Cp normalmente é entorno de 0.4～0.8, então iremos calibrar dentro dessa faixa.**

******* Na calibração, a vazão básica inicial será utilizado o valor de medição real.**

Source: JICA Survey Team

Table 7.4.8 Results of the Constant Calibration of the Basin Model (1984 Flood Event)

Tipo	Nome	Área de Drenagem	perda			Transformação					Vazão básica			
			Perda Inicial*	**Taxa Constante****	Impermea-bilidade	L	Lc	**Parâmetro Ct*****	Standard Lag	**Peaking Coefficient Cp******	Descarga inicial específico*****	Descarga Inicial	Recessão constante	Pico de recessão (Ratio to peak)
		km^2	**mm**	**mm/h**	%	km	km	-	hr	-	$m^3/s/100km^2$	m^3/s	-	-
Sub-bacia	Barragem Oeste	1.042.0	**20**	**2.1**	5	55	28	**1.9**	12.9	**0.6**	5	52	0.95	0.14
	Bacia 1	528.1	**20**	**2.1**	5	40	15	**1.9**	9.7	**0.6**	5	26	0.95	0.14
	Bacia 2	1.444.8	**20**	**2.1**	5	68	34	**1.9**	14.6	**0.6**	5	72	0.95	0.14
	Barragem Sul	1.273.0	**20**	**2.1**	5	62	31	**1.9**	13.8	**0.6**	5	64	0.95	0.14
	Bacia 3	372.0	**20**	**2.1**	5	25	13	**1.9**	8.1	**0.6**	5	19	0.95	0.14
	Bacia 4	381.3	**20**	**2.1**	5	25	13	**1.9**	8.1	**0.6**	5	19	0.95	0.14
	Barragem Norte	2.318.0	**20**	**1.0**	5	102	51	**1.9**	18.6	**0.6**	5	116	0.95	0.14
	Bacia 5	1.023.0	**20**	**1.0**	5	44	22	**1.9**	11.2	**0.6**	5	51	0.95	0.14
	Bacia 6	906.2	**20**	**2.1**	5	57	29	**1.9**	13.2	**0.6**	5	45	0.95	0.14
	Rio Benedito	831.0	**20**	**1.2**	5	74	37	**2.0**	16.1	**0.63**	5	42	0.95	0.14
	Rio dos Cedros	600.3	**20**	**1.2**	5	70	35	**2.0**	15.6	**0.63**	5	30	0.95	0.14
	Bacia 7	556.3	**20**	**2.1**	5	34	17	**1.9**	9.6	**0.6**	5	28	0.95	0.14
	Bacia 8	646.3	**20**	**2.1**	5	27	14	**1.9**	8.5	**0.6**	5	32	0.95	0.14
	Bacia 9	349.2	**20**	**2.1**	5	20	10	**1.9**	7.0	**0.6**	5	17	0.95	0.14
	Bacia 10	226.7	**20**	**2.1**	5	20	10	**1.9**	7.0	**0.6**	5	11	0.95	0.14
	Luis Alves	580.0	**20**	**2.1**	5	81	40	**1.9**	16.1	**0.6**	5	29	0.95	0.14
	Itajaí Mirim	1.206.6	**20**	**2.1**	5	133	67	**1.8**	20.7	**0.57**	5	60	0.95	0.14
	Bacia 11	472.3	**20**	**2.1**	5	57	29	**1.8**	12.5	**0.57**	5	24	0.95	0.14
	Bacia 12	175.7	**20**	**2.1**	5	30	15	**1.9**	8.9	**0.6**	5	9	0.95	0.14

: Modificação de imput inicial

Source: JICA Survey Team

Table 7.4.9 Results of the Constant Calibration of the Basin Model (April, 21th to 24th, 2010)

Tipo	Nome	Área de Drenagem	perda			Transformação					Vazão básica			
			Perda Inicial*	**Taxa Constante****	Impermea-bilidade	L	Lc	**Parâmetro Ct*****	Standard Lag	**Peaking Coefficient Cp******	Descarga inicial específico*****	Descarga Inicial	Recessão constante	Pico de recessão (Ratio to peak)
		km^2	**mm**	**mm/h**	%	km	km	-	hr	-	m^3/s/100km^2	m^3/s	-	-
Sub-bacia	Barragem Oeste	1.042.0	**38**	**6.7**	5	55	28	**1.9**	12.9	**0.6**	**0.5**	5	0.95	0.14
	Bacia 1	528.1	**38**	**6.7**	5	40	15	**1.9**	9.7	**0.6**	**0.5**	3	0.95	0.14
	Bacia 2	1.444.8	**38**	**6.7**	5	68	34	**1.9**	14.6	**0.6**	**0.5**	7	0.95	0.14
	Barragem Sul	1.273.0	**38**	**6.7**	5	62	31	**1.9**	13.8	**0.6**	**0.5**	6	0.95	0.14
	Bacia 3	372.0	**38**	**6.7**	5	25	13	**1.9**	8.1	**0.6**	**0.5**	2	0.95	0.14
	Bacia 4	381.3	**38**	**6.7**	5	25	13	**1.9**	8.1	**0.6**	**0.5**	2	0.95	0.14
	Barragem Norte	2.318.0	**38**	**6.4**	5	102	51	**1.9**	18.6	**0.6**	**0.5**	12	0.95	0.14
	Bacia 5	1.023.0	**38**	**6.4**	5	44	22	**1.9**	11.2	**0.6**	**0.5**	5	0.95	0.14
	Bacia 6	906.2	**38**	**6.7**	5	57	29	**1.9**	13.2	**0.6**	**0.5**	5	0.95	0.14
	Rio Benedito	831.0	**38**	**6.4**	5	74	37	**2.0**	16.1	**0.63**	**0.5**	4	0.95	0.14
	Rio dos Cedros	600.3	**38**	**6.4**	5	70	35	**2.0**	15.6	**0.63**	**0.5**	3	0.95	0.14
	Bacia 7	556.3	**38**	**6.7**	5	34	17	**1.9**	9.6	**0.6**	**0.5**	3	0.95	0.14
	Bacia 8	646.3	**38**	**6.7**	5	27	14	**1.9**	8.5	**0.6**	**0.5**	3	0.95	0.14
	Bacia 9	349.2	**38**	**6.7**	5	20	10	**1.9**	7.0	**0.6**	**0.5**	2	0.95	0.14
	Bacia 10	226.7	**38**	**6.7**	5	20	10	**1.9**	7.0	**0.6**	**0.5**	1	0.95	0.14
	Luis Alves	580.0	**38**	**6.7**	5	81	40	**1.9**	16.1	**0.6**	**0.5**	3	0.95	0.14
	Itajaí Mirim	1.206.6	**38**	**6.7**	5	133	67	**1.8**	20.7	**0.57**	**0.5**	6	0.95	0.14
	Bacia 11	472.3	**38**	**6.7**	5	57	29	**1.8**	12.5	**0.57**	**0.5**	2	0.95	0.14
	Bacia 12	175.7	**38**	**6.7**	5	30	15	**1.9**	8.9	**0.6**	**0.5**	1	0.95	0.14

: Modificação de Imput para enchente de 1984

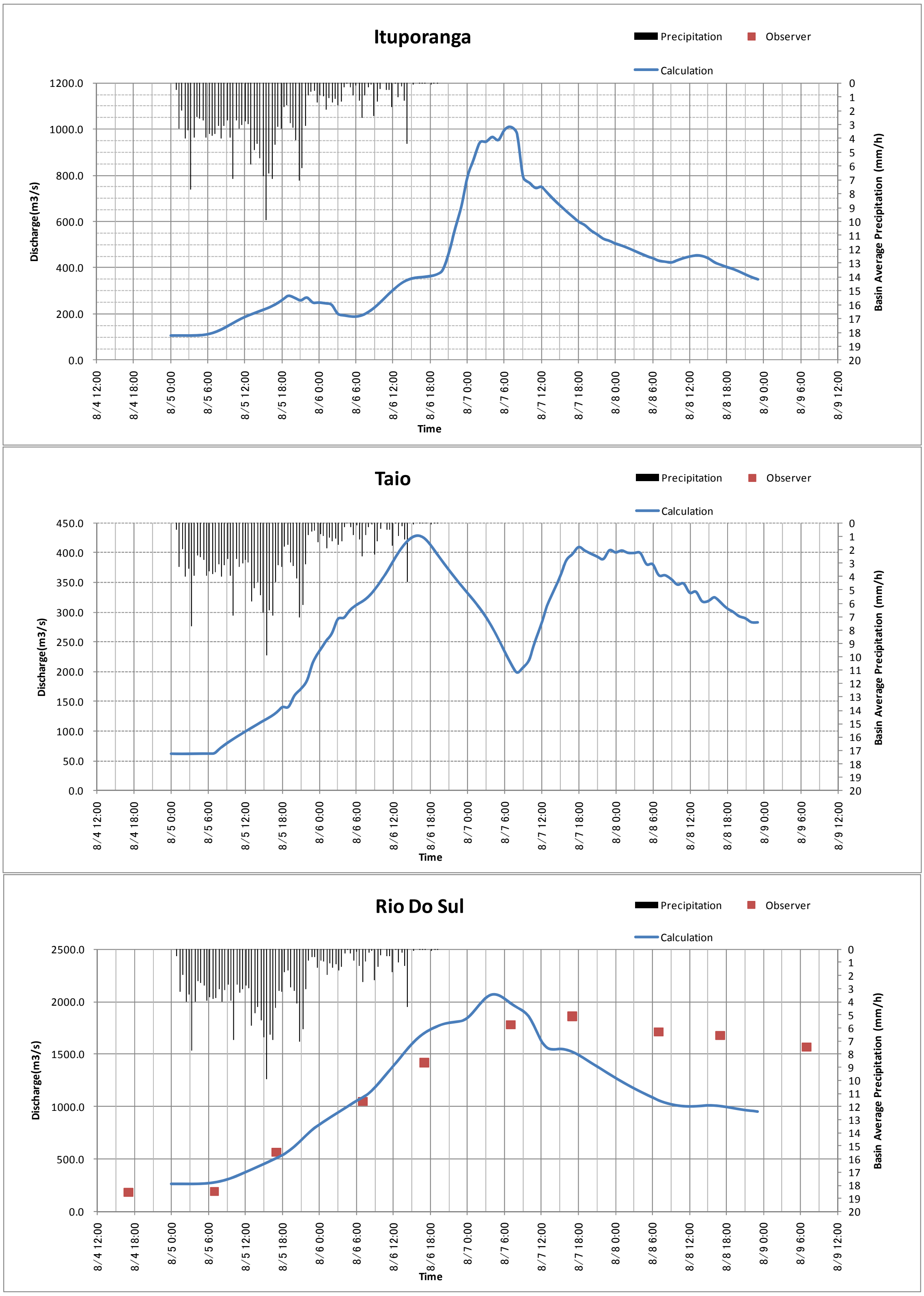
Source: JICA Survey Team

Table 7.4.10 Results of the Constant Calibration of the Basin Model (April 23th to 26th, 2010)

Tipo	Nome	Área de Drenagem	perda			Transformação					Vazão básica			
			Perda Inicial*	**Taxa Constante****	Impermea-bilidade	L	Lc	**Parâmetro Ct*****	Standard Lag	**Peaking Coefficient Cp******	Descarga inicial específico*****	Descarga Inicial	Recessão constante	Pico de recessão (Ratio to peak)
		km^2	**mm**	**mm/hr**	%	km	km	-	hr	-	m^3/s/100km^2	m^3/s	-	-
Sub-bacia	Barragem Oeste	1.042.0	**13**	**2.5**	5	55	28	**1.9**	12.9	**0.6**	**12**	125	0.95	0.14
	Bacia 1	528.1	**13**	**2.5**	5	40	15	**1.9**	9.7	**0.6**	**12**	63	0.95	0.14
	Bacia 2	1.444.8	**13**	**2.5**	5	68	34	**1.9**	14.6	**0.6**	**12**	173	0.95	0.14
	Barragem Sul	1.273.0	**13**	**2.5**	5	62	31	**1.9**	13.8	**0.6**	**12**	153	0.95	0.14
	Bacia 3	372.0	**13**	**2.0**	5	25	13	**1.9**	8.1	**0.6**	**12**	45	0.95	0.14
	Bacia 4	381.3	**13**	**2.0**	5	25	13	**1.9**	8.1	**0.6**	**12**	46	0.95	0.14
	Barragem Norte	2.318.0	**13**	**2.0**	5	102	51	**1.9**	18.6	**0.6**	**12**	278	0.95	0.14
	Bacia 5	1.023.0	**13**	**4.0**	5	44	22	**1.9**	11.2	**0.6**	**40**	409	0.95	0.14
	Bacia 6	906.2	**13**	**0.5**	5	57	29	**1.9**	13.2	**0.6**	**12**	109	0.95	0.14
	Rio Benedito	831.0	**13**	**2.3**	5	74	37	**2.0**	16.1	**0.63**	**12**	100	0.95	0.14
	Rio dos Cedros	600.3	**13**	**2.3**	5	70	35	**2.0**	15.6	**0.63**	**12**	72	0.95	0.14
	Bacia 7	556.3	**13**	**4.0**	5	34	17	**1.9**	9.6	**0.6**	**12**	67	0.95	0.14
	Bacia 8	646.3	**13**	**4.0**	5	27	14	**1.9**	8.5	**0.6**	**12**	78	0.95	0.14
	Bacia 9	349.2	**13**	**4.0**	5	20	10	**1.9**	7.0	**0.6**	**12**	42	0.95	0.14
	Bacia 10	226.7	**13**	**4.0**	5	20	10	**1.9**	7.0	**0.6**	**12**	27	0.95	0.14
	Luis Alves	580.0	**13**	**4.0**	5	81	40	**1.9**	16.1	**0.6**	**12**	70	0.95	0.14
	Itajaí Mirim	1.206.6	**13**	**4.0**	5	133	67	**1.8**	20.7	**0.57**	**12**	145	0.95	0.14
	Bacia 11	472.3	**13**	**4.0**	5	57	29	**1.8**	12.5	**0.57**	**12**	57	0.95	0.14
	Bacia 12	175.7	**13**	**4.0**	5	30	15	**1.9**	8.9	**0.6**	**12**	21	0.95	0.14

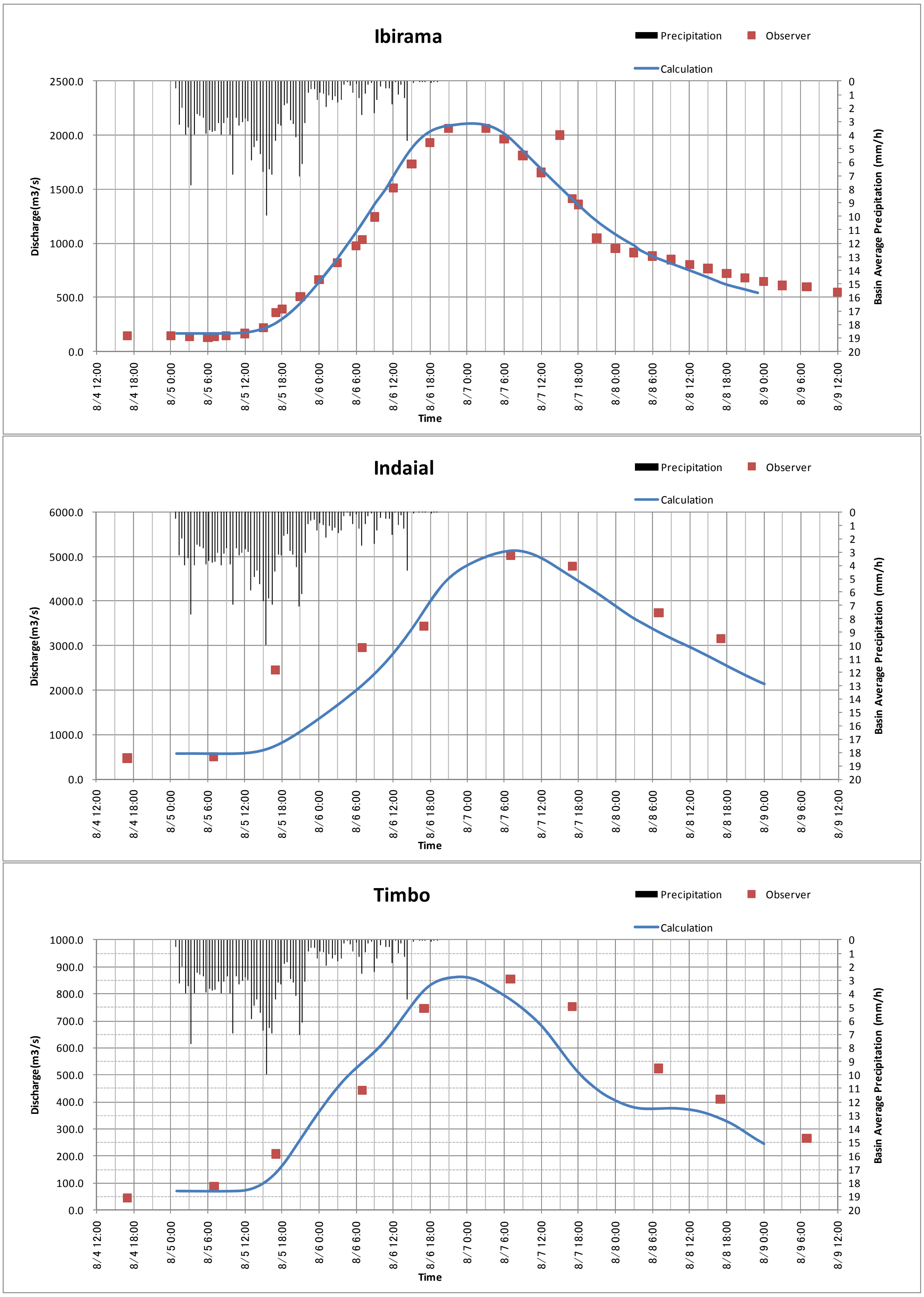
: Modificação de Imput para enchente de 1984

Source: JICA Survey Team



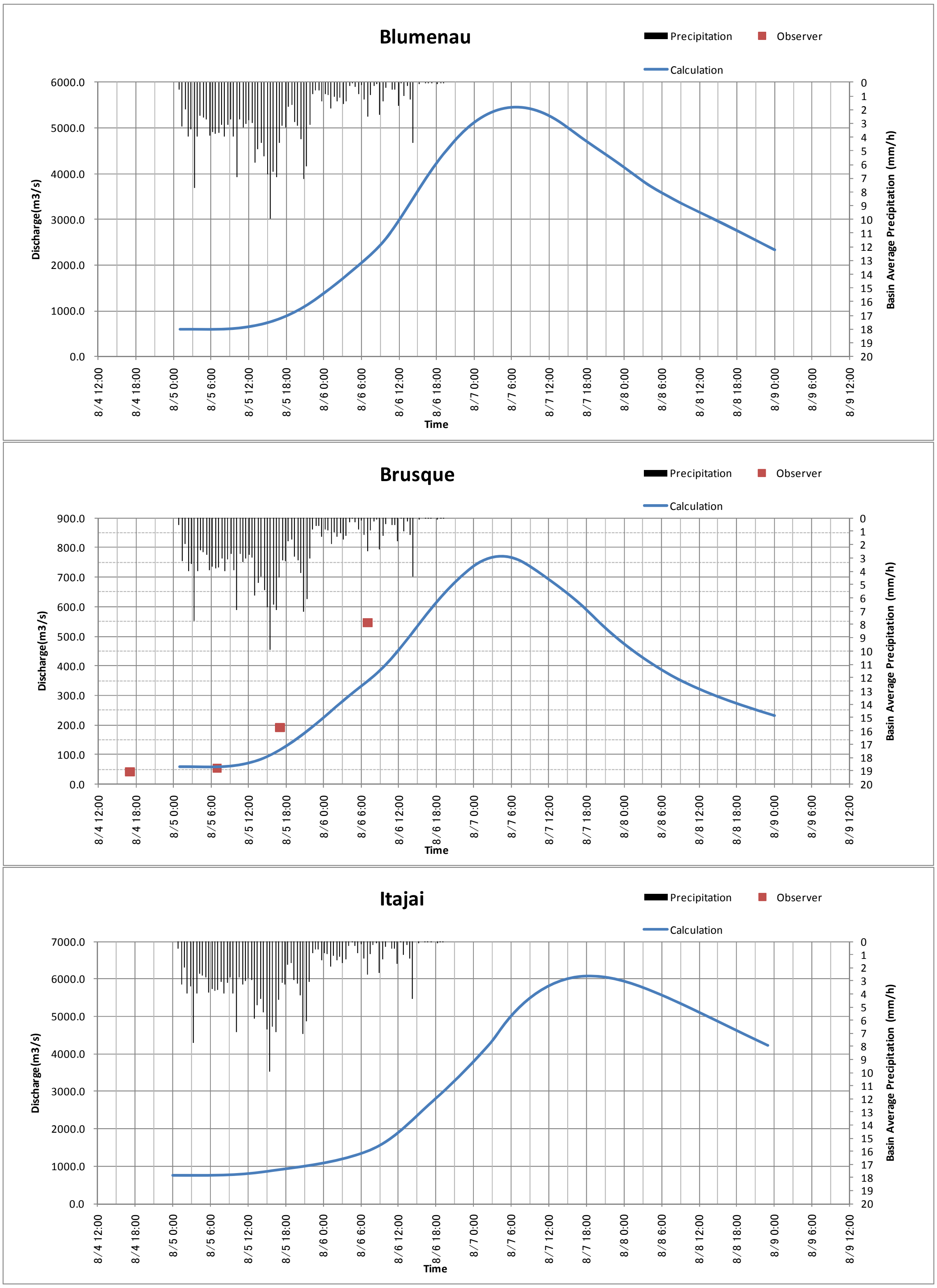
Source: JICA Survey Team

Figure 7.5.5 Results of the 1984 Flood event calibration (1/3)



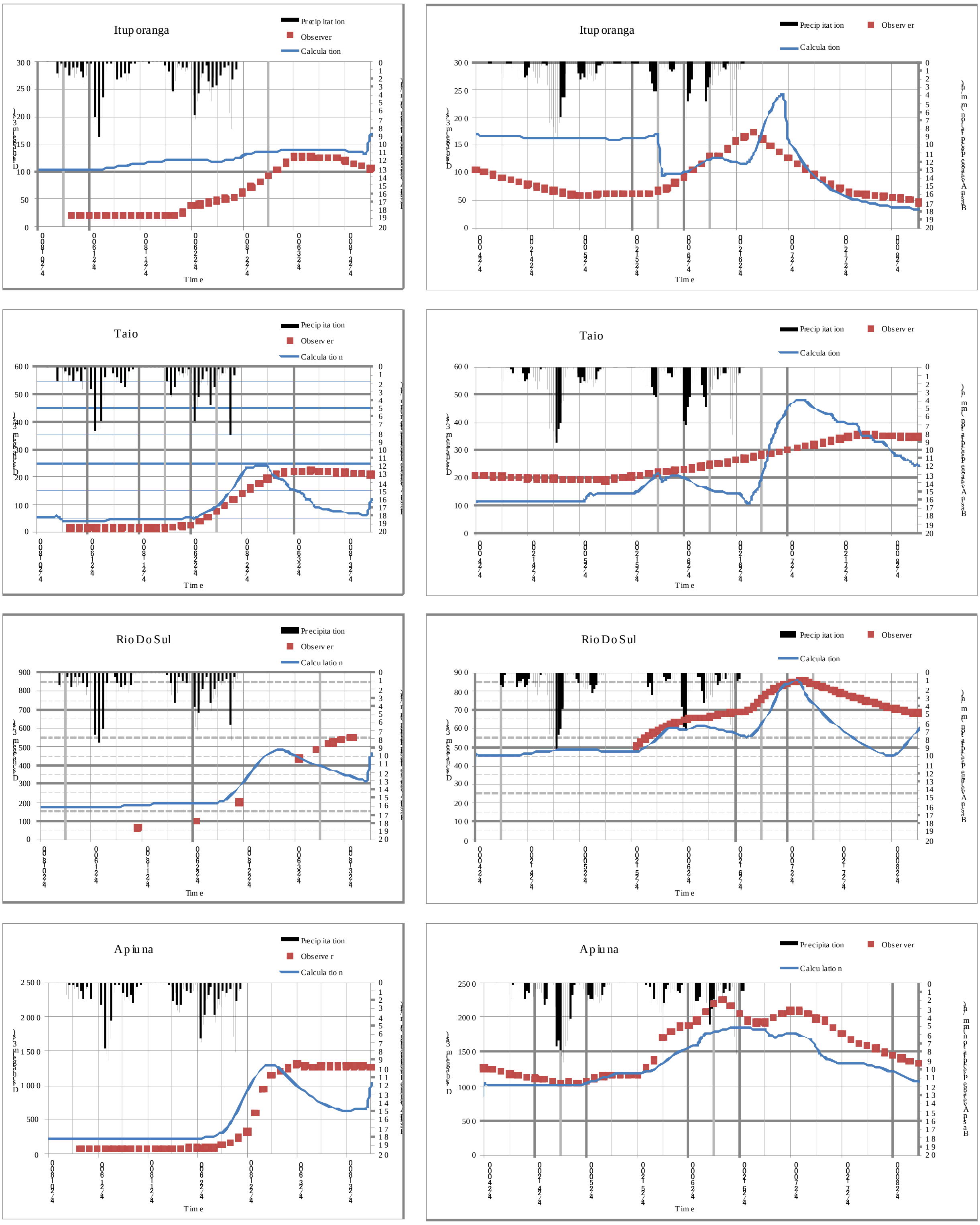
Source: JICA Survey Team

Figure 7.4.6 Results of the 1984 Flood event calibration (2/3)



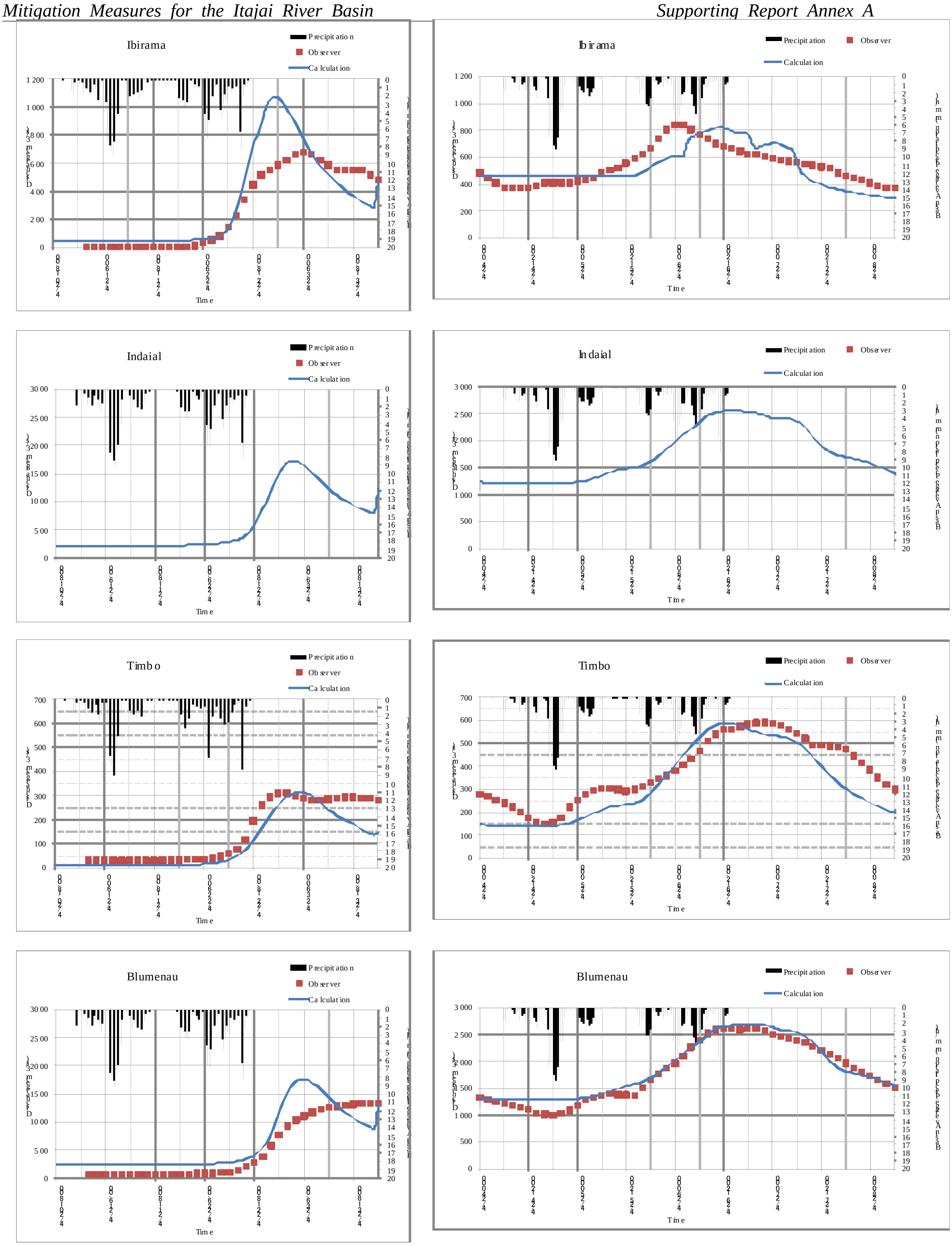
Source: JICA Survey Team

Figure 7.4.7 Results of the 1984 Flood event calibration (3/3)



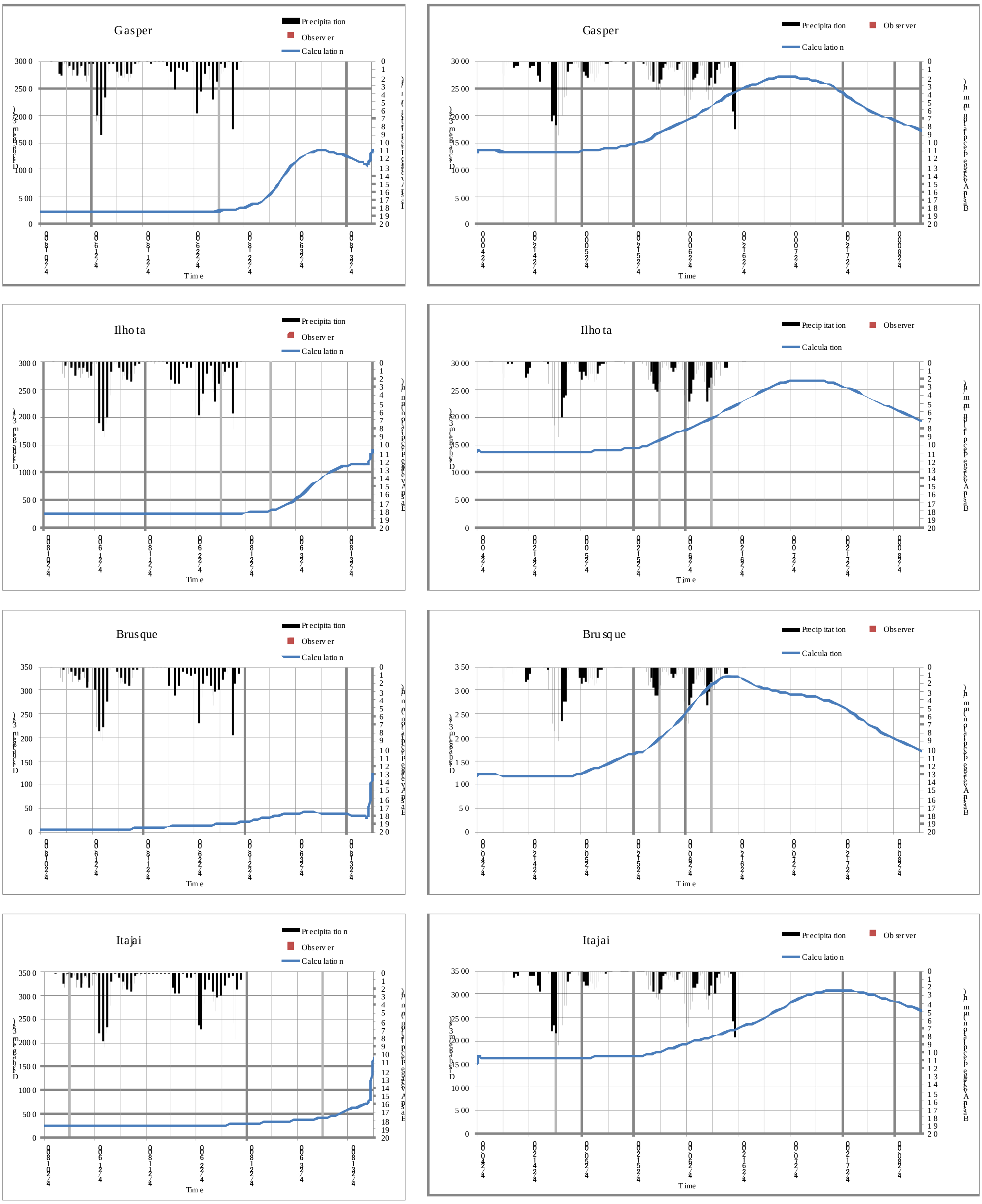
Source: JICA Survey Team

Figure 7.4.8 Results of the 2010 Flood event calibration (1/3)



Source: JICA Survey Team

Figure 7.4.9 Results of the 2010 Flood event calibration (2/3)



Source: JICA Survey Team

Figure 7.4.10 Results of the 2010 Flood event calibration (3/3)

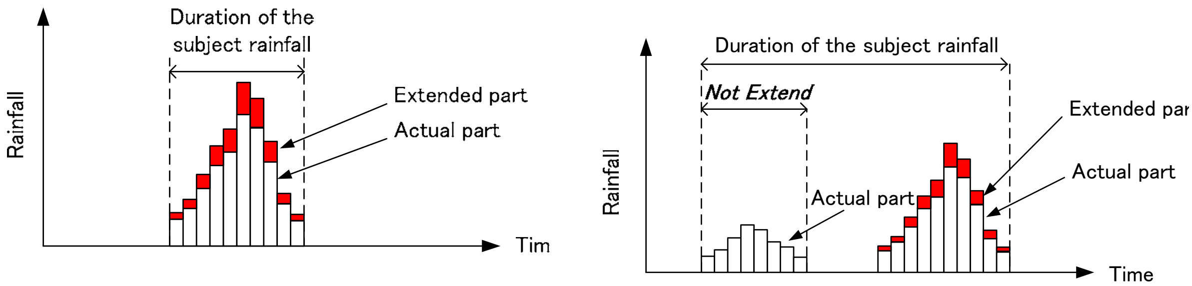
7.5 Design Discharge Resolution

The real rainfall occurs in differents standards, from region to region and according to the duration time. Even if rainfall rates are equal, if this rainfall standard are different, there will be difference in the flood discharge outflow also. Therefore, beyond the rainfall design, there is the necessity of establishing the distribution by region and time due to determine this rainfall design. Based on the past standard of flood rainfall, the standard for rainfall design should be established

Based on this kind of flood rainfall on the past, a standard of a extending (extrapolating) rainfall design should be established, also the outflow modeling (as explained in the sections at this chapter before) and the discharge design calculated for each Return Period.

7.5.1 Extending (extrapolating) Rainfall

As ilustrated in the figure bellow, four representative flood were choosen: April, 1983; May, 2005; April, 2010; and May, 2010. The extention of the rainfall was carried out due to establish the discharge rainfall design.



Source: JICA Survey Team

Figure 7.5.1 Extension of the rainfall standards

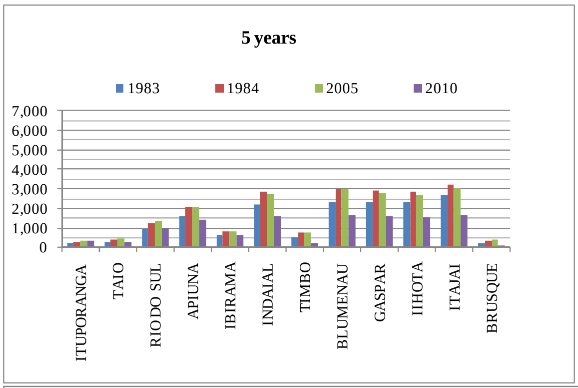
7.5.2 Calculation Methodology

The value obtained by the calibration of August, 1984 and April, 2010 will be adopted for the constant that will be used on the outflow calculation model. Based on the rainfall hyetograph for each flood, the calibration value from August, 1984 was adopted to July, 1983; 08/1984 and May, 2005; and the rainfall from the posterior phase from April, 2010 to April, 2010. Besides that, it was considered that all the gates of the three contention dams were opened.

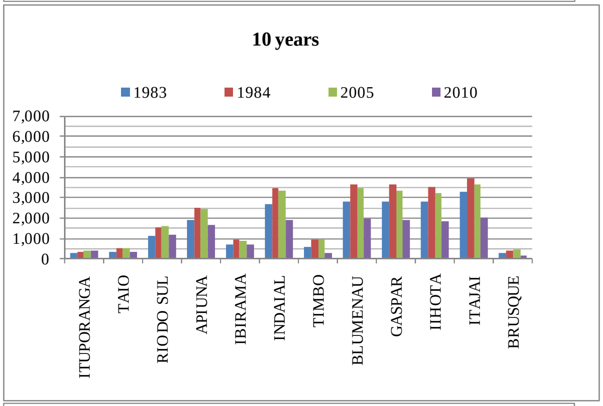
7.5.3 Calculation Results

The results of each rainfall design calculation are illustrated in the Figure 7.5.2 bellow.

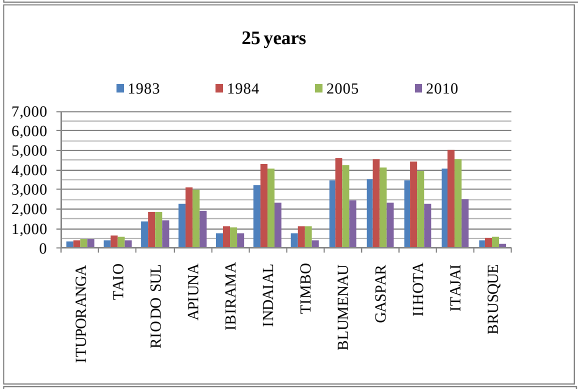
5 years					
ID	Cities / Towns	1983	1984	2005	2010
1	ITUPORANGA	250	310	370	350
2	TAIO	280	430	440	300
3	RIO DO SUL	930	1,250	1,350	1,020
4	APIUNA	1,580	2,060	2,060	1,440
5	IBIRAMA	620	840	810	650
6	INDAIAL	2,200	2,830	2,760	1,610
7	TIMBO	500	760	780	230
8	BLUMENAU	2,330	2,990	2,960	1,650
9	GASPAR	2,320	2,940	2,820	1,590
10	IIHOTA	2,310	2,840	2,700	1,560
11	ITAJAI	2,680	3,210	3,020	1,680
12	BRUSQUE	250	350	380	130



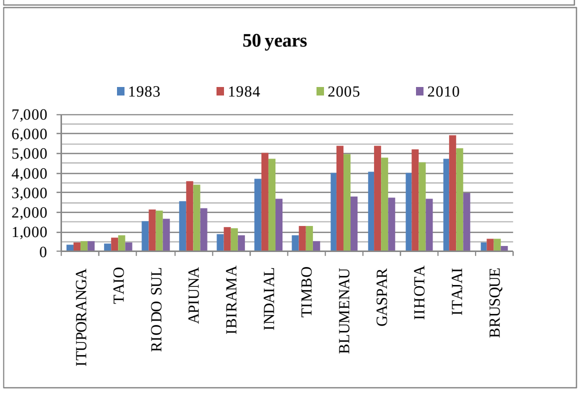
10 years					
ID	Cities / Towns	1983	1984	2005	2010
1	ITUPORANGA	290	370	420	410
2	TAIO	330	520	510	350
3	RIO DO SUL	1,110	1,520	1,580	1,200
4	APIUNA	1,890	2,510	2,450	1,650
5	IBIRAMA	700	970	910	710
6	INDAIAL	2,660	3,470	3,320	1,900
7	TIMBO	610	920	940	290
8	BLUMENAU	2,830	3,670	3,490	1,970
9	GASPAR	2,830	3,630	3,370	1,890
10	IIHOTA	2,810	3,500	3,230	1,830
11	ITAJAI	3,280	3,960	3,660	2,000
12	BRUSQUE	310	430	470	150



25 years					
ID	Cities / Towns	1983	1984	2005	2010
1	ITUPORANGA	330	430	490	470
2	TAIO	380	620	600	400
3	RIO DO SUL	1,340	1,860	1,870	1,450
4	APIUNA	2,280	3,100	2,960	1,920
5	IBIRAMA	790	1,120	1,040	770
6	INDAIAL	3,230	4,300	4,080	2,320
7	TIMBO	740	1,120	1,140	390
8	BLUMENAU	3,480	4,600	4,270	2,420
9	GASPAR	3,510	4,570	4,130	2,340
10	IIHOTA	3,470	4,400	3,930	2,270
11	ITAJAI	4,090	5,000	4,530	2,510
12	BRUSQUE	380	540	580	220



50 years					
ID	Cities / Towns	1983	1984	2005	2010
1	ITUPORANGA	370	490	550	520
2	TAIO	430	710	810	450
3	RIO DO SUL	1,530	2,150	2,110	1,680
4	APIUNA	2,580	3,590	3,380	2,180
5	IBIRAMA	870	1,250	1,170	830
6	INDAIAL	3,680	5,020	4,710	2,680
7	TIMBO	840	1,280	1,300	500
8	BLUMENAU	3,990	5,410	4,960	2,820
9	GASPAR	4,060	5,380	4,780	2,750
10	IIHOTA	4,010	5,200	4,550	2,660
11	ITAJAI	4,750	5,930	5,240	2,970
12	BRUSQUE	450	630	660	270



Source: JICA Survey Team

Figure 7.5.2 Probable flood discharge in each main city for their respective floods

7.5.4 Design Discharge Estimate Results for Each Return Period

The flood discharge from April, 1984 was selected based on the probable flood discharge calculated. This selection takes into consideration its larger values (in general terms), as flood discharge for the design purpose (safety margin) . The probable flood discharge for each reference place is illustrated in the Table 7.5.3 bellow.

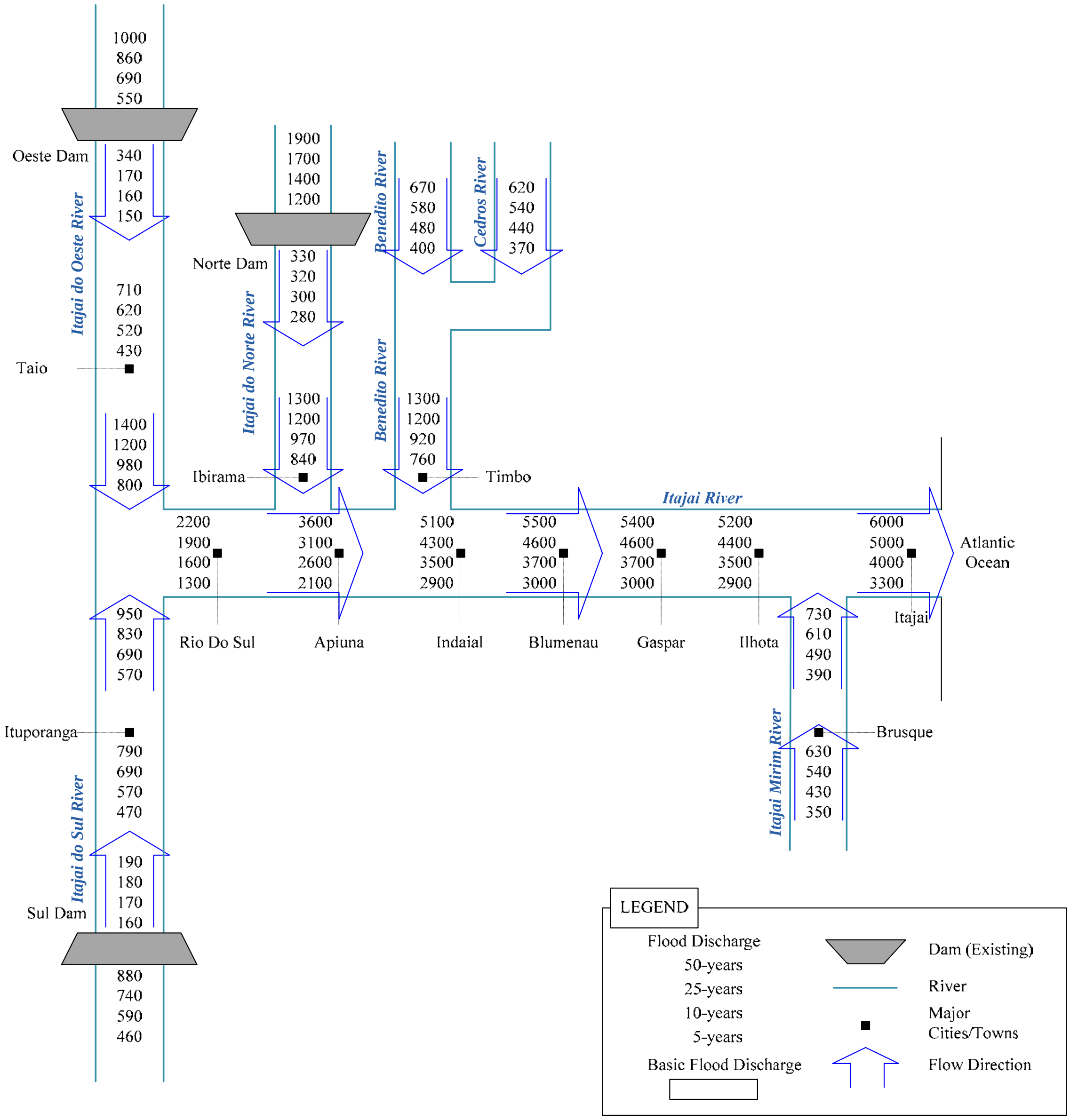


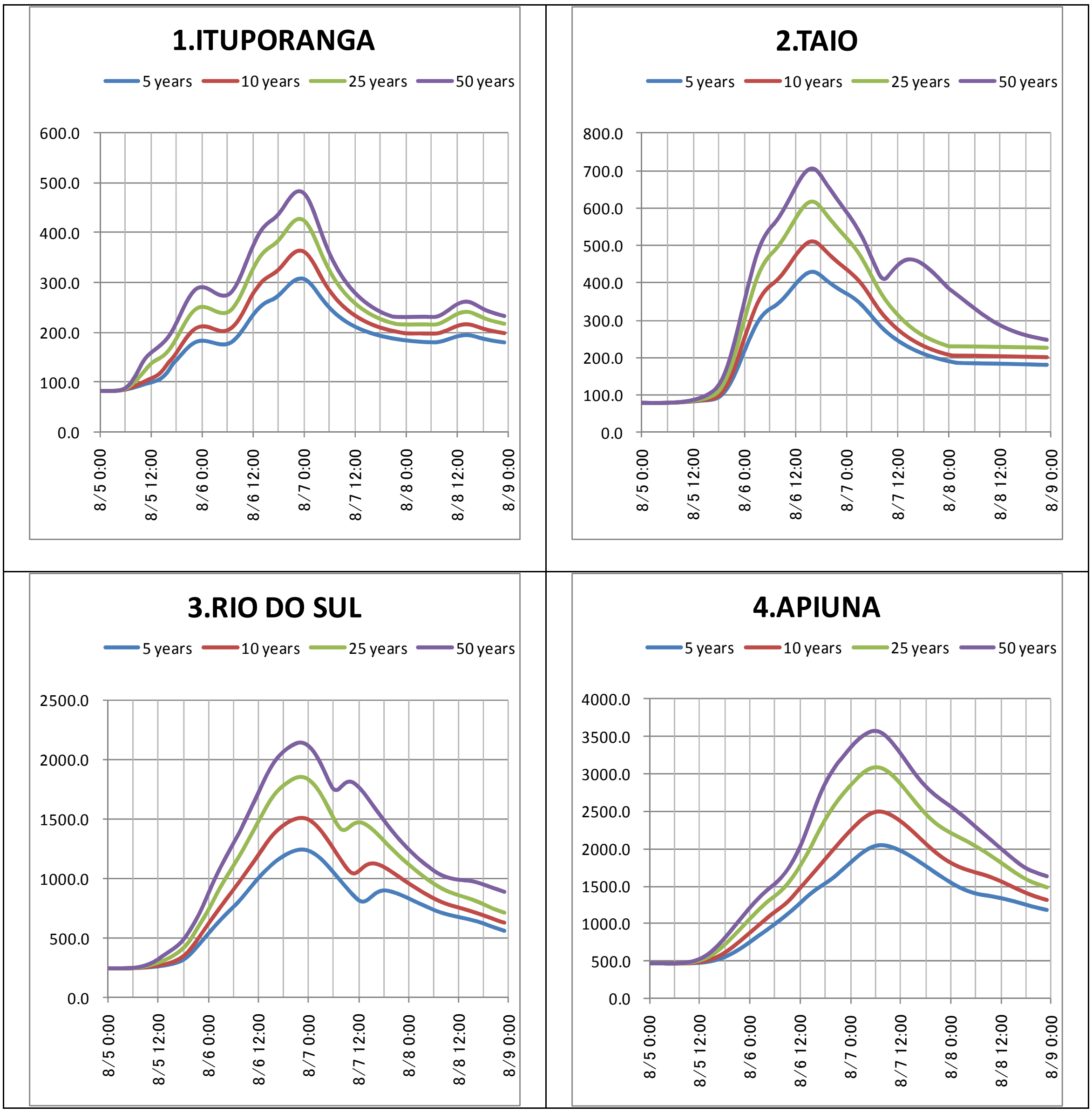
Figure 7.5.3 Flood discharge from each reference place

The arriving flood peak time calculated is illustrated in the Table 7.5.1. The difference of peak time between Rio do Sul and Blumenau city is from 7 to 10 hours; between Blumenau and Itajaí is from 14 to 17 hours. After 1 flood peak day in Rio do Sul the flood peak occurs in Itajaí. The design flood hydrograph for each city (reference place) is illustrated in the Figure 7.5.4.

Table 7.5.1 Largest Discharge Peak Time from each City, by Return Period

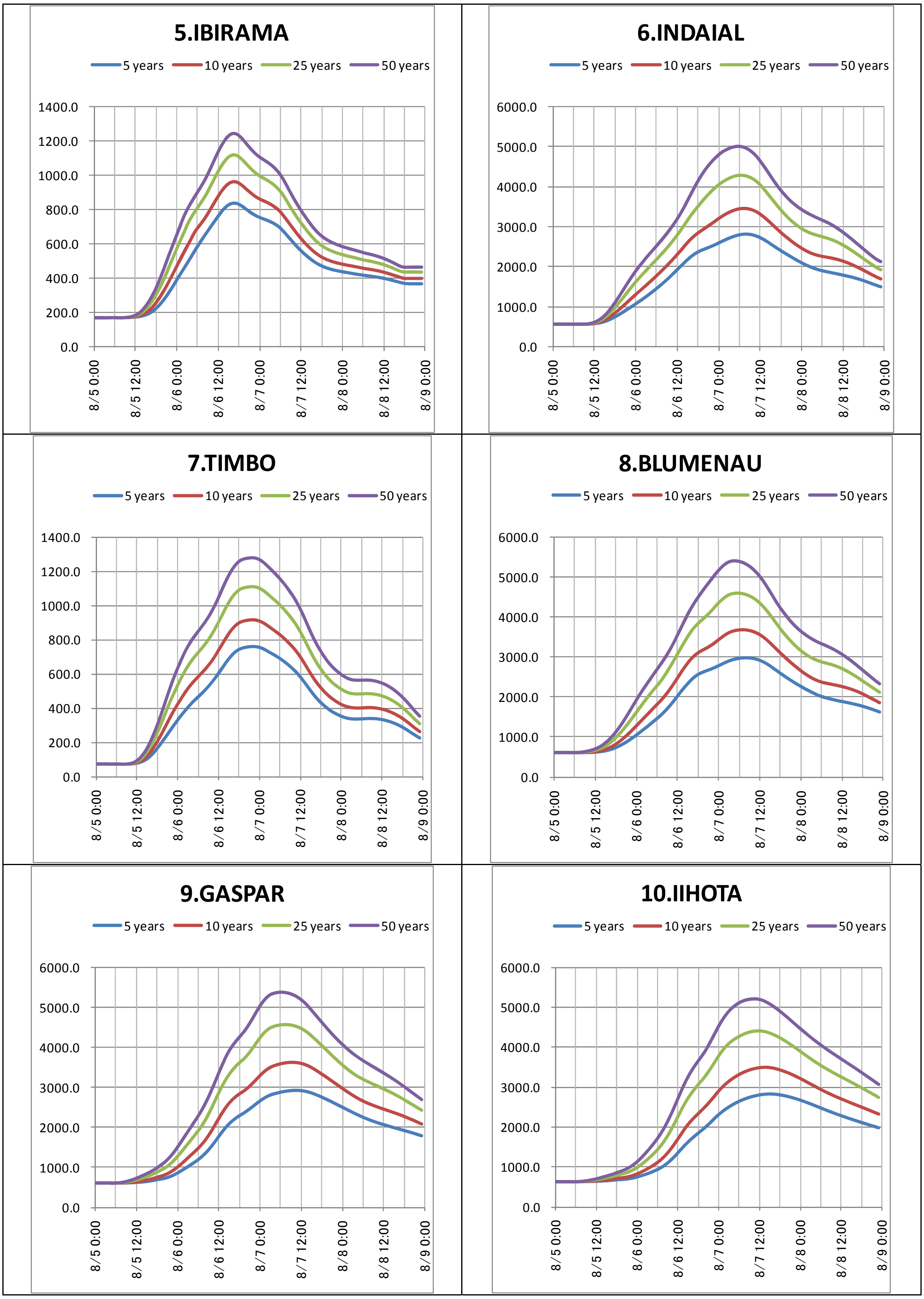
	Citys and Towns	Catchment Area km2	5 years		10 years		25 years		50 years	
			Discharge (m3/s)	Peak	Discharge (m3/s)	Peak	Discharge (m3/s)	Peak	Discharge (m3/s)	Peak
1	ITUPORANGA	1,645	310	08/06 23:00	370	08/06 23:00	430	08/06 23:00	490	08/06 23:00
2	TAIO	1,570	430	08/06 16:00	520	08/06 16:00	620	08/06 16:00	710	08/06 16:00
3	RIO DO SUL	5,041	1,300	08/06 22:00	1,600	08/06 22:00	1,900	08/06 22:00	2,200	08/06 22:00
4	APIUNA	9,288	2,100	08/07 07:00	2,600	08/07 07:00	3,100	08/07 06:00	3,600	08/07 06:00
5	IBIRAMA	3,341	840	08/06 17:00	970	08/06 17:00	1,200	08/06 17:00	1,300	08/06 17:00
6	INDAIAL	11,275	2,900	08/07 08:00	3,500	08/07 07:00	4,300	08/07 06:00	5,100	08/07 06:00
7	TIMBO	1,430	760	08/06 22:00	920	08/06 22:00	1,200	08/06 22:00	1,300	08/06 22:00
8	BLUMENAU	11,921	3,000	08/07 08:00	3,700	08/07 07:00	4,600	08/07 05:00	5,500	08/07 05:00
9	GASPAR	12,421	3,000	08/07 10:00	3,700	08/07 09:00	4,600	08/07 07:00	5,400	08/07 06:00
10	IIHOTA	12,673	2,900	08/07 15:00	3,500	08/07 13:00	4,400	08/07 12:00	5,200	08/07 10:00
11	ITAJAI	15,092	3,300	08/08 01:00	4,000	08/07 22:00	5,000	08/07 19:00	6,000	08/07 17:00
12	BRUSQUE	1,207	350	08/07 04:00	430	08/07 04:00	540	08/07 04:00	630	08/07 03:00

Source: JICA Survey Team



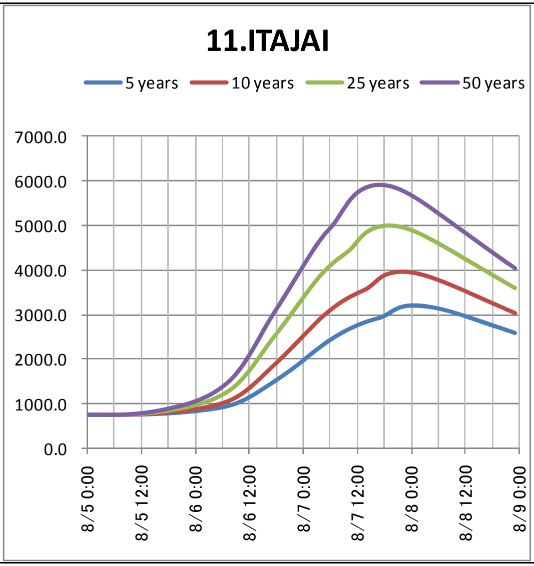
Source: JICA Survey Team

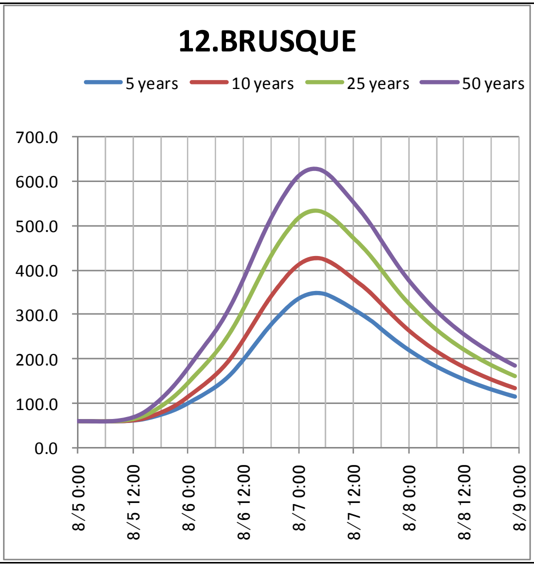
Figura 7.5.4 Design Flood Hydrograph for each reference place (1/2)



Source: JICA Survey Team

Figure 7.5.4 Design Flood Hydrograph for each reference place (2/3)





Source: JICA Survey Team

Figure 7.5.4 Design Flood Hydrograph for each reference place (3/3)

7.5.5 Flood Contention Dam Discharge Adjustments

The Figures 7.5.5 to 7.5.8 show the way that each dam works for each Return Period. In the table bellow, the effect of the flood control for each dam is orderly exposed.

Table 7.5.2 Influx and Discharge of each Dam per Return Period

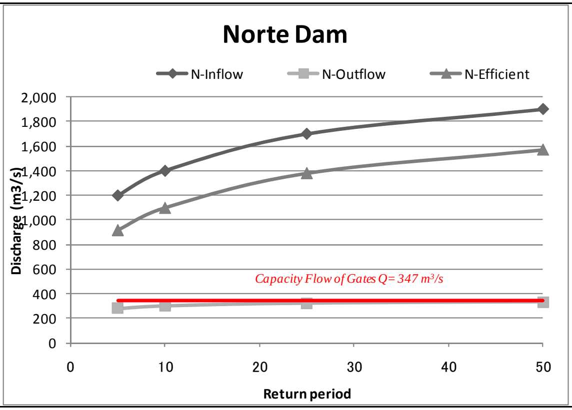
Unit：m^3/sec

Returen Period	Norte Dam			Oeste Dam			Sul Dam		
	N-Inflow	N-Outflow	N-Regulation	O-Inflow	O-Outflow	O-Regulation	S-Inflow	S-Outflow	S-Regulation
5 years	1,200	280	920	550	150	400	460	160	300
10 years	1,400	300	1,100	690	160	530	590	170	420
25 years	1,700	320	1,380	860	170	690	740	180	560
50 years	1,900	330	1,570	1,000	340	660	880	190	690

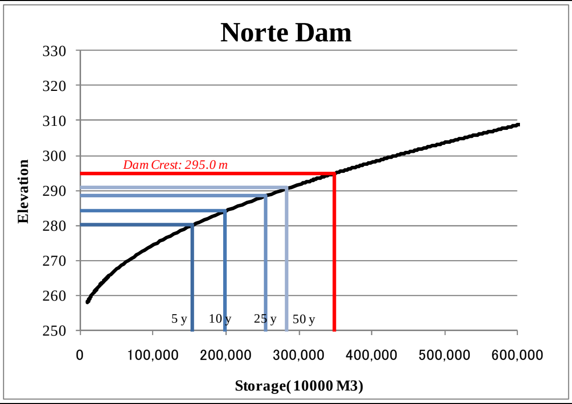
＊：Overflow situation

Source: JICA Survey Team

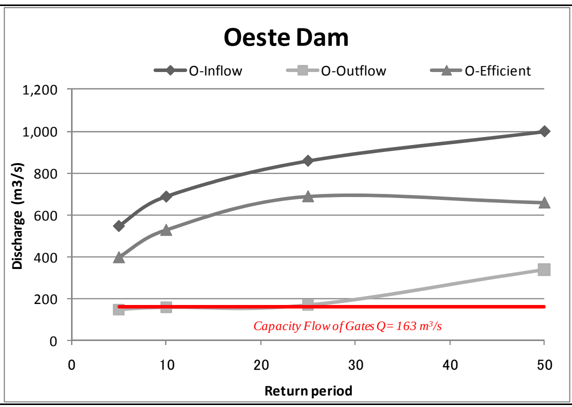
The reservoir water level in the Norte and Sul dams will not raise until achieve the spillway, even with 50 years of Return Period. So, there will not happen an overflow by the spillway. By the other side, in the Oeste dam, the reservoir will be almost full with the 25 return years flood; with 50 return years the waterlevel will exceed 0,9m higher from the spillway.



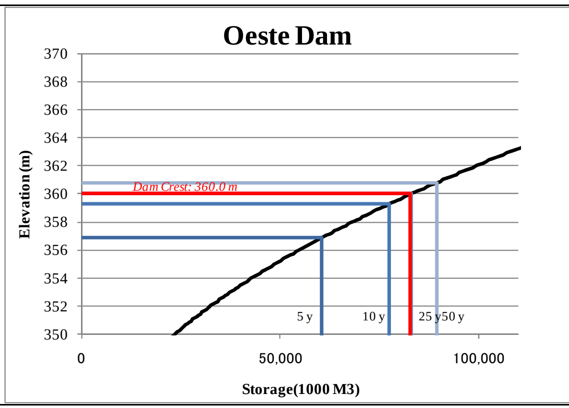
Influx, discharge, flood peak by return period



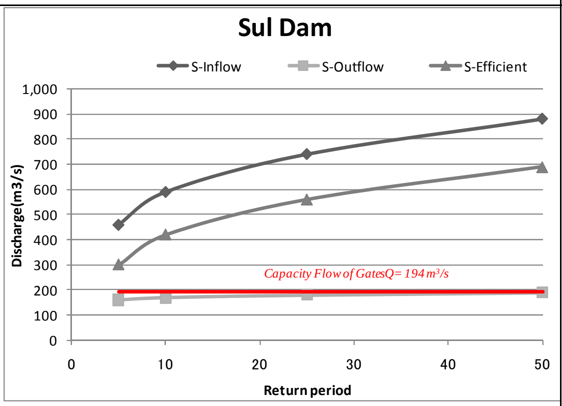
Maximum Water level of the Reservoir



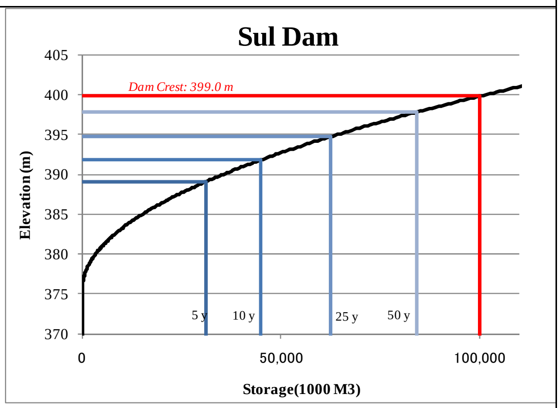
Influx, discharge, flood peak by return period



Maximum Water level of the Reservoir

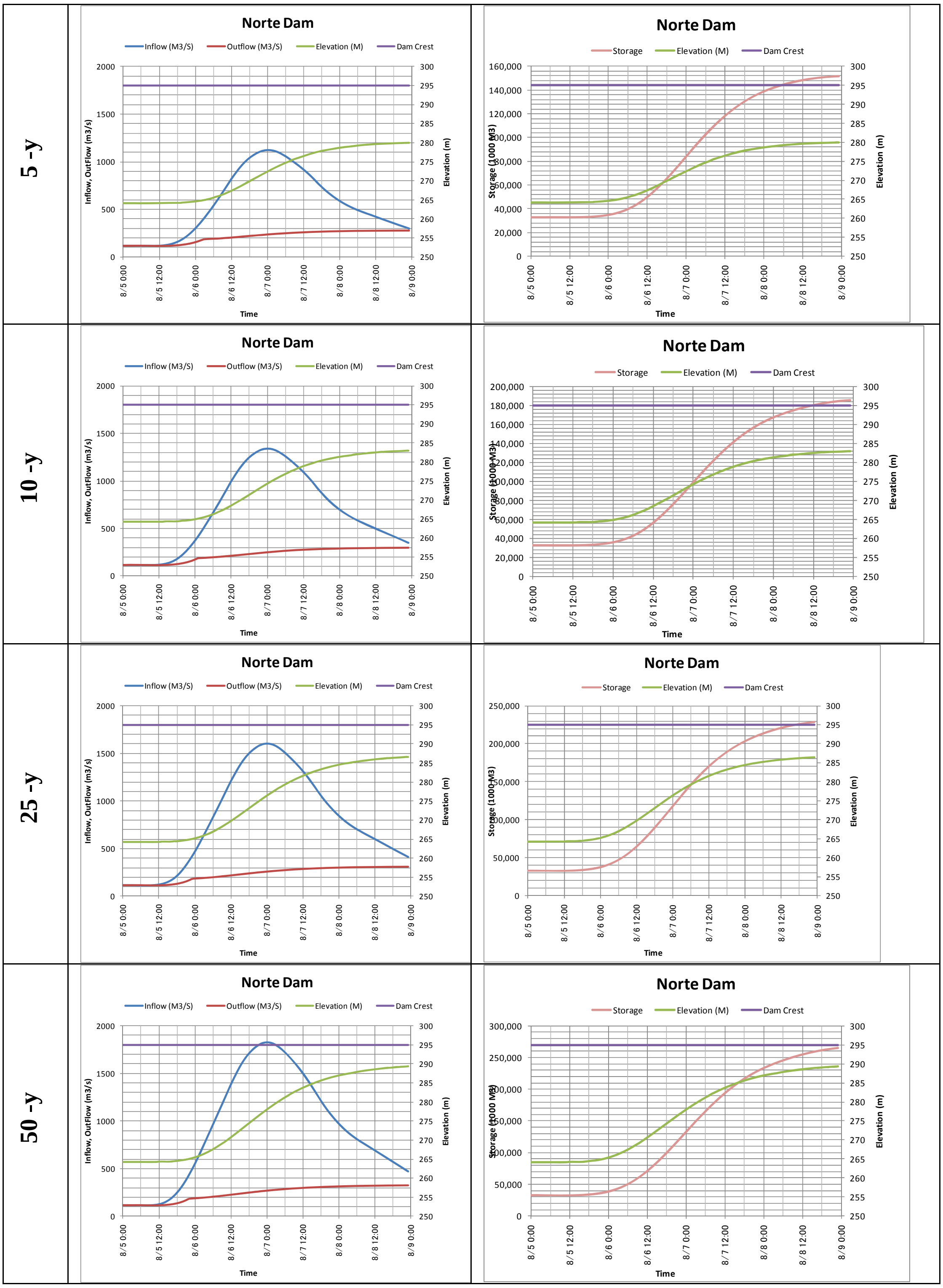


Influx, discharge, flood peak by return period



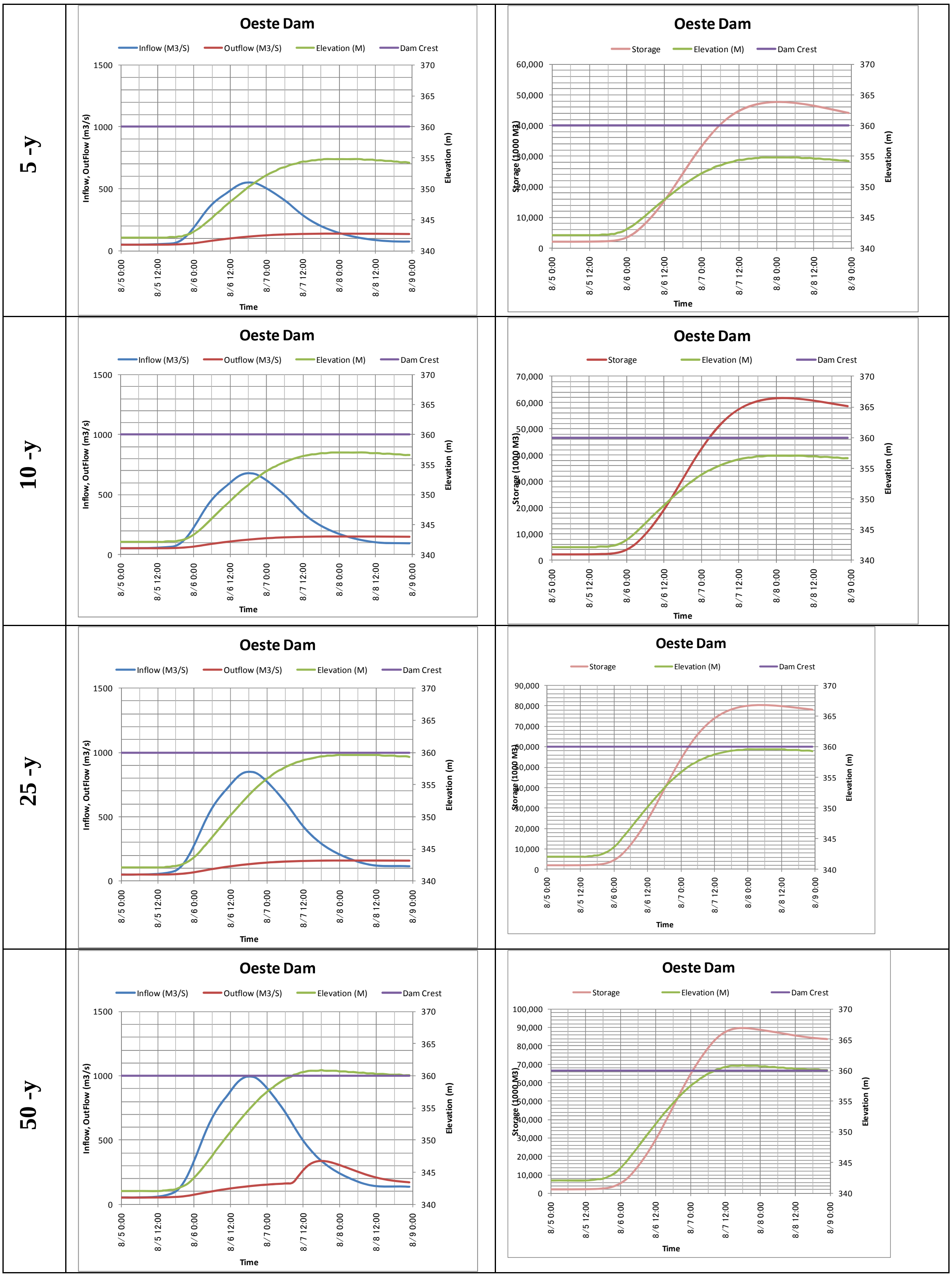
Maximum Water level of the Reservoir

Figure 7.5.5 Inflow, discharge, flood peak by Return Period, from the three dams and reservoir water level



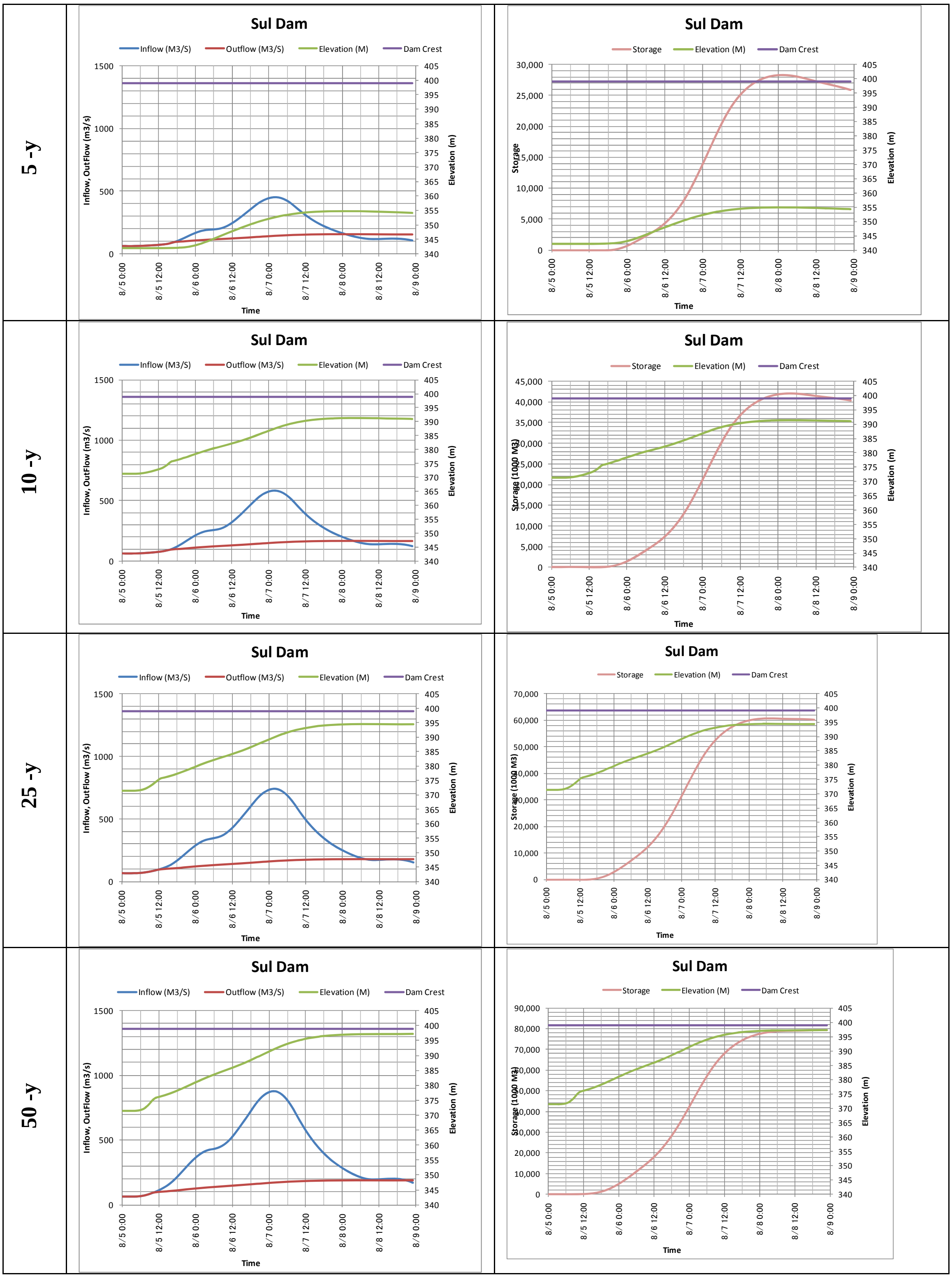
Source: JICA Survey Team

Figure 7.5.6 Norte dam: discharge and inflow hydrograph for each Return Period and water level hydrograph and reservoir capacity



Source: JICA Survey Team

Figure 7.5.7 Oeste Dam: discharge and affluence hydrograph for each Return Period and water level hydrograph and reservoir capacity



Source: JICA Survey Team

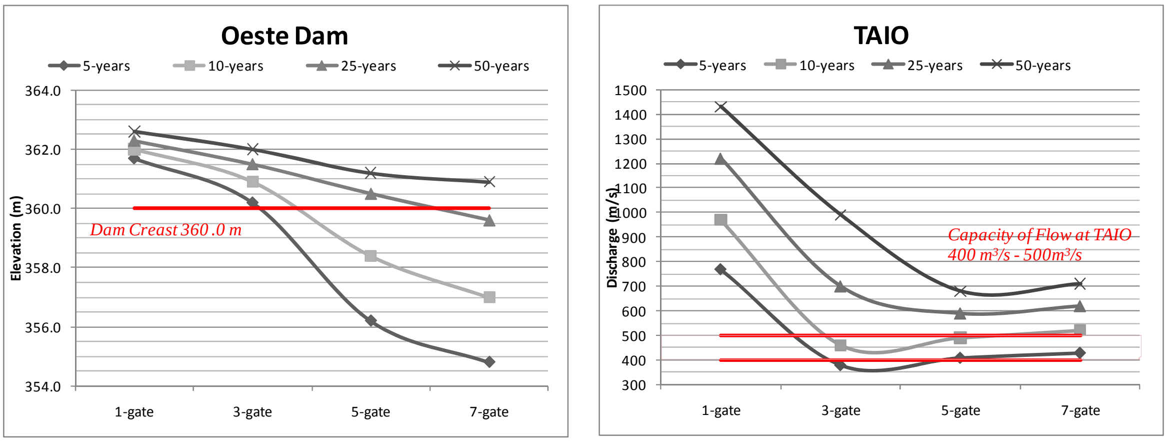
Figure 7.5.8 Sul Dam: Discharge and inflow hydrograph (for each Return Period), water level hydrograph and reservoir capacity

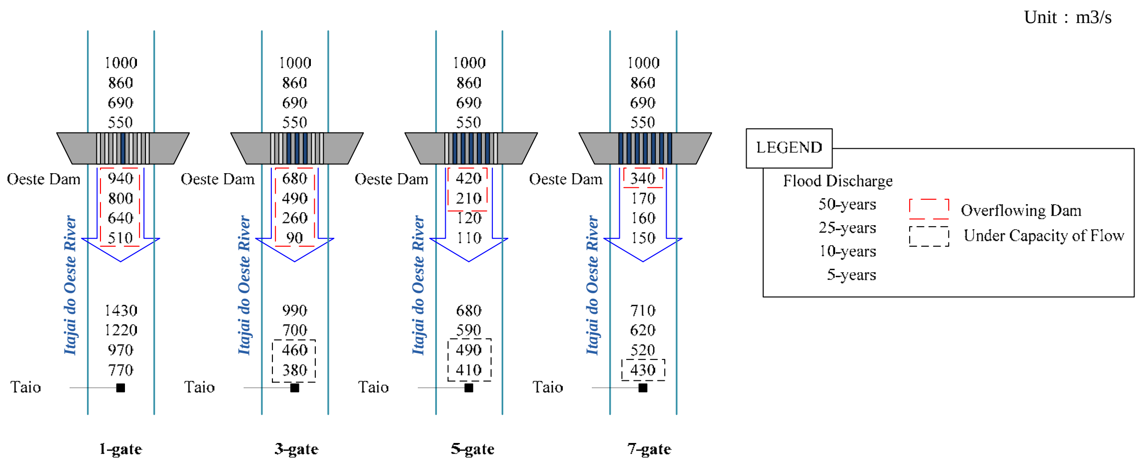
7.5.6. Oeste Dam Gate

In the 2010 Flood event occurred a overflow on the spillway, despite the flood was equivalent to 5 return years. The gates should be completely opened due to obtain the maximum flood control. The Flood event had two peaks and the gates were closed and opened separately, according to the Figure 7.4.5.

The Figure 7.5.9 shows the maximum contention level when the gates operations are working (7 gates in the ducts of adduction) in the Oeste Dam; and the Flood discharge of Taió City which is located by the downstream of the dam. The more the number of completely opened gates, the less the discharge; this causes an increase on the water level of the reservoir and makes the spillway overflow. In the Oeste dam, even if the four of the seven existing gates were closed and if 5 return years flood happen, the spillway overflow occurs.

Furthermore, the outflow capacity of the river channel near to Taió City is around 400-500 m³/sec; the discharge will overpass the outflow capacity for floods larger than 25 return years and when using seven openings gates.





Source: JICA Survey Team

Figure 7.5.9 Variation of the maximum level contention when the Oeste dam is used and relation between the flood discharge in Taió City