CHAPTER 9

RUNOFF LOADS FROM THE BASIN

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Estimation of river runoff load is fundamentally important for the selection of the priority basins which necessitate urgent measures for water quality improvement. Discharge and water quality necessary to calculate the river runoff load, however, are affected by meteorological conditions, inflow amount of domestic and industrial wastewater, current land use within the basin and many other factors. Consequently, repeated observations under different conditions are usually necessary to obtain a highly accurate annual river runoff load.

With a limited time available to come up with a highly accurate annual river runoff load, an original estimation method was developed in this study. The basic concept of this method, observation results, estimation process and the runoff feature from the basin are described in this chapter.

9.1 Outline of the River Survey

9.1.1 Observation Items

Discharge and water quality of rivers change with time and the seasons depending on the point sources and precipitation conditions. They are also largely affected by periodical fluctuations in tidal currents. Runoff discharge and runoff load is influenced to a large extent by urbanization of the basin and the utilization of the land. Thus to estimate the average discharge and water quality of a river based on survey data over certain time intervals requires a systematic qualitative and quantitative approach to measure the elements and the effects of change.

The following six kinds of observations were carried out in this survey:

(1) Regular survey on the major twenty-five (25) rivers on clear days (once a month)
(2) Hourly change (24 hours) survey on three model rivers
(3) Continuous survey on two model rivers on rainy days

(4) Detailed survey on major highly polluted rivers on clear days
(5) Analysis of rain water quality
(6) Survey of drainage canals discharging water into Jurujuba Bay on clear days

Of these, (1) mainly aims at obtaining the difference in base runoff discharge and base runoff load between the dry and rainy seasons; (2) focuses on the effect of human activities and changes in the sea level have on discharge and the water quality; and (3) on the effect on the rainfall on discharge and water quality. Based on the observation results, the river load estimate model mentioned below was established; (4) to identify tributary rivers and drainage canals with large runoff loads for highly polluted rivers; (5) grasp of rainfall load; and (6) to accurately measure the inflow load into the highly polluted Jurujuba Bay.

9.1.2 Observed Rivers and Observed frequency

In accordance with the survey objectives, target rivers and observation periods were determined as follows:

(1) Regular surveys on the 25 rivers on clear days

Discharge and water quality observations were carried out on 25 rivers, major 20 rivers in the basin and 5 major tributary rivers, nine times from May 1992 to April 1993 at the fixed points. Observation stations on the 25 rivers are shown in **Fig.9.1-1.** The area of basin covered by each observation station are shown in **Fig.9.1-2.**

(2) Hourly change (24 hours) survey on model rivers

Rio Macacu, Rio Acari and Rio s.J.de Meriti were selected as the three model rivers, see **Fig. 9.1-1.**

Rio Macacu is a natural type river. Its basin is mainly made up of grasslands and forests. The Rio Acari and Rio Sao Joao de Meriti are urban type rivers with basins consisting of urban areas.

The discharge and the water quality at the observation stations on the Rio Macacu and Rio Acari were unaffected by tidal fluctuations, while the Rio Sao Joao de Meriti observation stations were within the tidal zone. Therefore, by comparing the results obtained from these rivers, the effects of various human activities and tidal fluctuations on the water quality and runoff load can be determined. Land use conditions in the basins of the three rivers are shown in **Fig. 9.1-3**.

Further, discharge and water quality observations were carried out for 24 hours, at 2-hour intervals, twice in the Rio Macacu and Rio Acari, in the dry and rainy seasons (September 1992, April 1993), and once in the Rio S.J. de Meriti, in the dry season (December 1992).

Additional discharge and water quality observations over 24 hours were carried out once in the Rio Guapimirim in the dry season (October 1993) for reference, as the Rio Guapimirim observation stations were within tidal zone.

(3) Continuous survey carried out in two model rivers during the rainy season

The Rio Macacu and Rio Acari, whose observation stations were not influenced by tidal fluctuations, were selected as model rivers, and continuous surveys on the discharge and the water quality were carried out in their respective basins for two weeks, from November 16 to 30, 1992.

(4) Detailed observation of highly polluted rivers

Detailed surveys on the discharge and the water quality of highly polluted rivers on clear days were carried out three times at the 29 stations on the seven rivers shown in **Fig.9.1-4**, from November 1992 to April 1993.

(5) Rain water quality analysis

Water quality analysis was carried out on rain water samples taken three times in December 1992 at the 3 stations (Petrobras, UFRJ, UFF).

(6) Survey of the drainage canals discharging water into Jurujuba Bay on clear days

Discharge and water quality observations were done twice on the drainage canal, Station 14, which discharges water into Jurujuba Bay in May and June 1993 as shown in **Fig.9.1-5**.

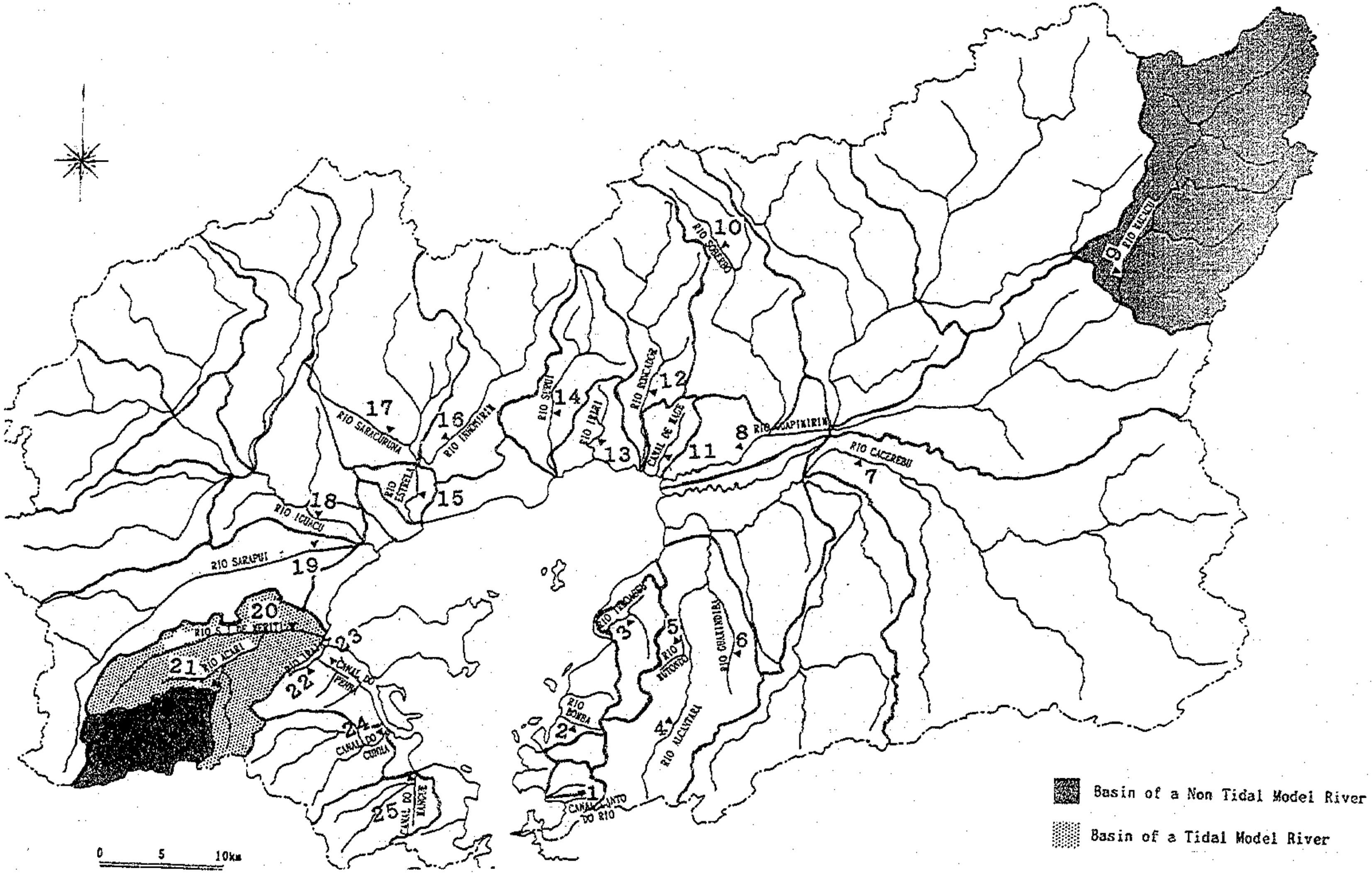


Fig. 9.1- 1 Observation Stations for the River Survey

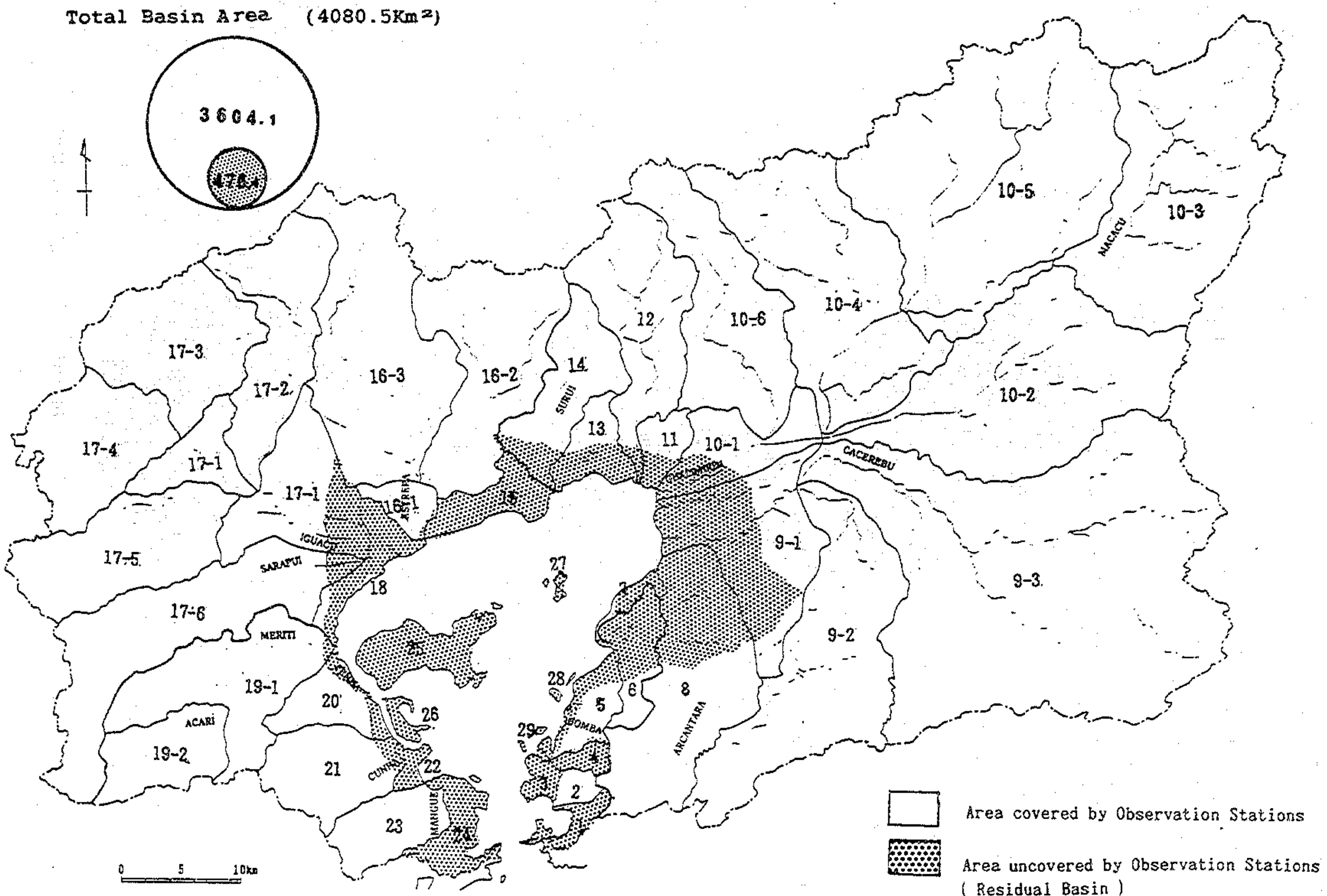


Fig. 9.1- 2 Basin Area covered by Observation Stations

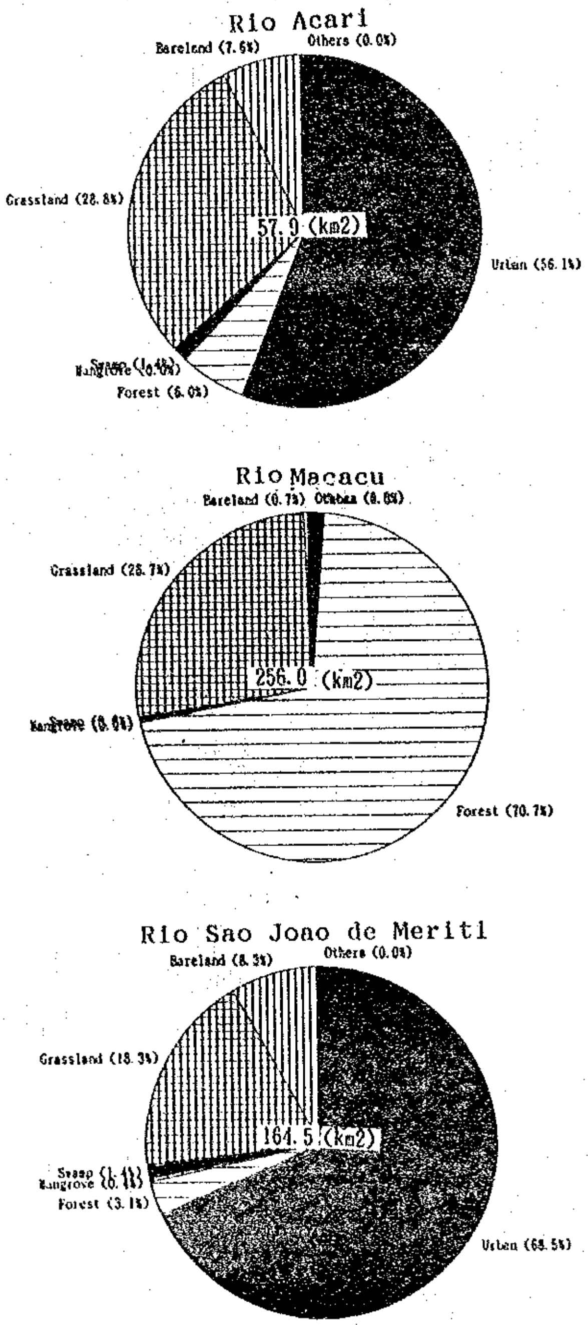
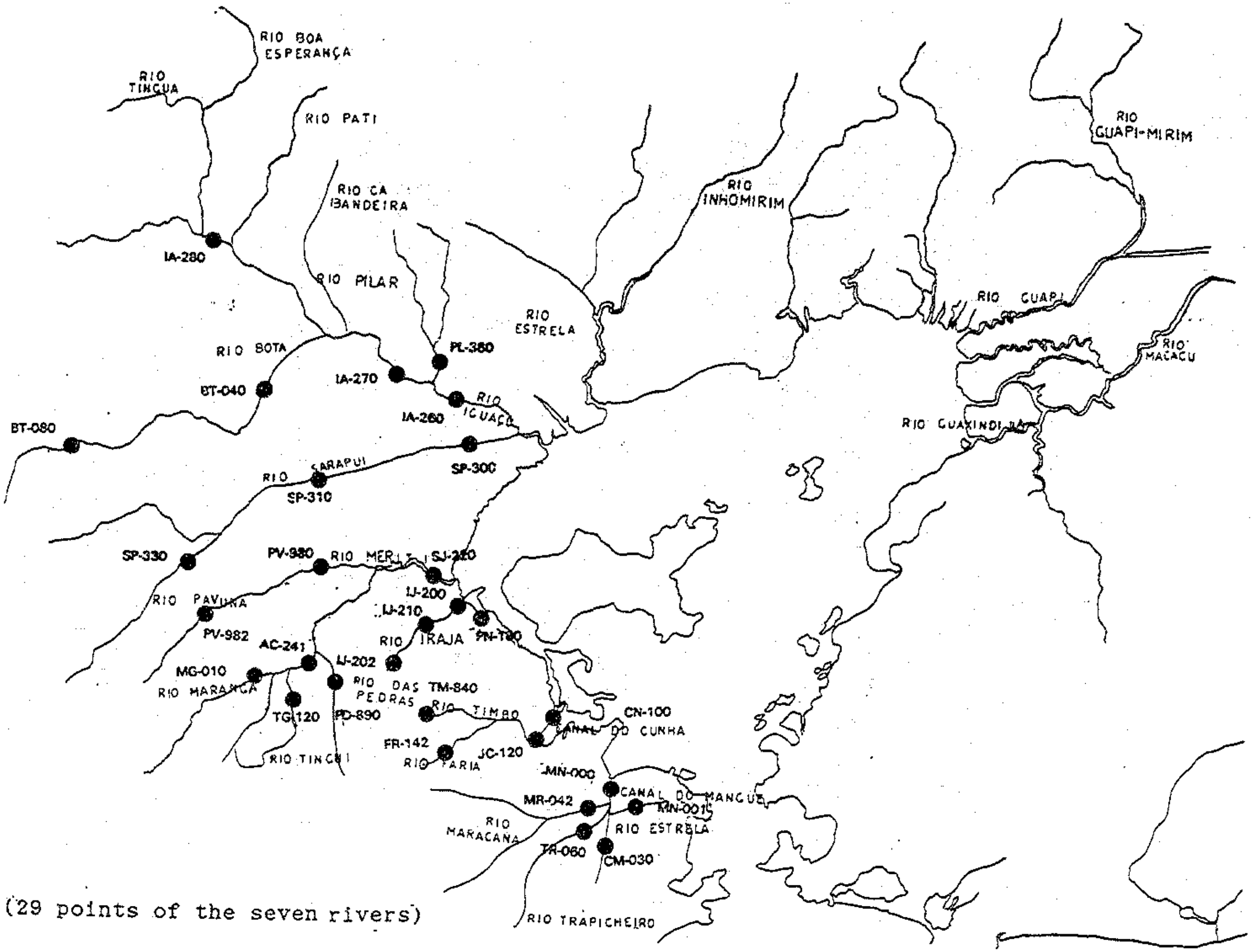


Fig. 9.1- 3 Land use Conditions of Model River Basins



(29 points of the seven rivers)

Fig. 9.1-4 Detailed Observation Stations for the Highly Polluted Rivers

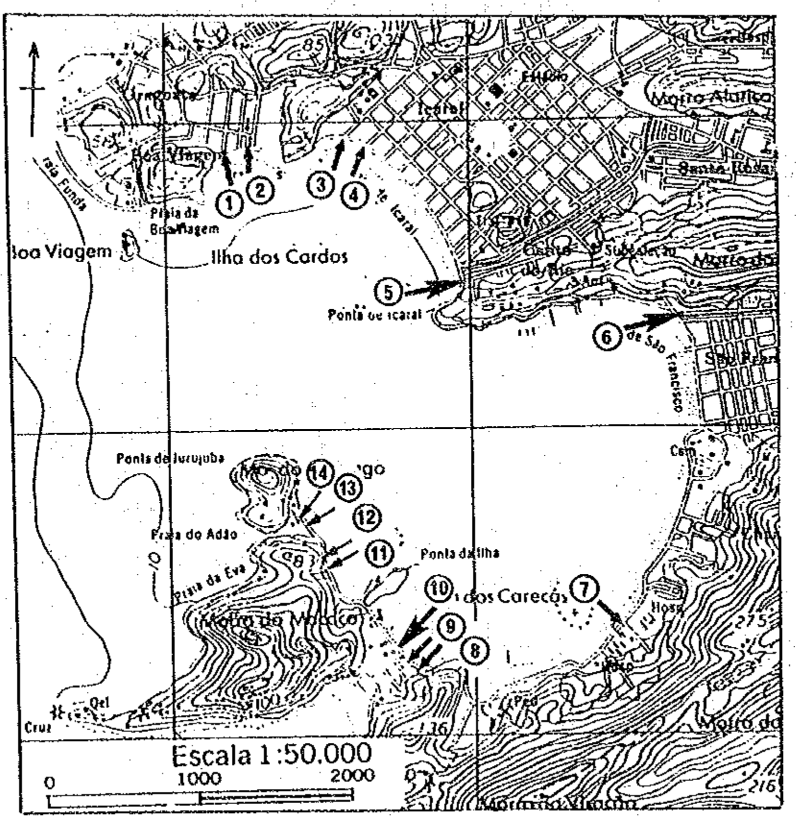


Fig. 9.1- 5 Observation Stations for the Drainage Canals inflowing into Jurujuba Bay

9.1.3 Observation Method

(1) Discharge measurement

The discharge amount was obtained from each river's cross sectional area and flow velocity. The river cross sectional area was measured from the results of the width and water level measurements conducted at each observation station. Velocity was measuremed using an electromagnetic current meter.

In the case where the observation stations were located in a tidal zone, discharge measurements were taken in the period from three hours after high tide to one hour before low tide.

(2) Sampling of river water

Ideally riverwater samples should be taken from 1/5 of the river's depth below the water surface. Sampling was carried out using buckets.

(3) Analysis of water quality

Water temperature, transparency, water color, pH, DO, EC and Salinity were measured on site. Water quality was analyzed at FEEMA's laboratory for the following 31 items: BOD, D-BOD, COD(Mn), COD(Cr), TOC, DOC, SS, TN, K-N, D-TN, NH_4-N, NO_2-N, NO_3-N, O-N, TP, D-TP, PO_4-P, OP, Fecal Coli., Total Coli., Normal Hexane-Extracts, Phenol, CN, As, Cu, Zn, T-Hg, Cr. Cr^{6+}, Cd and Pb. The methods used were those mentioned in Chapter 4.2 of the Supporting Report, Volume II.

(4) Collection of precipitation data during the survey

Precipitation data was obtained during the survey period at Duque de Caxi(PETROBRAS) is shown in **Fig.9.1-6**. Precipitation throughout the survey period varied widely from the normal years, as shown in **Fig.2.3-1**.

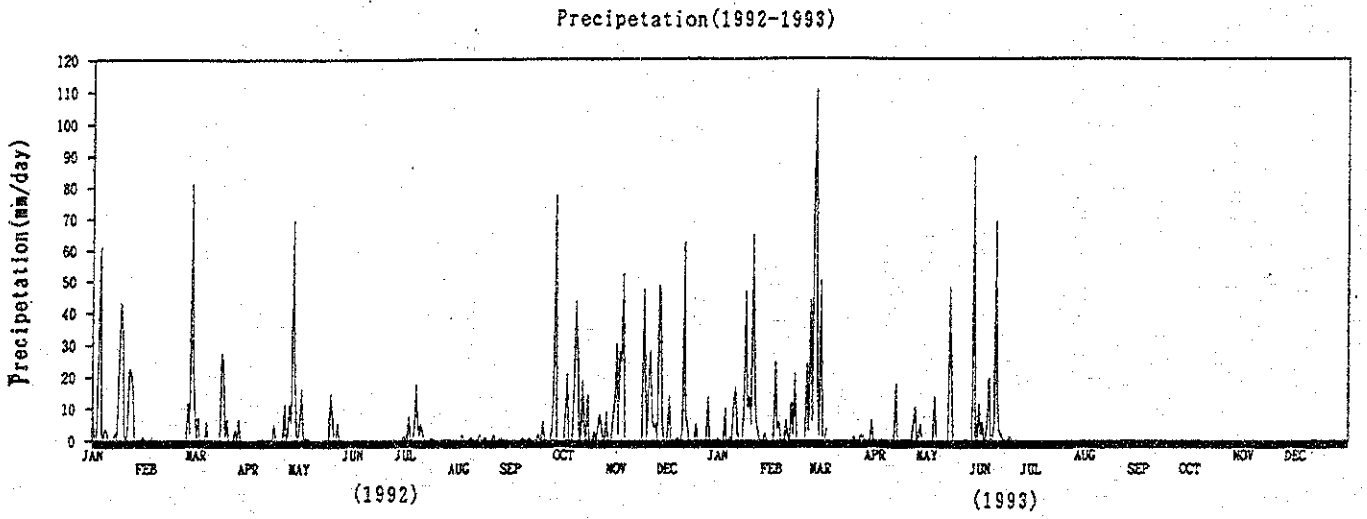


Fig. 9.1-6 Precipitation at Duque de Caxlas (PETROBRAS) during the Survey Period (January 1992 - June 1993)

9.2 Observed Water Quality, Discharge and Runoff Load

9.2.1 Water Quality

(1) Mean Water quality

The average of the 9 measurements conducted from May 1992 to April 1993 is shown in **Table 9.2-1**. Most of the major rivers in the western basin including the Rio Sao Joao de Meriti show a value of 20mg/l of BOD or more, this is regarded as a high pollution level. For DO, most of these rivers show a value of 5mg/l or less, proving that this environment is not a favorable habitat for fish.

Classification of the 25 major rivers into five groups by water quality (BOD and TN), those used as artifical pollution indices is shown in **Fig.9.2-1**. Those in: Group A have a BOD value of 5mg/l or less and a TN value of 2mg/l or less; Group B have a BOD value of 5 to 10mg/l and a TN value of 2 to 5 mg/l; Group C, 10 to 20mg/l and 5 to 10mg/l; Group D, 20 to 55mg/l and 10 to 15mg/l; Group E, 55mg/l or more and 15mg/l or more.

Rivers such as the Rio Macacu and Rio Guapimirim, having basin areas primarily consisting of woods and grasslands, are classified into Group A, while rivers such as the Rio Alcantara, Rio Bomba and Rio Mutondo, having basin areas (Sao Goncalo) with sharply increasing population, due to urbanization belong to Group E. Therefore, river water quality is very much influenced by the land use conditions of their respective basins.

(2) Features of water quality in each river

To further understand the features of water quality in each river, a radar chart was prepared for six selected main rivers, using BOD, COD(Cr), TN and Total-Coliform as indices (**Fig.9.2-2**). The rectangles in the figure indicate the level of river water quality. A larger rectangle indicates a higher pollution level.

The classification of rivers by water quality shown in the radar chart leads to the following 3 categories:

Table 9.2- 1 Water Quality (Average Value during the Survey Period) of 25 Rivers (1992-1993)

(Number of Data : 9)

No	Name	Area of Basin Covered (Km^2)	NO.	Basin Area (Km^2)	Population	Population Density (p/km^2)	Land use Type	Water Quality(Average Value) BOD (mg/l)	COD(Mn) (mg/l)	COD(Cr) (mg/l)	TN (mg/l)	TP (mg/l)	DO (mg/l)	Total Coli x 1000 (MPN/100ml)
1 C1780	CANAL CANTO DO RIO	7.40	2	7.40	41,745	5.64	Urb/S.T	26.0	11.1	74.3	14.6	1.2	2.8	5,050
2 BM760	RIO BOMBA	3.40	5	26.20	183,099	6.99	Urban	74.8	25.0	191.0	23.4	3.4	1.7	42,333
3 IB810	RIO IMBOASSU	11.60	6	30.80	138,636	4.50	Urban	8.8	11.5	1440.0	4.0	0.6	2.5	527
4 AN740	RIO ALCANTARA	58.50	8	144.60	470,420	3.25	Urban	613.8	170.9	337.8	24.8	16.4	3.9	49,667
5 MT820	RIO MUTONDO	5.50	8			3.25	Urban	58.3	20.0	125.9	20.2	3.1	1.2	27,667
6 GX720	RIO GUAXINDIBA	11.80	8			3.25	Urban	11.6	10.5	44.0	9.4	1.6	1.3	5,225
7 CC622	RIO CACEREBU	758.40	9	846.70	336,193	0.40	N/A	8.9	9.5	35.2	1.6	0.3	1.8	20
8 GP600	RIO GUAPIMIRIM	1233.70	10	1253.10	69,853	0.06	N/A	2.8	6.1	20.4	0.9	0.1	3.8	98
*9 MC967	RIO MACACU	256.00	10-3	256.00	18,577	0.07	N/A	1.8	2.5	10.0	0.7	0.1	6.9	322
*10 SB998	RIO SOBERBO	45.20	10-6	132.40	17,911	0.14	N/A	55.2	21.5	114.4	1.2	0.2	4.3	4,665
11 MG580	CANAL DE MAGE	4.60	11	18.30	8,458	0.46	N/A	28.0	16.1	83.2	9.3	1.6	1.1	53,317
12 RN560	RIO RONCADOR	107.00	12	111.40	36,370	0.33	N/A	2.3	4.4	14.5	0.8	0.1	6.1	91
13 IR540	RIO IRIRI	8.40	13	27.80	10,684	0.38	N/A	6.2	12.1	45.5	1.5	0.3	1.3	132
14 SR500	RIO SURUI	53.20	14	68.80	12,910	0.19	N/A	3.5	5.8	23.2	0.9	0.2	4.4	150
15 ES400	RIO ESTRELA	342.50	16	342.50	302,495	0.88	N/A	15.1	8.1	33.6	2.4	0.4	1.0	776
*16 IN460	RIO INHOMIRIM	139.00	16-2	139.00	84,106	0.61	N/A	2.6	3.7	15.2	1.8	0.1	3.6	338
*17 SC420	RIO SARACURUNA	186.00	16-3	186.00	194,173	1.04	N/A	9.7	3.7	24.1	2.3	0.1	3.3	166
18 IA260	RIO IGUACU	544.20	17-1~5	562.80	758,010	1.35	N/A	9.2	8.1	37.1	4.8	0.8	1.1	3,007
19 SP300	RIO SARAPUI	159.80	17-6	165.50	1,012,275	6.12	Urban	25.9	12.1	68.7	14.5	2.2	0.7	17,450
20 SJ220	RIO S.J.DE MERITI	163.50	19	164.50	1,492,458	9.07	Urban	24.7	17.0	144.8	13.0	1.7	0.5	30,600
*21 AC241	RIO ACARI	57.90	19-2	57.90	438,076	7.57	Urban	35.7	11.4	71.9	11.1	2.0	2.0	29,800
22 IJ200	RIO IRAJA	27.30	20	35.70	500,276	14.01	Urban	50.0	15.3	104.9	13.7	2.1	0.9	100,833
23 PN180	CANAL DO PENHA	-	20	-				49.4	15.7	121.6	14.3	2.3	0.4	86,333
24 CN100	CANAL DO CUNHA	60.50	21	63.60	815,389	12.82	Urban	50.1	11.7	98.7	12.3	1.8	0.6	47,000
25 MN000	CANAL DO MANGUE	42.80	23	42.80	500,876	11.70	Urb/S.T	44.4	13.3	115.7	12.1	1.9	0.7	24,060
TOTAL		3604.10		3912.50	6,690,147									

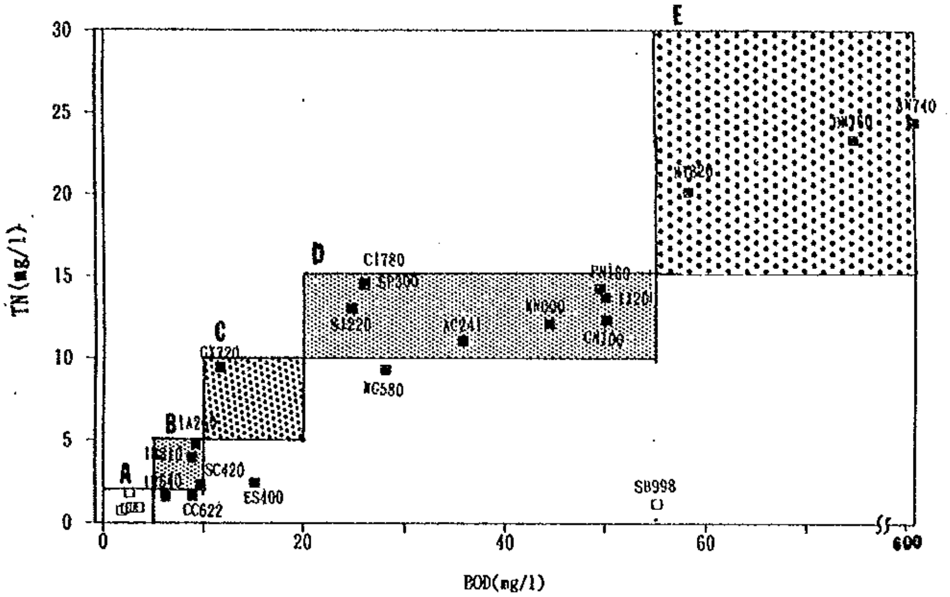


Fig. 9.2- 1 Classification of the 25 Rivers in terms of BOD and TN

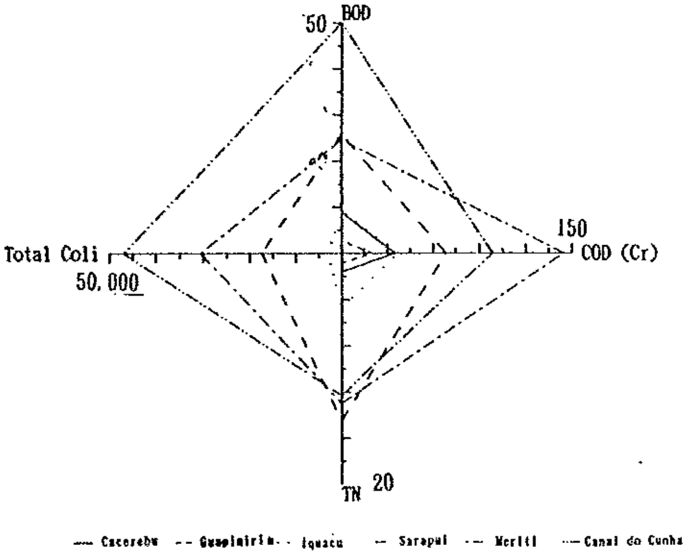


Fig. 9.2- 2 Characteristics of the Water Quality in the Major Rivers

(1) Small rectangles signify uncontaminated natural rivers or rivers polluted by agriculture, (2) large rectangles signify rivers highly polluted with domestic wastewater, and (3) irregular shaped rectangles signify rivers polluted with industrial wastewater.

Rivers belonging to category (1) are the Rio Guapimirim, Rio Macacu and Rio Inhomirin; the Rio Bomba, Rio Mutondo, Rio Iraja, Canal do Cunha and Rio Acari belong to category (2); the Rio Alcantara, Rio Soberdo and Rio S.J.de Meriti belong to category (3).

(3) Achievement of water quality environmental standards

CONAMA No.20 classifies rivers into several dozen groups by their characteristics, and stipulates the water quality standards in terms of pH, BOD, TDS, DO, No. of coliform and turbidity (**Table 14.3-1**).

The 91 rivers that flow into Guanabara Bay were classified in terms of BOD (**Fig. 14.3-1**); and the achievement levels of these rivers in terms of the water quality standards for BOD, DO and No. of coliform are shown in **Fig.9.2-3**.

According to the results of the 9 surveys carried out from May 1992 to April 1993, the achievement ratio of the rivers is extremely low: 24% for BOD, 16% for DO and 40% for No. of coliform. Only the Rio Guapimirim/Macacu and Rio Roncador in the northeasten basin met the water quality standards.

BOD exceeding 20mg/l was observed in highly polluted rivers in the western basin (Rio de Janeiro) and the eastern basin (Niteroi and Sao Goncalo). These areas are particularly highly urbanized.

CONAMA No.20 does not specify the water quality standards for hazardous substances such as Cd, CN, Pb, Cr^{+6}, T-Hg and PCBs.

For a comparison of the achievement ratio for these substances, Japanese water quality environmental standards were used, and the satisfaction rates are shown in **Table 9.2-2**. Some rivers such as the Rio S. J. de Meriti and Rio Alcantara have very low satisfaction rates.

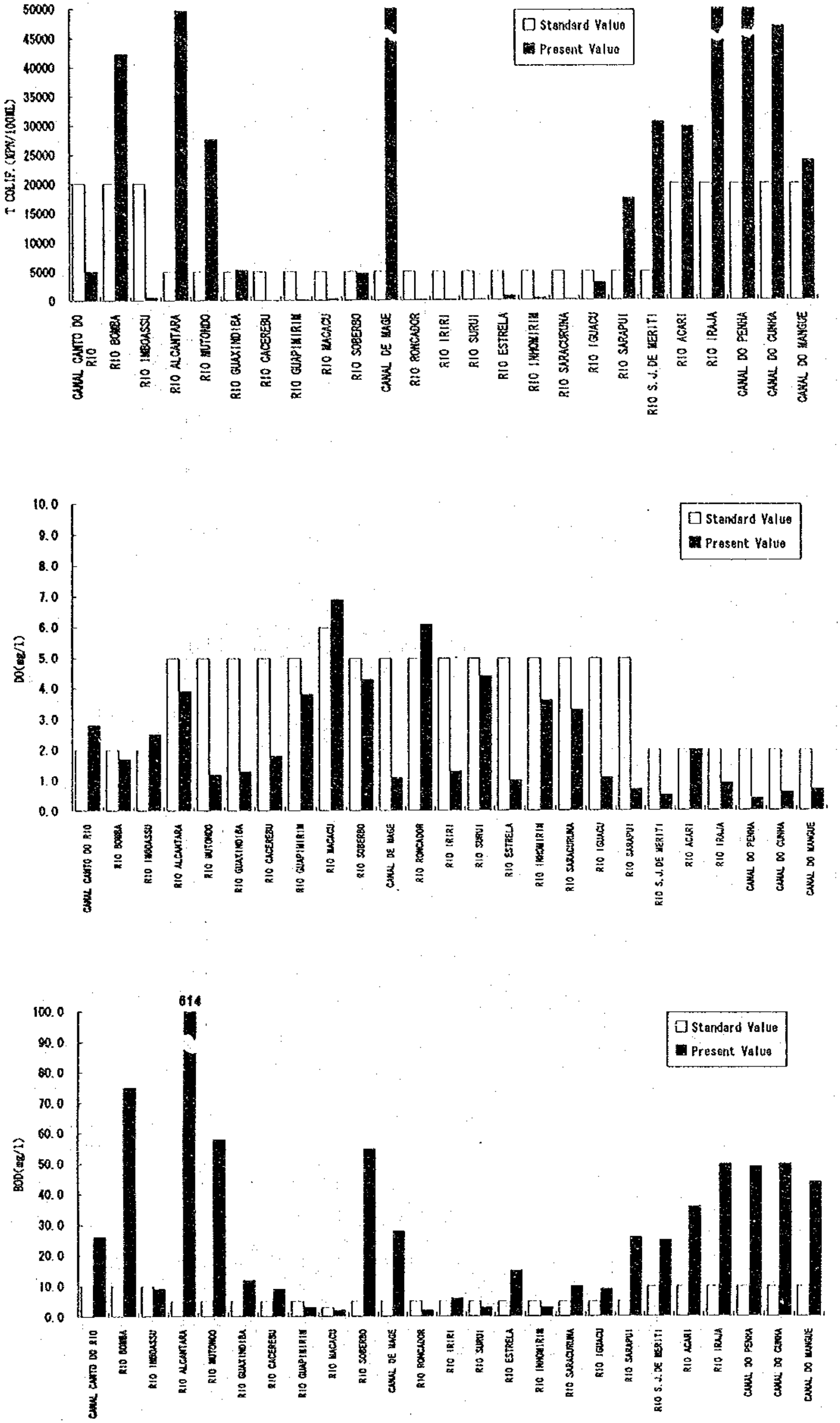


Fig. 9.2- 3 Achievement Levels of the three Water Quality Standards

Table 9.2-2 Unsatisfactory Rates of Water Quality with respect to Environmental Standards

No	Name	Area of Basin Covered (Km2)	NO.	Cadmium		Lead		Chromium VI		Mercury	
				0.01mg/l<	No. of Samples	0.1mg/l<	No. of Samples	0.05mg/l<	No. of Samples	0.005mg/l<	No. of Samples
1 CI780	CANAL CANTO DO RIO	7.40	2	0	13	0	13	0	5	0	13
2 BM760	RIO BOMBA	3.40	5	0	13	0	13	0	5	0	13
3 IB810	RIO IMBOASSU	11.60	6	2	13	1	13	0	5	0	13
4 AN740	RIO ALCANTARA	58.50	8	0	13	0	13	0	5	2	13
5 MT820	RIO MUTONDO	5.50	8	0	13	0	13	0	5	0	13
6 GX720	RIO GUAXINDIBA	11.80	8	0	13	0	13	0	5	0	13
7 CC622	RIO CACEREBU	758.40	9	2	13	1	13	0	5	0	13
8 GP600	RIO GUAPIMIRIM	1233.70	10	0	13	0	13	0	5	0	13
*9 MC967	RIO MACACU	256.00	10-3	0	13	0	13	0	5	0	13
*10 SB998	RIO SOBERBO	45.20	10-6	0	13	0	13	0	5	0	13
11 MG580	CANAL DE MAGE	4.60	11	0	13	0	13	0	5	1	13
12 RN560	RIO RONCADOR	107.00	12	0	12	0	12	0	4	0	12
13 IR540	RIO IRIRI	8.40	13	0	13	0	13	0	5	0	13
14 SR500	RIO SURUI	53.20	14	0	13	0	13	0	5	0	13
15 ES400	RIO ESTRELA	342.50	16	2	13	2	13	0	5	0	13
*16 IN460	RIO INHOMIRIM	139.00	16-2	1	13	0	13	0	5	0	13
*17 SC420	RIO SARACURUNA	186.00	16-3	1	13	0	13	0	5	0	13
18 IA260	RIO IGUACU	544.20	17-1~5	0	13	0	13	0	5	0	13
19 SP300	RIO SARAPUI	159.80	17-6	0	13	0	13	0	5	0	13
20 SJ220	RIO S.J.DE MERITI	163.50	19	2	13	0	13	0	5	1	13
*21 AC241	RIO ACARI	57.90	19-2	0	11	0	11	0	3	0	11
22 IJ200	RIO IRAJA	27.30	20	0	13	0	13	0	5	0	13
23 PN180	CANAL DO PENHA	-	20	2	13	1	13	0	5	0	13
24 CN100	CANAL DO CUNHA	60.50	21	0	13	0	13	0	5	0	13
25 MN000	CANAL DO MANGUE	42.80	23	1	13	0	13	0	5	0	13
TOTAL		3604.10		13	322	5	322	0	122	4	322
				4.0%		1.6%		0.0%		1.2%	

(4) Seasonal change in water quality

Seasonal change in river water quality (monthly change) for the water quality items is shown in **Fig.9.2-4**. According to this figure, the water quality was more likely to be worse in the dry season than in the rainy season. However, there was no distinct change between water quality in the dry season and rainy season.

(5) Annual change of water quality

Annual change of water quality was examined based on the results of water analysis carried out, though irregularly, by FEEMA in the period of 1980 to 1991 and the results obtained in this survey (1992 to 1993).

Fig.9.2-5 is a representation of the annual change of BOD in the 25 rivers; of these, the Rio Bomba, Rio S.J.de Meriti and Canal de Mangue show recovering tendencies, while the Rio Alcantara, Rio Guaxindiba, Rio Cacerebu, Rio Soberbo, Canal de Mage, Rio Estrela, Rio Saracuruna and Rio Iraja show worsening tendencies.

Notable changes in the water quality of other rivers were not observed. NH_4-N, TP and DO tendencies were observed to be similar to BODs.

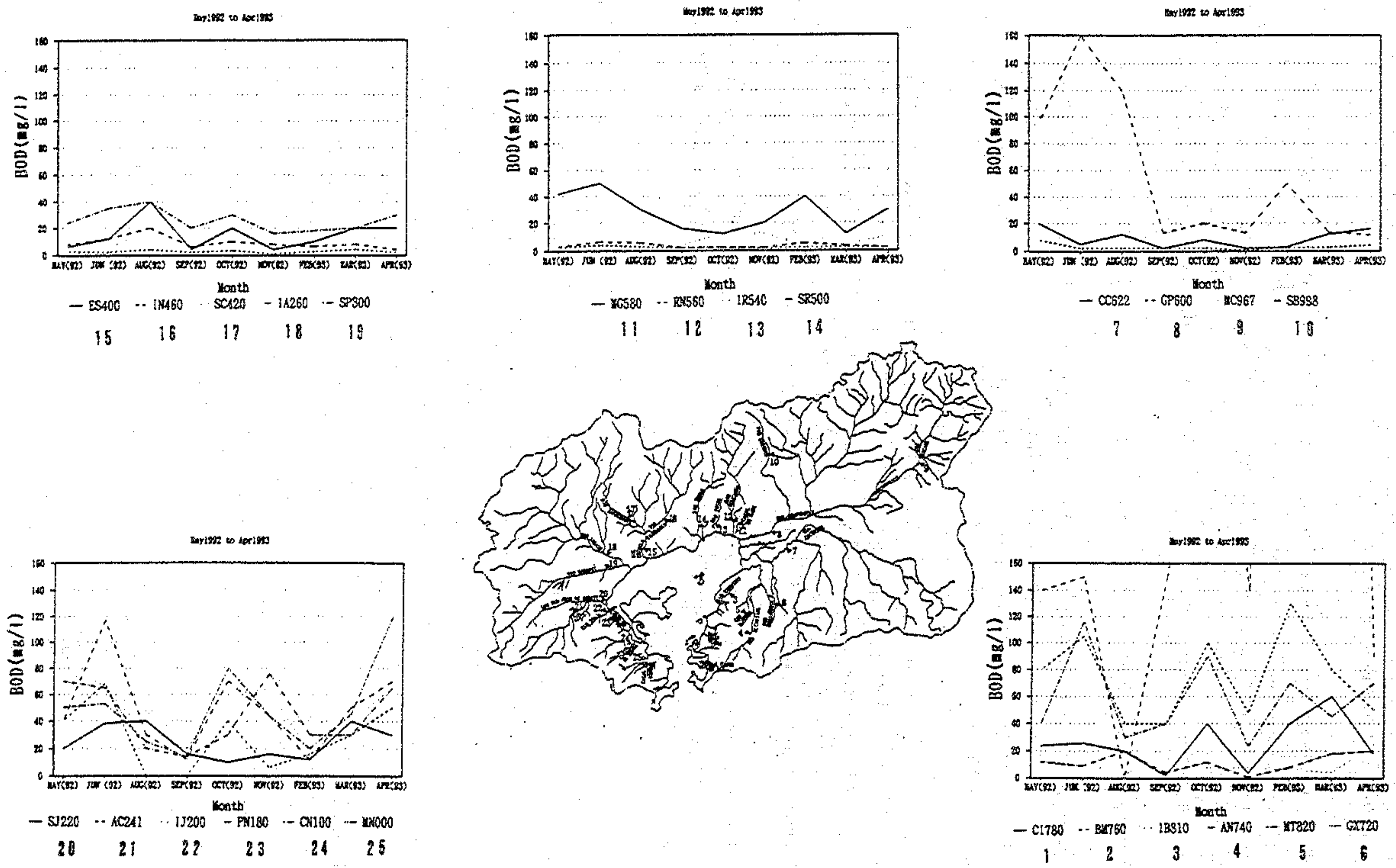


Fig. 9.2- 4 Monthly Change of River Water Quality (BOD)

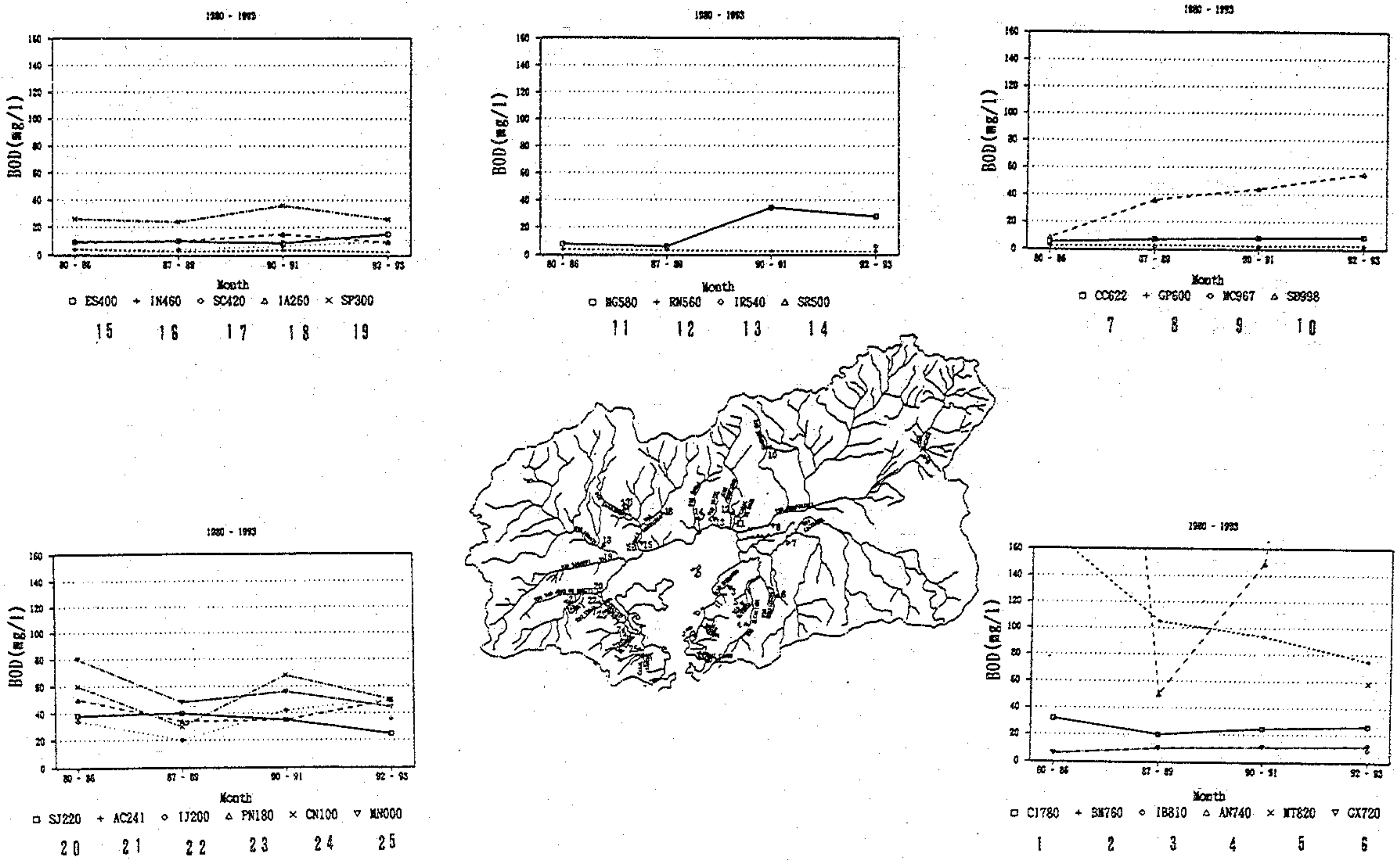


Fig. 9.2- 5 Annual Change of River Water Quality (BOD)

9.2.2 Runoff Discharge and Runoff Load

The means of the results obtained from the seven surveys (1992 to 1993) were used to calculate the total runoff discharge and total runoff load of the 20 rivers (basin area covered: 3604.1km^2) flowing directly into Guanabara Bay **(Fig.9.2-6, Table 9.2-3)**.

The mean total runoff discharge of the 20 rivers is 257.5m^3/s and the mean total runoff load is 318.3t/day of BOD, 194.7t/day of COD(Mn), 1220.8t/day of COD(Cr), 113.6t/day of TN and 18.7t/day of TP.

The runoff discharge and runoff load values of each river vary widely from month to month. Moreover, variations in precipitation in the tidal rivers are accompanied by tidal fluctuations, hence the calculated runoff discharge and runoff load are not purely of these rivers alone but are influenced by other factors.

The runoff load ratios for each river, if the total runoff load of the 20 rivers is 100%, are shown in **Fig.9.2-7**. The runoff load of the 9 largest rivers amounts to 90 - 95 % of the total runoff load.

9.2.3 Hourly Change and Seasonal Change in Water Quality and Runoff Load on Clear Days

Figs.9.2-8 to **9.2-10** show the comparison between the hourly change in runoff load of the natural type river model, Rio Macacu, and those of the urban type river model, Rio Acari.

Rio Acari, urban type river, is influenced by human activities and thus changes abruptly depending on the time of day in runoff load. Changes by season, however, were small. On the other hand, The Rio Macacu, a natural type river, changed only marginly due to time, in runoff load, but seasonal changes were large.

As shown in **Table 9.2.4**, the specific runoff load of urban type rivers is several times larger than that of natural type rivers. Consequently, it is possible to assume that the base runoff discharge of natural type rivers is basically influenced by precipitation, while that of urban type rivers is largely influenced by the volume of wastewater.

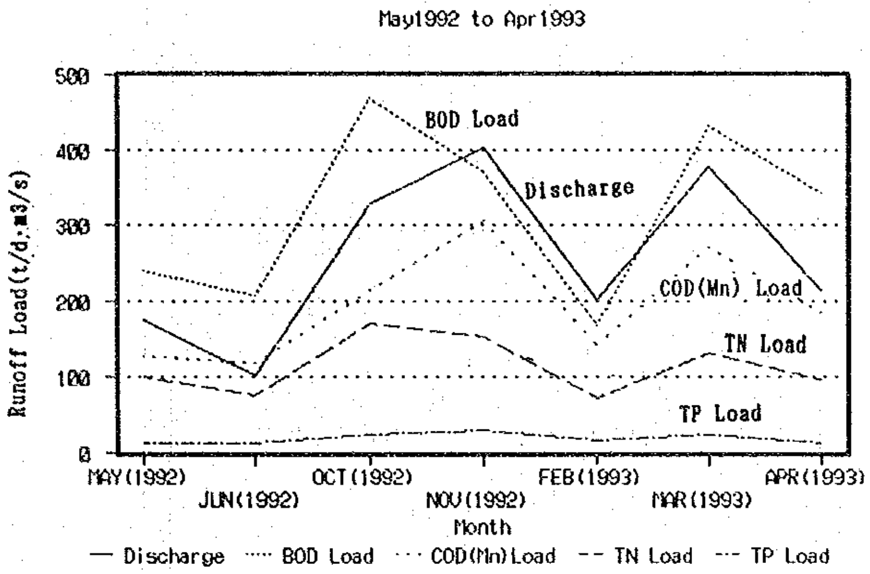


Fig. 9.2- 6 Monthly Change of total Runoff Load from the 20 Rivers

Table 9.2-3 Runoff Load (Average Value) from the 20 rivers (1992-1993)

(Number of Data : 9)

No	Name	Covered Basin Area (Km^2)	NO.	Basin Area (Km^2)	Population	Population Density (p/km^2)	Land use Type	Runoff Load(Average Value)					
								Discharge (m3/s)	BOD (t/d)	COD(Mn) (t/d)	COD(Cr) (t/d)	TN (t/d)	TP (t/d)
1 CI780	CANAL CANTO DO RIO	7.40	2	7.40	41,745	5.64	Urb/S.T	1.0	2.5	1.0	5.4	1.0	0.1
2 BM760	RIO BOMBA	3.40	5	26.20	183,099	6.99	Urban	0.1	0.8	0.3	2.1	0.2	0.0
3 IB810	RIO IMBOASSU	11.60	6	30.80	138,636	4.50	Urban	3.8	2.6	3.1	138.4	0.9	0.2
4 AN740	RIO ALCANTARA	58.50	8	144.60	470,420	3.25	Urban	0.1	3.6	0.9	1.2	0.1	0.1
5 MT820	RIO MUTONDO	5.50	8			3.25	Urban	0.2	1.0	0.4	2.0	0.4	0.1
6 GX720	RIO GUAXINDIBA	11.80	8			3.25	Urban	0.1	0.1	0.1	0.4	0.0	0.0
7 CC622	RIO CACEREBU	758.40	9	846.70	336,193	0.40	N/A	35.2	29.0	30.6	112.9	3.9	1.1
8 GP600	RIO GUAPIMIRIM	1233.70	10	1253.10	69,853	0.06	N/A	53.5	12.2	30.0	99.7	4.3	0.9
*9 MC967	RIO MACACU	256.00	10-3	256.00	18,577	0.07	N/A	8.8	1.2	2.0	8.2	0.6	0.1
*10 SB998	RIO SOBERBO	45.20	10-6	132.40	17,911	0.14	N/A	1.5	4.4	2.0	10.0	0.1	0.0
11 MG580	CANAL DE MAGE	4.60	11	18.30	8,458	0.46	N/A	0.5	1.0	0.5	2.9	0.4	0.1
12 RN560	RIO RONCADOR	107.00	12	111.40	36,370	0.33	N/A	8.3	1.4	3.3	11.1	0.4	0.1
13 IR540	RIO IRIRI	8.40	13	27.80	10,684	0.38	N/A	0.5	0.3	0.5	2.1	0.1	0.0
14 SR500	RIO SURUI	53.20	14	68.80	12,910	0.19	N/A	4.4	1.2	2.4	8.9	0.3	0.1
15 ES400	RIO ESTRELA	342.50	16	342.50	302,495	0.88	N/A	32.8	40.6	20.9	59.6	5.8	1.2
*16 IN460	RIO INHOMIRIM	139.00	16-2	139.00	84,106	0.61	N/A	2.7	0.6	0.9	4.0	0.4	0.0
*17 SC420	RIO SARACURUNA	186.00	16-3	186.00	194,173	1.04	N/A	3.0	2.4	0.9	6.5	0.6	0.0
18 IA260	RIO IGUACU	544.20	17-1~5	562.80	758,010	1.35	N/A	43.1	30.1	23.3	114.0	12.4	2.3
19 SP300	RIO SARAPUI	159.80	17-6	165.50	1,012,275	6.12	Urban	24.0	47.3	21.9	132.3	27.2	4.6
20 SJ220	RIO S.J.DE MERITI	163.50	19	164.50	1,492,458	9.07	Urban	31.7	57.9	38.3	350.2	33.3	4.6
*21 AC241	RIO ACARI	57.90	19-2	57.90	438,076	7.57	Urban	7.0	22.7	7.3	44.4	6.7	1.2
22 IJ200	RIO IRAJA	27.30	20	35.70	500,276	14.01	Urban	3.0	14.4	3.4	26.5	4.0	0.6
23 PN180	CANAL DO PENHA	-	20	-				1.1	5.2	1.3	15.3	1.4	0.2
24 CN100	CANAL DO CUNHA	60.50	21	63.60	815,389	12.82	Urban	8.9	44.6	7.2	80.9	11.4	1.6
25 MN000	CANAL DO MANGUE	42.80	23	42.80	500,876	11.70	Urb/S.T	5.1	22.5	5.3	55.1	6.0	0.9
TOTAL		3604.10		3912.50	6,690,147			257.47	318.28	194.71	1220.80	113.60	18.71

*:excluded from total amount

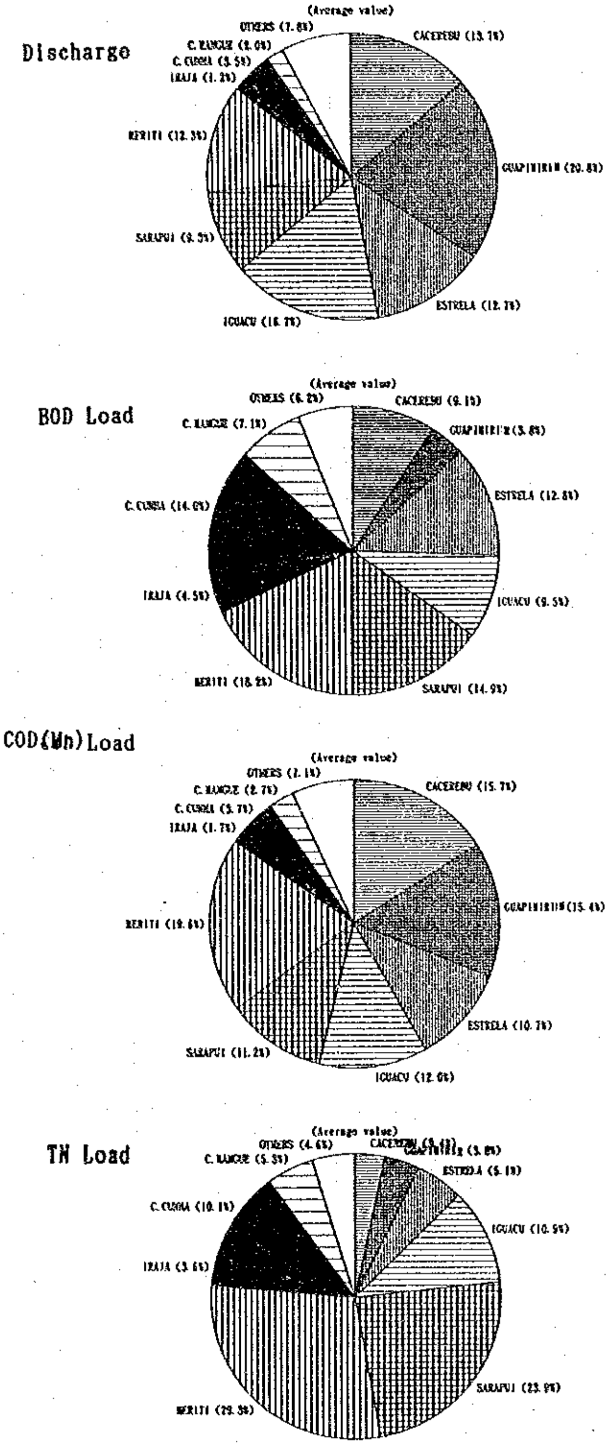


Fig. 9.2- 7 Contribution Ratio of Runoff Load by River

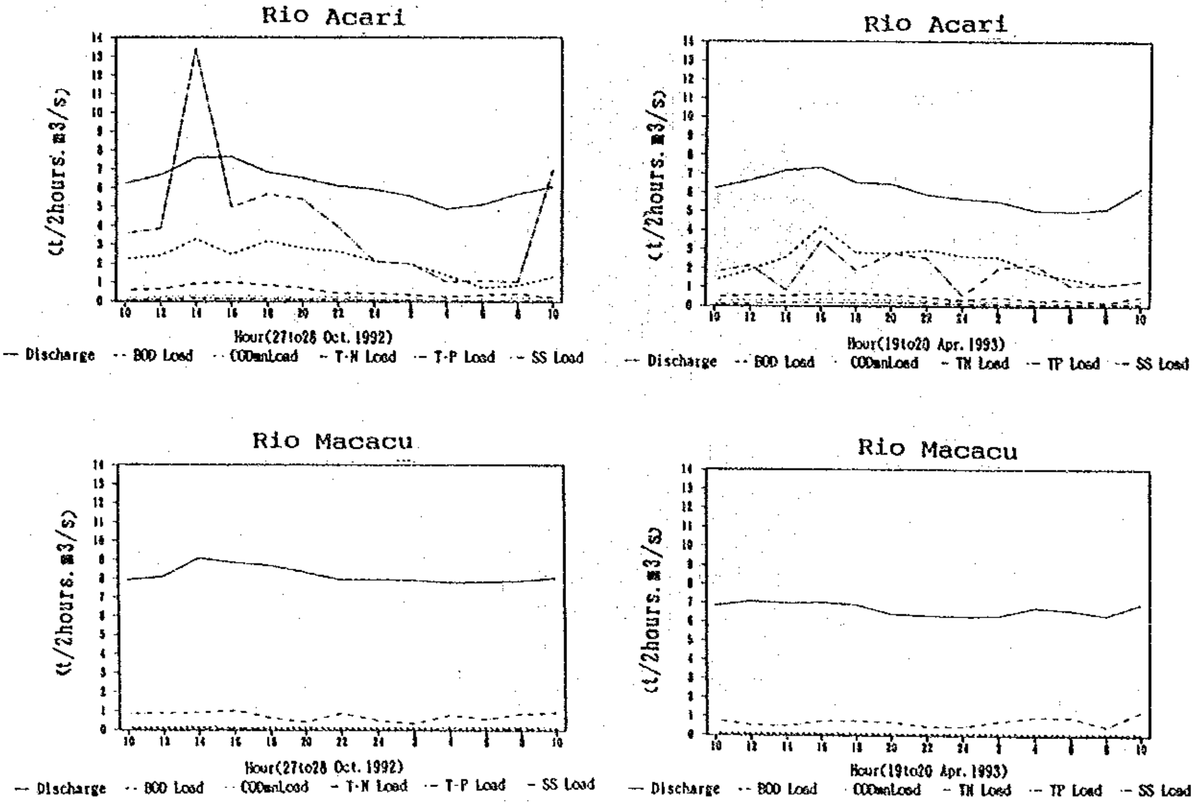


Fig. 9.2- 8 Hourly Change of Runoff Load on Clear Days between the two Non-tidal Rivers

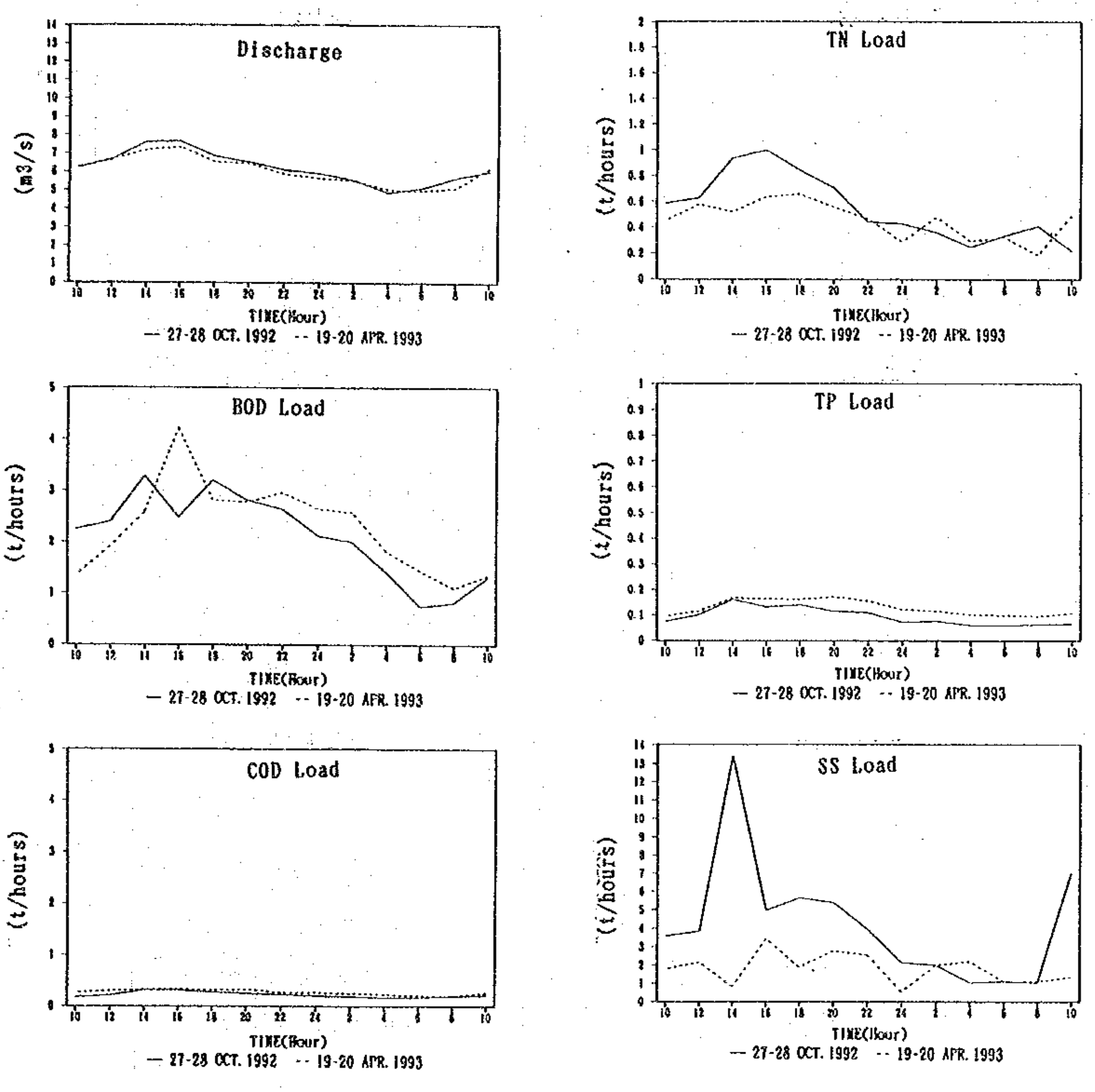


Fig. 9.2-9 Hourly Change of Runoff Load on Clear Days in the Rio Acari

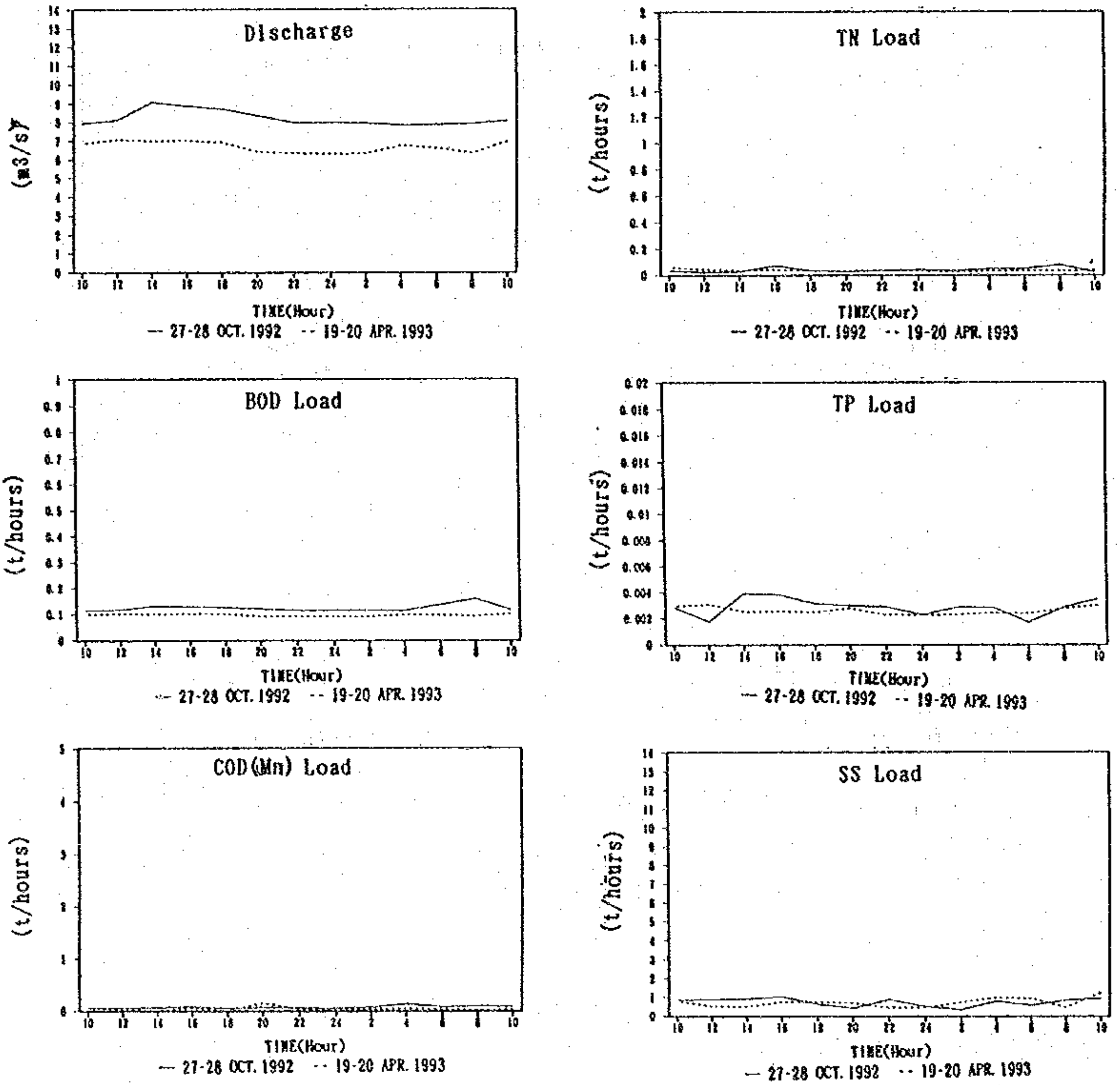


Fig. 9.2-10 Hourly Change of Runoff Load on Clear Days in the Rio Macacu

Table 9.2- 4 Comparison of Runoff Load between the two Non-Tidal Model Rivers (Clear Days / Rainy Days)

(19to20 APR.1993)

River Name	Basin Area (km2)	Precipitation (mm/day)	Runoff Load Discharge (m3/s)	BOD Load (t/day)	CODmnLoad (t/day)	T-N Load (t/day)	T-P Load (t/day)	SS Load (t/day)	Specific Runoff Load Discharge (m3/s/km2)	BOD Load (t/d/km2)	CODmnLoad (t/d/km2)	T-N Load (t/d/km2)	T-P Load (t/d/km2)	SS Load (t/d/km2)
Rio Acari (A)	57.9	0.00	6.048	28.229	3.235	5.462	1.571	22.067	0.104	0.488	0.056	0.094	0.027	0.381
Rio Macacu(B)	256.0	0.00	6.656	1.150	0.487	0.402	0.031	8.239	0.026	0.004	0.002	0.002	0.000	0.032
Magnification(A/B)									4.0	108.5	29.4	60.1	224.1	11.8

(27to28 Oct.1992)

River Name	Basin Area (km2)	Precipitation (mm/day)	Runoff Load Discharge (m3/s)	BOD Load (t/day)	CODmnLoad (t/day)	T-N Load (t/day)	T-P Load (t/day)	SS Load (t/day)	Specific Runoff Load Discharge (m3/s/km2)	BOD Load (t/d/km2)	CODmnLoad (t/d/km2)	T-N Load (t/d/km2)	T-P Load (t/d/km2)	SS Load (t/d/km2)
Rio Acari (A)	57.9	0.00	6.227	25.697	2.653	6.744	1.157	49.850	0.108	0.444	0.046	0.116	0.020	0.861
Rio Macacu(B)	256.0	0.00	8.198	1.485	0.855	0.629	0.034	8.664	0.032	0.006	0.003	0.002	0.000	0.034
Magnification(A/B)									3.4	76.5	13.7	47.4	150.5	25.4

(16to30 Nov.1992)

		Mean Prec. (mm/d)	Basin Area (km2)	Runoff Load Discharge (m3/s)	BOD Load (t/day)	CODmnLoad (t/day)	TN Load (t/day)	TP Load (t/day)	SS Load (t/day)	Specific Runoff Load Discharge (m3/s/km2)	BOD Load (t/d/km2)	CODmnLoad (t/d/km2)	TN Load (t/d/km2)	TP Load (t/d/km2)	SS Load (t/d/km2)
Rio Macacu	Clear day	0.000	256.0	8.198	1.485	0.855	0.475	0.034	8.665	0.032	0.006	0.003	0.002	0.000	0.034
	Rainy day	14.280		16.011	1.191	1.971	1.185	0.123	51.902	0.063	0.005	0.008	0.005	0.000	0.203
		16.750		24.043	1.961	8.886	2.135	0.342	110.553	0.094	0.008	0.035	0.008	0.001	0.432
		24.080		30.471	4.048	19.058	3.974	0.215	259.509	0.119	0.016	0.074	0.016	0.001	1.014
Rio Acari	Clear day	0.000	57.9	6.227	25.697	2.653	6.738	1.157	49.850	0.108	0.444	0.046	0.116	0.020	0.861
	Rainy day	12.000		10.252	32.840	9.112	6.140	1.041	63.079	0.177	0.567	0.157	0.106	0.018	1.089
		24.080		27.834	57.296	44.677	9.567	0.759	652.206	0.481	0.990	0.772	0.165	0.013	11.264
Rio Macacu	Minimum		256.0	7.815	1.356	0.624	0.300	0.024	5.148	0.031	0.005	0.002	0.001	0.000	0.020

9.2.4 Fluctuations in Tidal River Runoff Discharge and Water Quality

Figs.9.2-11 shows the change in 24 hours on clear days observed in the rainy season for an urban type tidal river (Rio Sao Joao de Meriti), mentioned earlier. **Fig. 9.2-12** shows the change in 24 hours on clear days observed in the dry season for a natural type tidal river (Rio Guapimirim). These diagrams show a considerable change, influenced by human activities and the sea level.

Therefore, water quality observations for 24 hours (surveys at high and low tides) should be carried out to understand changes in water quality brought about by tidal fluctuations, in order to determine the mean runoff discharge and runoff load of rivers in tidal zones.

9.2.5 Hourly Change in Water Quality and Runoff Load on Rainy Days

Hourly change in water quality and runoff load of the two model rivers on rainy days during the rainy season are shown in **Figs.9.2-13** and **9.2-14**. Rainfall data was collected at the station of Duque de Caxias (PETROBRAS). The water quality in the Rio Acari, an urban type river, deteriorates at the beginning of rainfall and thus has a greater load than the Rio Macacu, a natural type river.

Fig.9.2-15 illustrates the relationship between specific runoff load and precipitation. Specific runoff load of an urban type river is several times to several hundred times that of a natural type river. **Fig.9.2-16** and **Table 9.2-4** show the difference between the specific runoff load on the rainy days and that on the clear days. The former is dozens of times larger than the latter, indicating that the load on rainy days occupies a large part of the total runoff load.

The total runoff load on rainy days is the sum of the load resulting from precipitation and the load deposited in the basin on clear days and washed away by rain on rainy days.

Therefore, runoff load is largely influenced by the period of clear days prior to the observation and the magnitude of the rainfall.

The survey encountered some problems that should be taken into account: (1) The number of clear days preceding the survey period was insufficient; (2) Although observations should be conducted under various rainfall intensities, all observations carried out in this survey were under moderate rainfall conditions; (3) Initial water quality of the runoff was not fully analyzed. (4) Relationship between hourly rainfall intensity and runoff load was not clearly understood.

These problems are expected to be solved in future surveys.

9.2.6 Pollution load flowing into Jurujuba Bay

Jurujuba Bay, with a water area of 7.25 km^2, extends to Icarai and Charistas forming picturesque beaches frequented by a great number of people in spite of the high levels of pollution. Therefore, the loads discharged from the drainage canals were studied in detail and the following results were obtained: daily, 6.89 tons of BOD, and 2.31 tons of TN flow into the bay on clear days during the dry season.

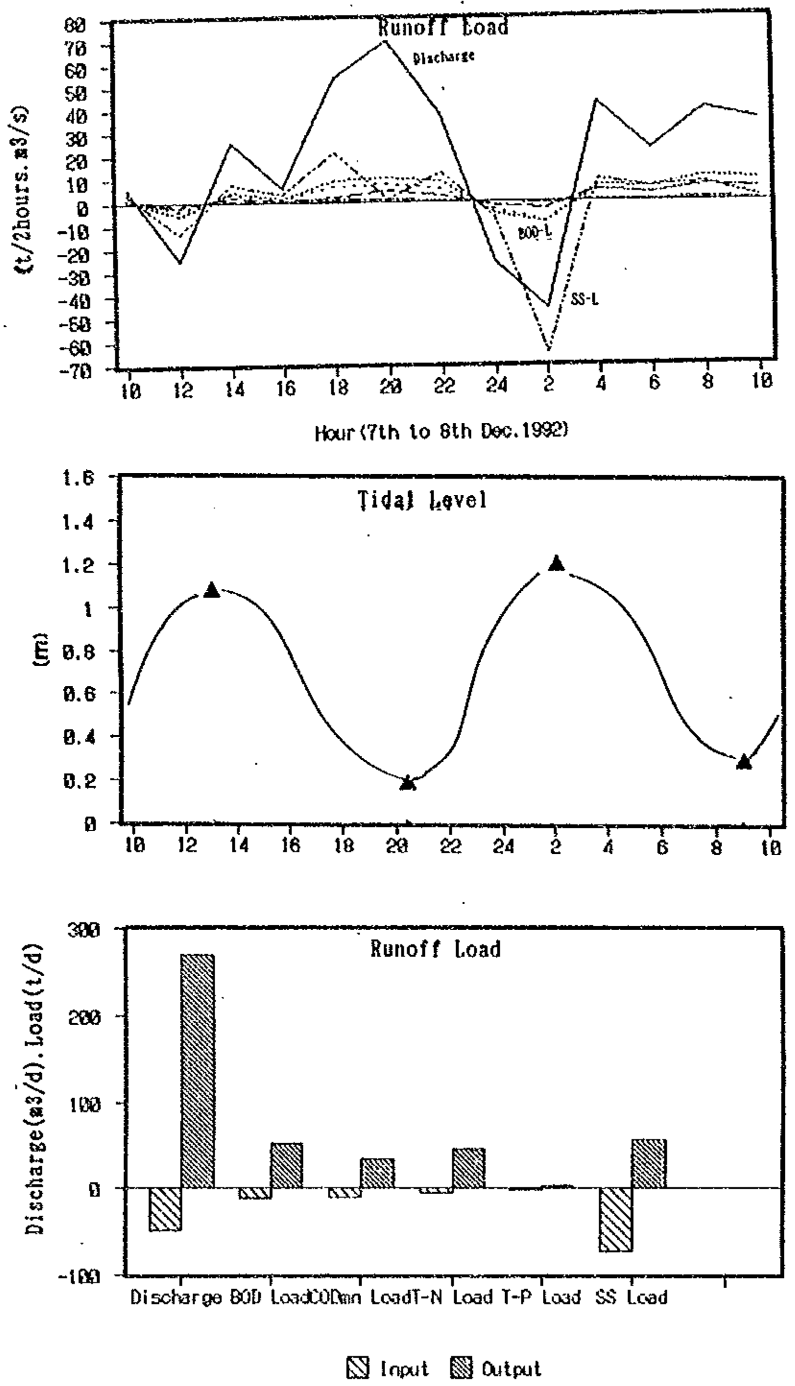


Fig. 9.2-11 Hourly Change of Runoff Load on Clear Days in the Rio S.J. de Meriti

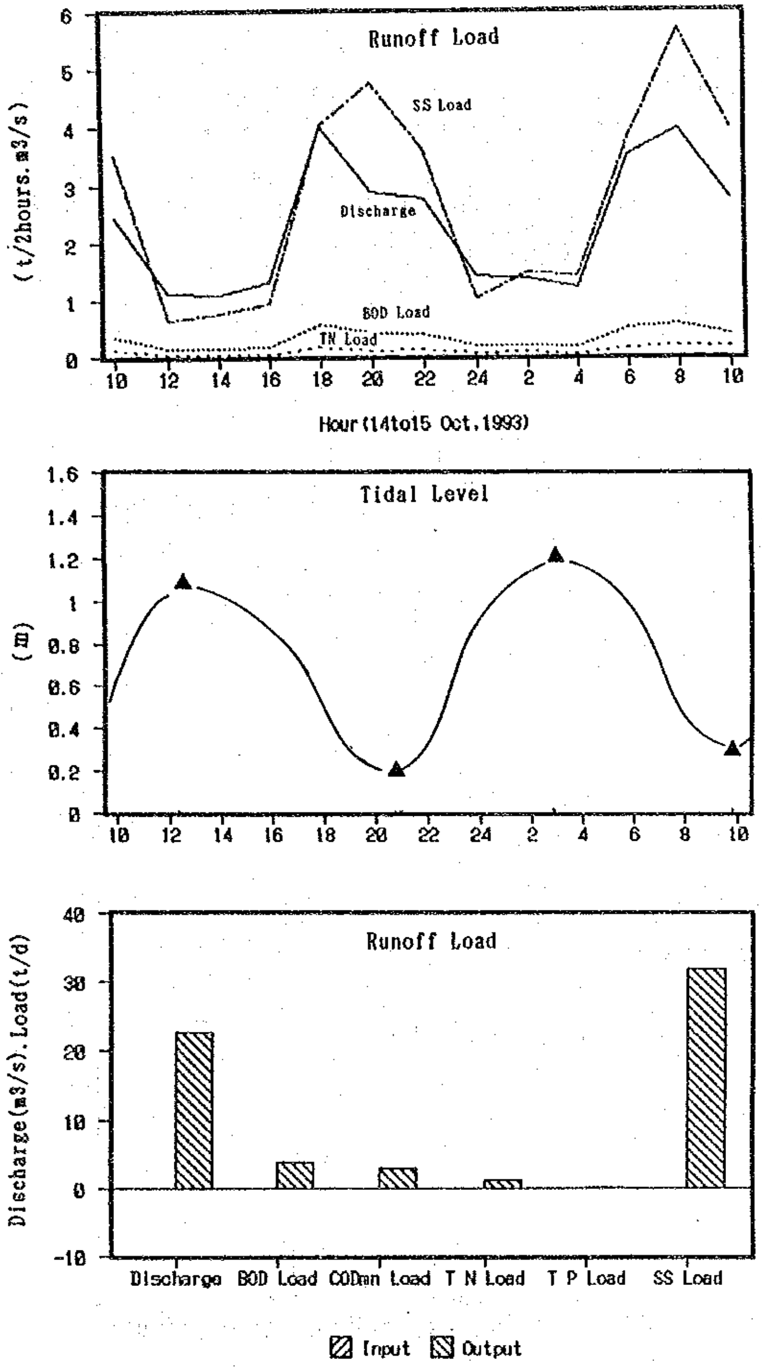


Fig. 9.2-12 Hourly Change of Runoff Load on Clear Days in the Rio Guapimirim

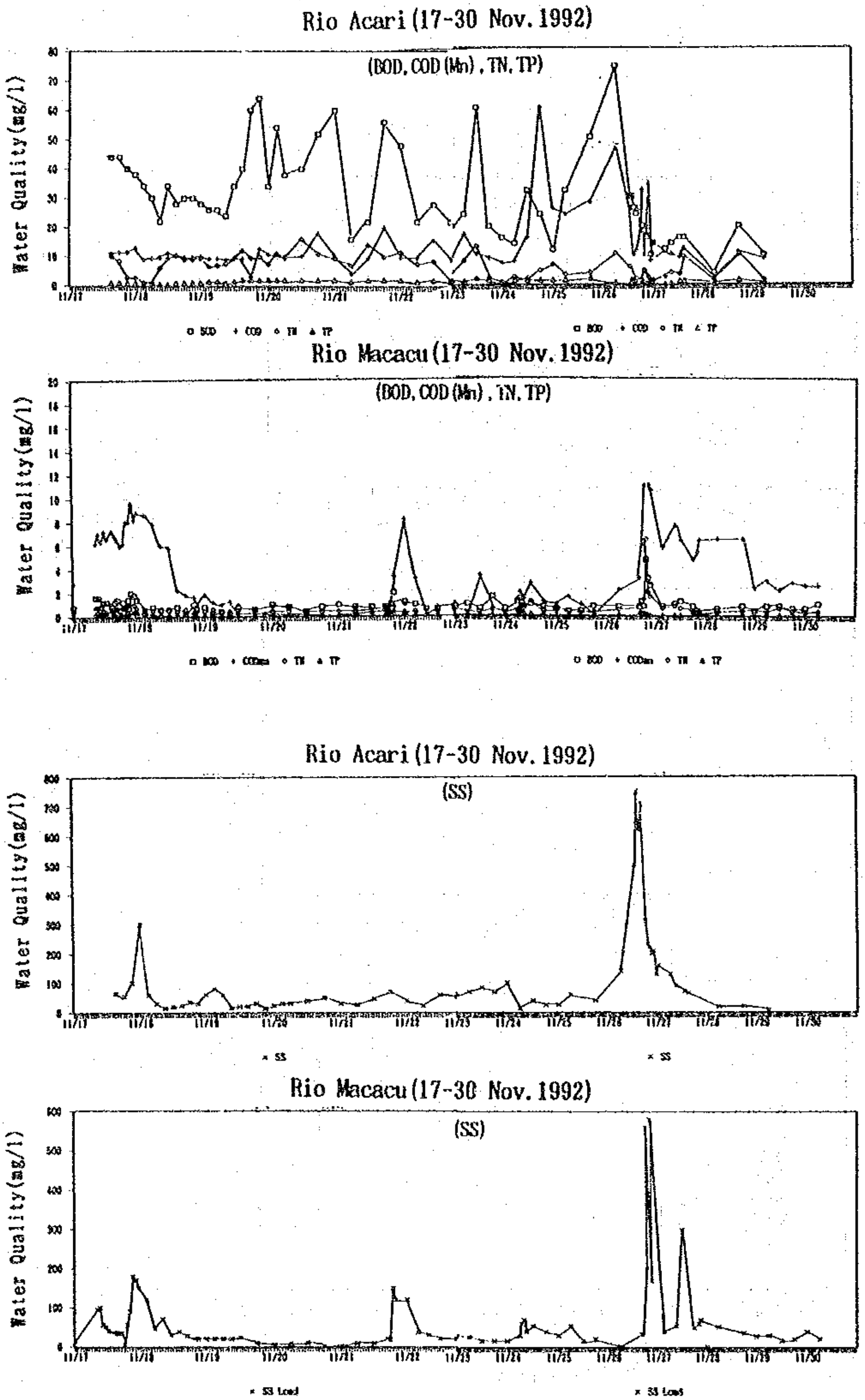


Fig. 9.2-13 Water Quality Change with Time in the two Model Rivers on Rainy Days

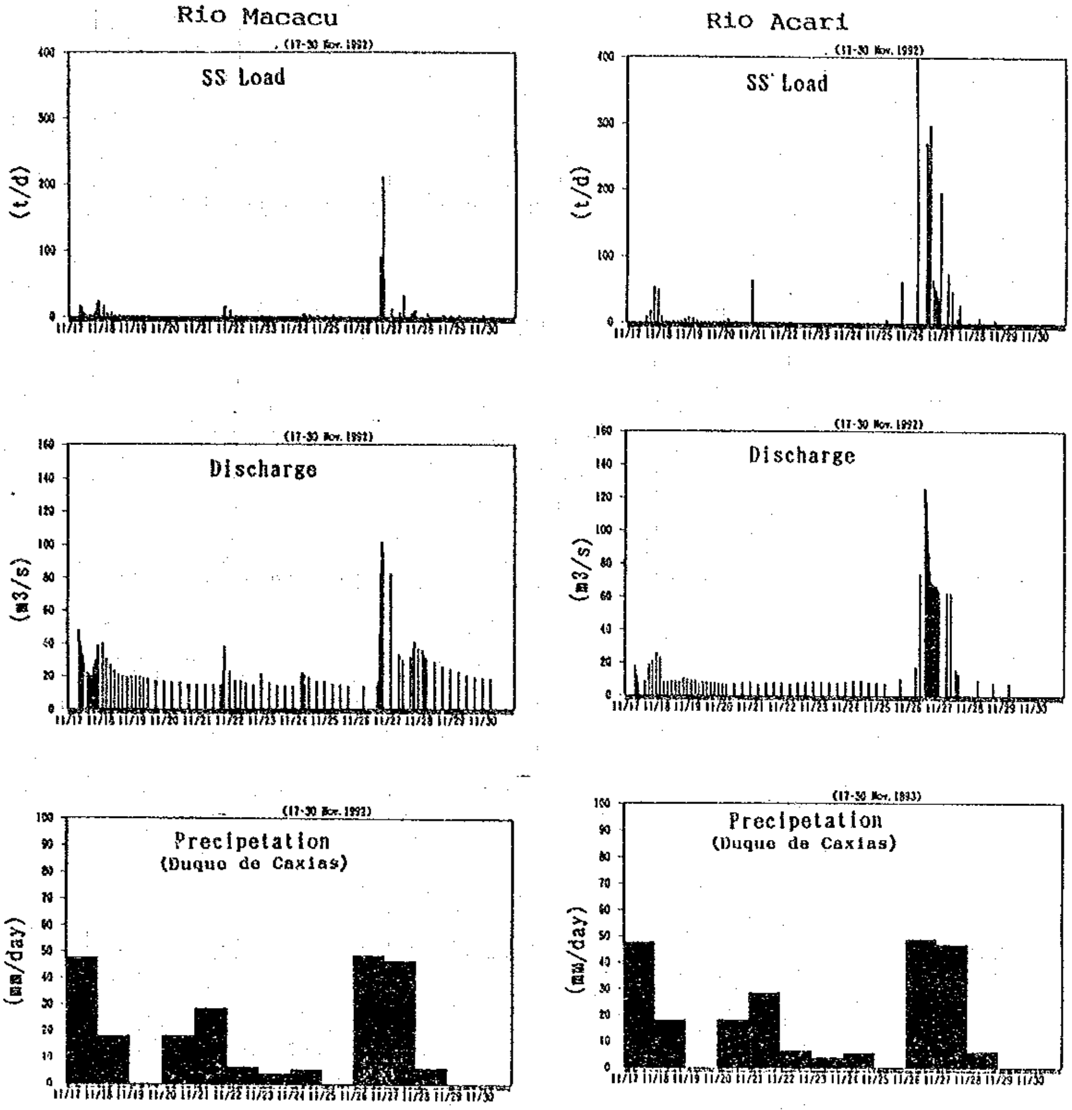


Fig. 9.2-14(1) Runoff Load Change with Time in the two Model Rivers in Freshet Time

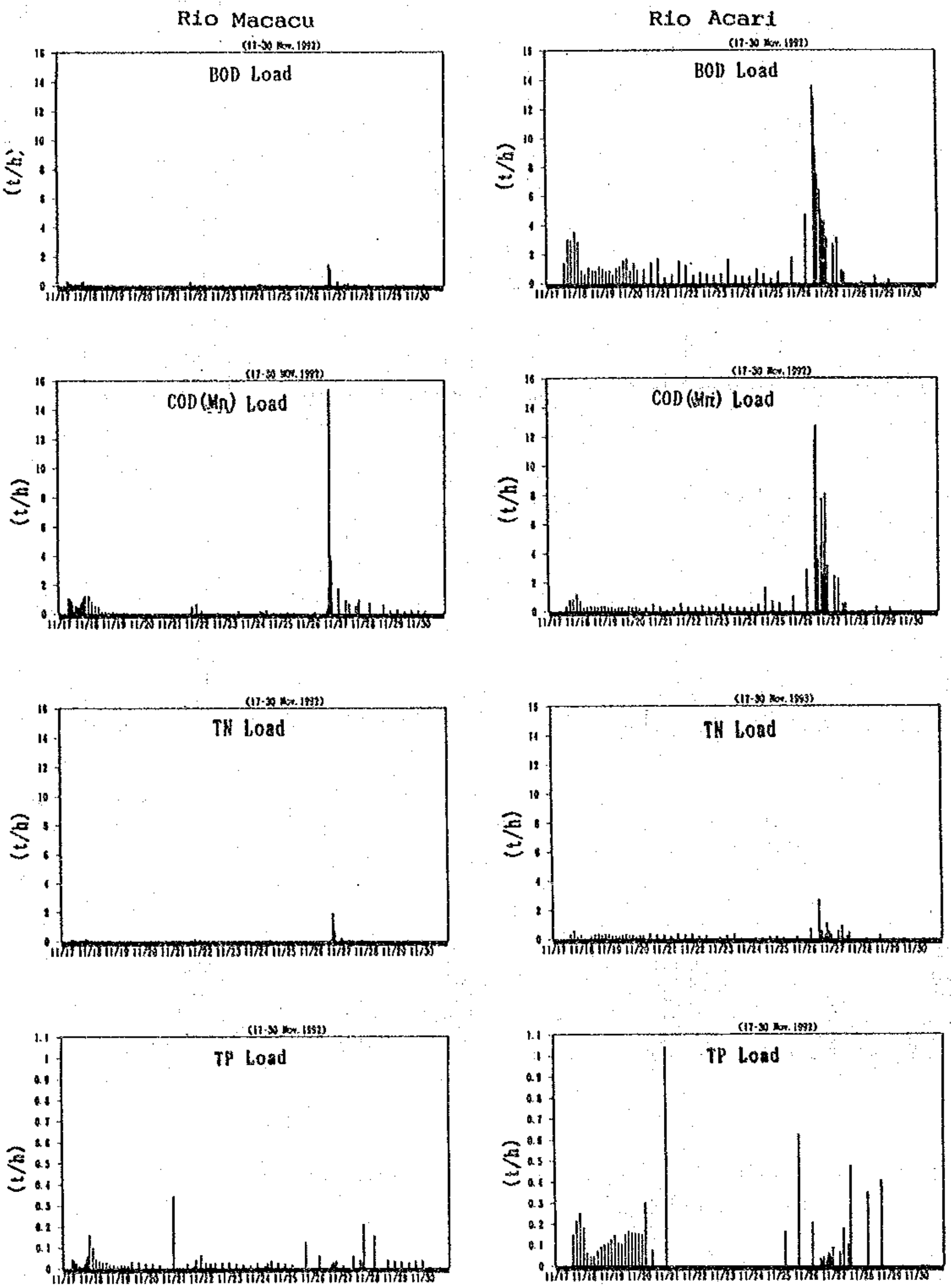
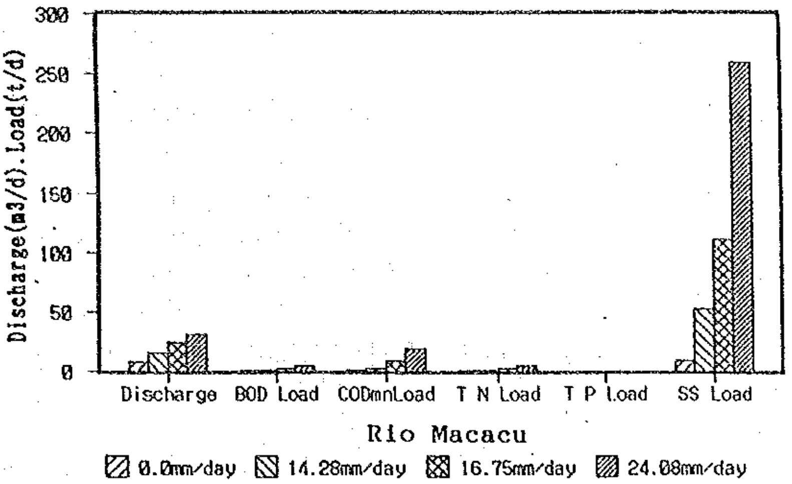


Fig. 9.2-14(2) Runoff Load Change with Time in the two Model Rivers in Freshet Time



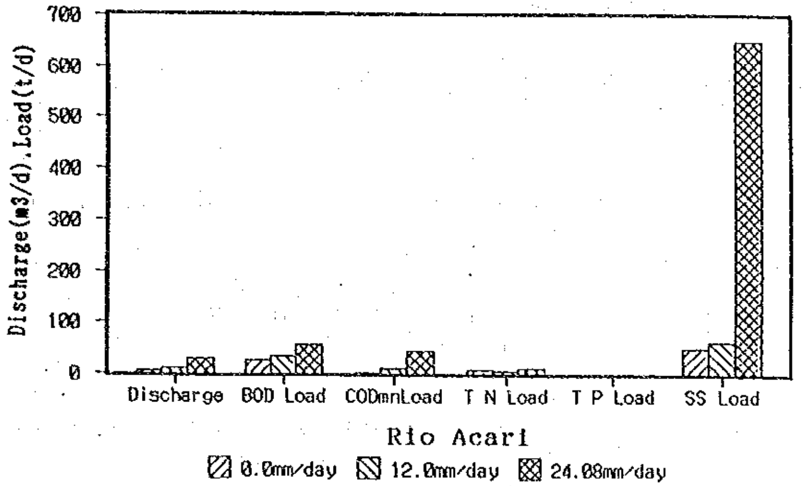


Fig. 9.2-15 Runoff Load Differences with Rain Intensity

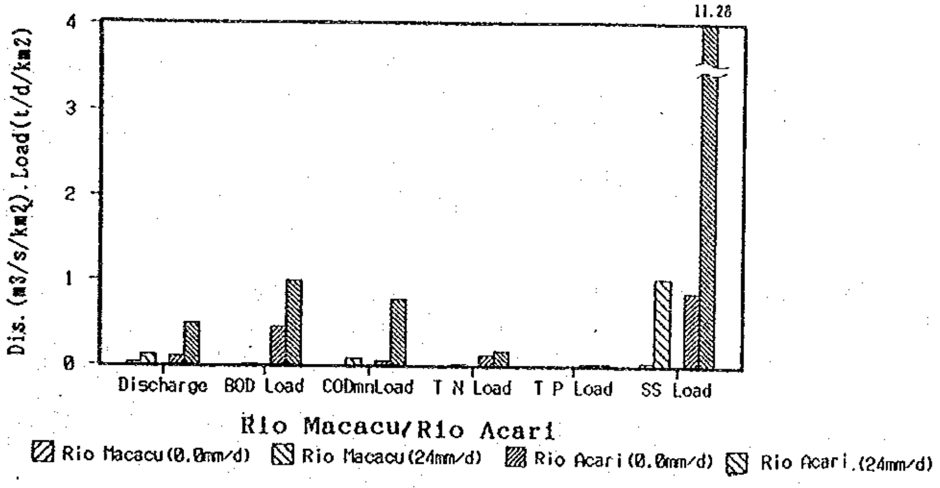


Fig. 9.2-16 Specific Runoff Load Differences with Rainfall Intensity between the two Model Rivers

9.3 Estimate of Runoff Load from the Basin

9.3.1 Need and Function for Estimation Model of Runoff Load

According to the observation data obtained in this survey, the discharge, water quality and runoff load characteristics of the main rivers in the basin were as described in the previous sections. However, in order to estimate the annual runoff load flowing into the bay from each sub-basin with accuracy, measurements should be carried out repeatedly under different conditions and a lengthy period and tremendous effort is needing in accumulating this data.

Accordingly, a runoff load estimation model including the various factors that restrict runoff load was formulated and designed to serve the following six purposes:

(1) To estimate runoff load on rainy days (in the dry and rainy seasons),

(2) To estimate the runoff discharge and runoff load of tidal rivers,

(3) To estimate the runoff loads from uncovered areas of the observation station,

(4) To estimate the future runoff loads according to changes in population,

(5) To estimate the average runoff load over a long period of time,

(6) To estimate an accurate runoff load with the least effort.

According to the pollution runoff mechanism chart (**Fig.9.3-1**), the generated pollution load from each source, and the runoff ratio estimated from the estimated effluent load and actual river runoff load will be used to estimate the runoff load in other basins. This method is called the generated pollution load method.

However, effluent load in the basin cannot be estimated due to insufficient point and non-point source data which is fundamental to such an estimation.

Accordingly, to estimate effluent load from both point and non-point sources, this report collected the basic data on runoff and water quality of model rivers in small basins, calculated their runoff load and used these as the generated pollution load for effluent loads of the larger basins.

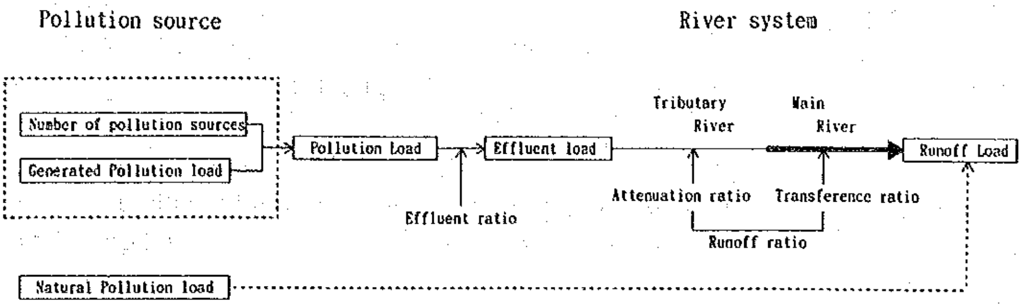


Fig. 9.3- 1 Pollution Runoff Mechanism

9.3.2 Structure of the Estimation Model of Runoff Load

(1) Model Concept

The runoff load from the Guanabara Bay basin is known to be influenced by various factors. From the results of studies carried out on the aforementioned items, rainfall conditions, land use conditions, daily human activities, and industrial activities are the main influential factors.

As the population in the basin grows and the effects of human and industrial activities expand, the size of cities increase and land use conditions change. Therefore, land utilization, human and industrial activities are represented by population density.

Accordingly, runoff load was defined as a function of population density (Dp) and precipitation (Pr) in the basin, and the following equation was established:

L(Runoff load) = f(Dp, Pr)

(2) Estimation Model for Runoff Discharge

The estimation model comprises the runoff discharge model and runoff load model. The elements of each model and their relationship are represented as follows:

Runoff discharge (Q) = base runoff discharge (Qb) +
attained runoff volume of wastewater (Qw)
+ precipitation runoff discharge (Qp)

Runoff load (L) = runoff discharge (Q) x water quality (C) x
runoff ratio (R) **(Fig.9.3-2)**

Runoff discharge on clear days is the value observed when the preceding period of clear days is five days or more. On the other hand, runoff discharge on rainy days is the value observed in other cases.

Runoff discharge on clear days (Qc) = Qb + Qw
Runoff discharge on rainy days (Qr) = Qb + Qw + Qp
(Fig.9.3-3 and 9.3-4)

The basic runoff load in the rainy season is larger than that in the dry season because of rainfall. Therefore, calculations of runoff load should be carried out separately for the dry season and rainy season, using different basic runoff discharge values.

The descriptions of each element are as follows:

(1) Base runoff discharge (Qb)

A base runoff discharge is the constant discharge amount mainly originating from underground water. The base runoff discharge in the natural type river, Rio Macacu, was the lowest flow measured on consecutive clear days.

(2) Attained runoff volume of Waste water (Qw)

Attained runoff volume of waste water is defined, for convenience, as the wastewater amount from every point source reaching the observation stations. It is obtained by subtracting the basic runoff discharge amount (Qb) from the runoff discharge amount (Qc) on clear days.

(3) Precipitation discharge amount (Qp)

The precipitation runoff discharge is the rain-affected amount of water discharged. It is precisely defined as the sum of the runoff discharge measured from the point where discharge increases after rainfall until the point where the runoff discharge returns to the normal level on a clear day. For convenience, the runoff discharge amount when the mean precipitation intensity exceeded 10mm/day was used.

The precipitation runoff discharge varies depending on the scale of rainfall, rainfall intensity, basin characteristics and number of preceding clear days; in actual estimation, relation of these elements to precipitation runoff discharge should be thoroughly analyzed.

In this survey, rainfall amount and the runoff discharges of the two model rivers (natural type and urban type) were used to analyze the relationship between rainfall intensity and precipitation runoff discharge. Precipitation intensity was classified by a notch of 10mm. Runoff discharge largely varies depending on rainfall intensity even if the volumes precipitated are the same. This factor was not represented in this model.

Runoff discharge differs as precipitation varies by area. Originally, the precipitation amount to be used for the model should be the amounts measured at several stations in consideration of rainfall distribution. However, such data was not obtained. The study was, therefore, left with no choice but to use the precipitation data obtained at only one observation station in Duque de Caxias, namely Petrobas, to estimate the precipitation runoff load.

(4) Estimation Model for Runoff Load

Runoff load is represented by the following equation:

Runoff load (L) = base runoff load (Lb) + attained runoff
load of waste water (Lw) + precipitation runoff load (Lp)

(a) Base runoff load (Lb) = load derived from said base runoff discharge

(b) Attained runoff load of waste water (Lw) = Runoff load in clear days minus base runoff load; this value is equivalent to point source runoff load on clear days.

ing to rainfall, precipitation runoff load when rainfall intensity is 10mm/day or more.

Runoff load is obtained by using the empirical equation to represent relation between runoff discharge and runoff load. Runoff load varies to a great extent depending on the number of preceding clear days and rainfall intensity. This factor is not represented in this model because of deficiencies in the data.

(d) Runoff ratio

The process of the pollutants being discharged from their source and flowing into a river is defined as attenuation, the linear process of flowing downstream as transference, and the whole flow process from the source to the observation station as runoff. Thus runoff ratio is the product of the attenuation ratio and transference ratio. Runoff ratio is the ratio of pollution load that reaches a reference point to all the total pollution load discharged in the basin.

Runoff ratio is influenced by the size of the basin, river bed conditions, runoff time and discharge. Of these, discharge most controls the runoff ratio thus influencing the ratio largely between clear days and rainy days. Survey results in Japan report that BOD runoff ratio is directly proportional to population density/(basin area)$^{1/2}$.

Here the relationship between the two is obtained assuming X=log(runoff ratio, %) and Y=log (population density/(basin acreage)$^{1/2}$) to calculate the discharge and runoff rate of BOD and COD(Mn). T-N, T-P and SS are assumed to be as soluble and runoff ratio is calculated by using the same equation as that for discharge.

Runoff ratio is calculated by using the observation data of a group of rivers. Runoff ratio is shown in **Fig.9.3-5.**

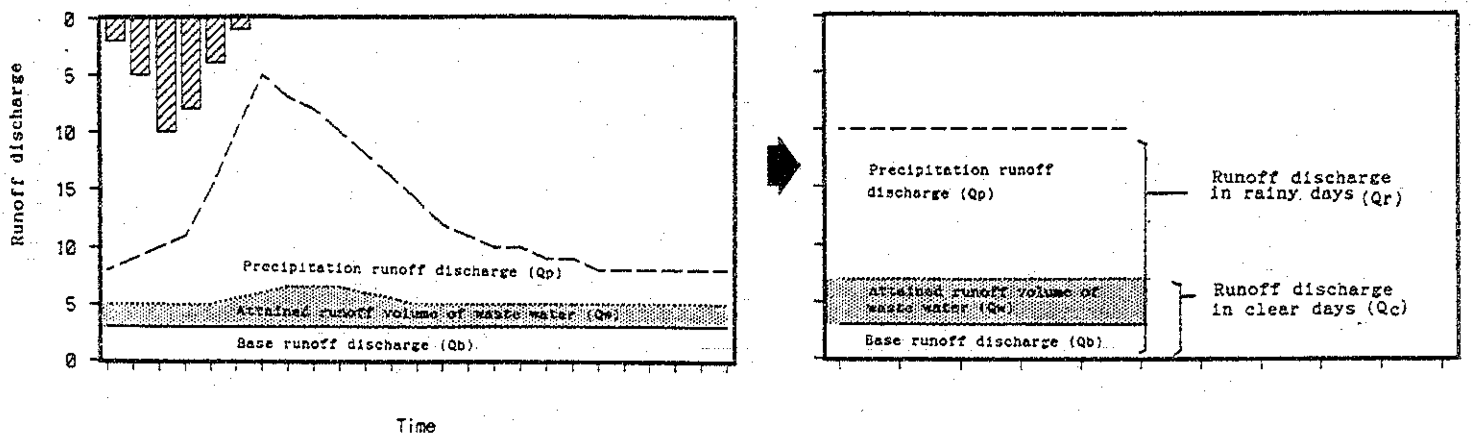


Fig. 9.3- 2 Schematic Hydrograph and Constitution of Discharge

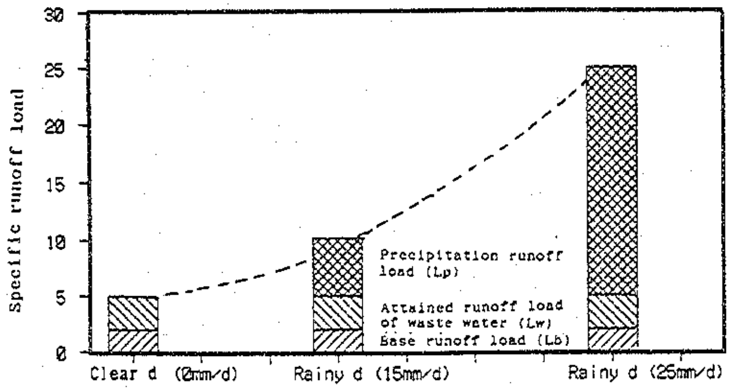


Fig. 9.3- 3 Runoff Load Differences between Clear Days and Rainy Days

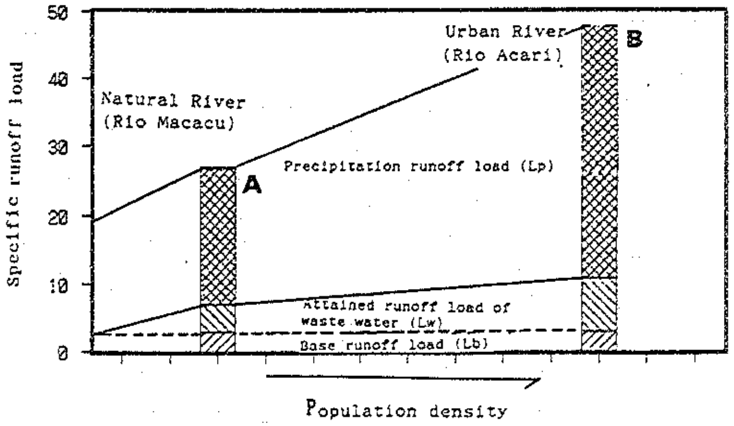


Fig. 9.3- 4 Runoff Load Constitution of Natural Type and Urban Type Rivers

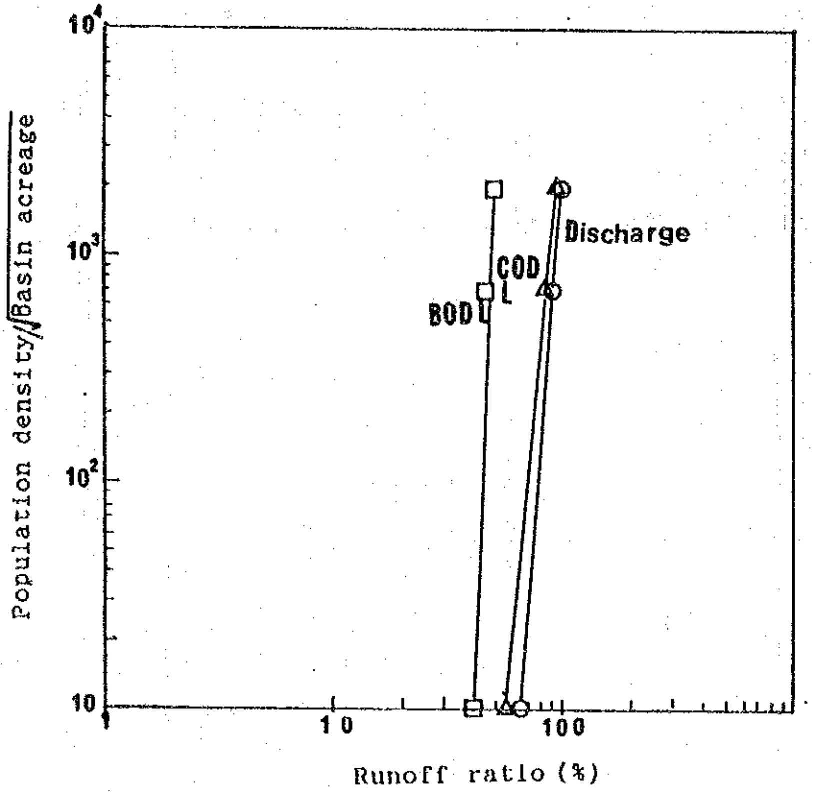


Fig. 9.3- 5 Relationship between Runoff Ratio and Population Density/Basin Area

9.3.3 Procedure for Calculation of Runoff Discharge and Runoff Load

The annual runoff load was calculated in accordance with the operation flow chart (**Fig. 9.3-6.**).

Annual runoff load = runoff load on clear days + runoff load on rainy days
= runoff load in the dry season + runoff load in the rainy season.

The specific runoff volume and specific runoff load have a linear relation on log-log diagram for suspension solids, abundant at the initial stages of rainfall.

Therefore the runoff load; for water quality parameters with high runoff ratios in the initial stages (e.g., BOD, COD,TN,TP and SS) and are discharged as suspended solids, were calculated using the regression model.

Further, the specific load of each river was determined using population density; which strongly correlates to basin land utilization and generation load-factors that largely influence specific load; as a parameter.

Runoff load on clear and rainy days was calculated using the Separation Method 1, shown in **Fig. 9.3-7.**

Assumptions for the calculation of runoff load on clear days and runoff load on rainy days, to be carried out separately, are described below.

(1) Runoff load on clear days = base runoff load + attained runoff load
Base runoff load (discharge) = minimum value over 24-hour continuous observation (runoff load)

(2) Calculation of the runoff ratio on clear days (re)
Runoff ratio = runoff load (measured value)/effluent load(estimated value)
Runoff ratio of each basin was calculated from population density, basin area and the measured runoff ratio of the model rivers.

Runoff ratio on rainy days was obtained from the precipitation per day and specific runoff discharge per day.

(3) Runoff load per day on clear days = specific runoff load x basin area.

(4) Calculation of rainy days by rainfall scales
Annual precipitation is arranged as precipitation per one continuous rainfall and classified in scales of 10mm to calculate rainy days by months.

(5) Calculation of specific runoff load of each basin by rainfall graphs.
Rainfall exceeding 10mm is classified into scales of 10mm. The runoff load for the mean precipitation of rainfall scales was obtained using the regression model; then the value was multiplied by the number of rainfalls (number of rainy days) in order to calculate the runoff load of each rainfall scale.

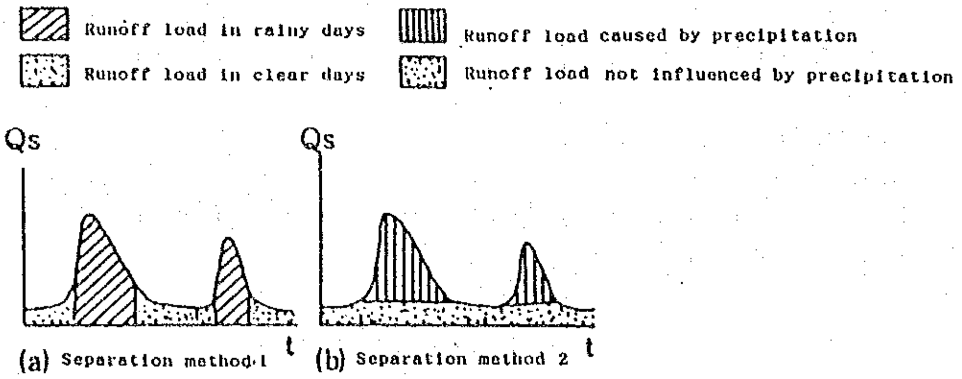
(6) Calculation of specific runoff load of each basin on rainy days

(7) Runoff load per day on rainy days = specific runoff load per day x basin area.

(8) Runoff load per month = runoff load on rainy days in each month + runoff load on clear days in each by month

(9) Annual runoff load = runoff load in the dry season + runoff load in the rainy season

(10) Runoff loads of unsurveyed areas, downstream of observation stations, were calculated for each basin assuming that the basins are homogeneous.



(a) Separation method 1 (b) Separation method 2

Fig. 9.3- 7 Concept of Separation Methods

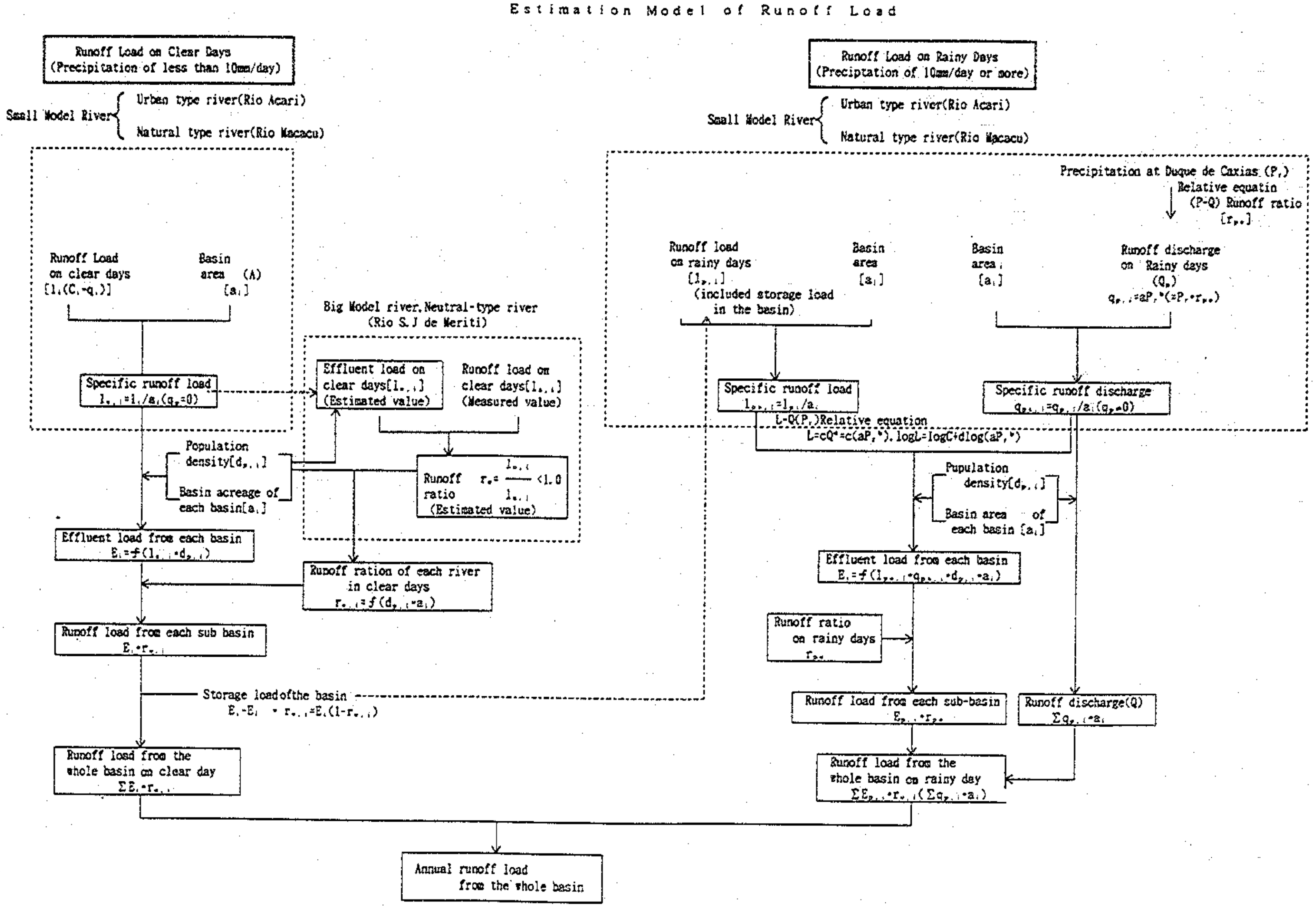


Fig. 9.3- 6 Procedure for Calculation of Annual Runoff Load

9.3.4 Setting of Parameters

(1) Runoff ratio (re)

The relationship between runoff ratio on clear days (X) and population density/(basin acreage)$^{1/2}$ (Y) can be calculated using the following equation: $Y = a*X^b$ (see **Fig.9.3-5**). Runoff ratio on rainy days is assumed to be 1.0, because it is included in the relationship between precipitation and runoff discharge.

Indicator	Equation	Coefficient of correlation
Discharge (TN, TP, SS)	$Y=3.382*X^{14.73}$	0.995
BOD	$Y=4*10^{\wedge}9*X^{29.79}$	0.999
CDD (Mn)	$Y=5.70*X^{11.97}$	0.995

(2) Runoff discharge (mean discharge)(Q)

The relationship between discharge (Q) and precipitation (mean precipitation (Pr)) in the model rivers can be obtained using the following equation:

$$Q = aPr^b$$

River Name	Equation	Coefficient of correlation
Rio Macacu	$Q=0.00106R^{1.525}$	0.967
Rio Acari	$Q=0.00279R^{1.626}$	0.991

(3) Runoff load (L)

The relationship between runoff discharge (Q) and runoff load(L) can be determined through the following equation:

Empirical equation: $L = cQ^d$

Therefore,

$$\log L = \log c + d * \log(aPr^b)$$

Indicator	Equation	Coefficient of correlation	Equation	Coefficient of correlation
BOD Load	$L = 0.045Q^{0.599}$	0.832	$L = 1.463Q^{0.540}$	1.000
COD(Mn) Load	$L = 10.998Q^{2.447}$	0.975	$L = 3.170Q^{1.847}$	0.993
TN Load	$L = 0.328Q^{1.497}$	0.986	$L = 0.192Q^{0.266}$	0.861
TP Load	$L = 0.040Q^{1.632}$	0.934	$L = 0.011Q^{-0.293}$	0.996
SS Load	$L = 190.957Q^{2.506}$	0.997	$L = 37.200Q^{1.811}$	0.969

* L:t/d/km^2, Q:m^3/s/km^2

(4) specific discharge (Qs) and specific runoff load (Ls) by Population Density (D)

The relationship between population density (Dp) and specific runoff load (L) can be obtained using the following equations:

$$Ls\ (Qs) = e * Dp + f$$

Dp : population density (people/km^2)
e,f: coefficients

Mean rainfall in runoff period; <10mm/day, 10-20mm/day, 20-30mm/day, 30-40mm/day

Established precipitation : 0mm/day, 15mm/day, 25mm/day, 35mm/day

Indicator	Precipitation	Instituted Precipitation	Dry Season	Rainy Season
Discharge	0-10mm/day	<10mm/day	Qs=0.0105D+0.0251	Qs=0.0101D+0.0305
	10-20mm/day	15mm/day	Qs=0.0243D+0.0444	Qs=0.0239D+0.0471
	20-30mm/day	25mm/day	Qs=0.0584D+0.0817	Qs=0.0580D+0.0845
	30-40mm/day	35mm/day	Qs=0.1027D+0.1278	Qs=0.1023D+0.1306
BOD Load	0-10mm/day	<10mm/day	Ls=0.0641D+0.0022	Ls=0.0582D+0.0035
	10-20mm/day	15mm/day	Ls=0.0865D+0.0035	Ls=0.0865D+0.0040
	20-30mm/day	25mm/day	Ls=0.1357D+0.0044	Ls=0.1356D+0.0049
	30-40mm/day	35mm/day	Ls=0.1824D+0.0052	Ls=0.1823D+0.0057
COD(Mn) Load	0-10mm/day	<10mm/day	Ls=0.0072D+0.0012	Ls=0.0057D+0.0026
	10-20mm/day	15mm/day	Ls=0.0264D+0.0066	Ls=0.0264D+0.0073
	20-30mm/day	25mm/day	Ls=0.1209D+0.0432	Ls=0.1209D+0.0432
	30-40mm/day	35mm/day	Ls=0.3275D+0.1537	Ls=0.3274D+0.1543
TN Load	0-10mm/day	<10mm/day	Ls=0.0123D+0.0010	Ls=0.0152D+0.0010
	10-20mm/day	15mm/day	Ls=0.0167D+0.0028	Ls=0.0167D+0.0028
	20-30mm/day	25mm/day	Ls=0.0202D+0.0088	Ls=0.0202D+0.0088
	30-40mm/day	35mm/day	Ls=0.0222D+0.0190	Ls=0.0222D+0.0190
TP Load	0-10mm/day	<10mm/day	Ls=0.0036D+0.0000	Ls=0.0026D+0.0000
	10-20mm/day	15mm/day	Ls=0.0021D+0.0002	Ls=0.0021D+0.0002
	20-30mm/day	25mm/day	Ls=0.0016D+0.0008	Ls=0.0016D+0.0008
	30-40mm/day	35mm/day	Ls=0.0012D+0.0019	Ls0.0012D+0.0019
SS Load	0-10mm/day	<10mm/day	Ls=0.0470D+0.0251	Ls=0.1107D+0.0231
	10-20mm/day	15mm/day	Ls=0.3241D+0.1026	Ls=0.3242D+0.1020
	20-30mm/day	25mm/day	Ls=1.4298D+0.6874	Ls=1.4298D+0.6868
	30-40mm/day	35mm/day	Ls=3.7660D+2.5073	Ls=3.7661D+2.5067

(5) Specific runoff load (Ls)

(a) Base runoff (Qb) and base load (Lb)

Base runoff and base load were obtained from the data (minimum runoff discharge) of the 24-hour observation conducted on the natural type river, Rio Macacu.

Discharge (m^3/s/km^2)	BOD Load (t/d/km^2)	COD(Mn) Load (t/d/km^2)	TN Load (t/d/km^2)	TP Load (t/d/km^2)	SS Load (t/d/km^2)
0.031	0.005	0.002	0.001	0.000	0.020

(b) Specific runoff discharge per day (Qs) and specific runoff load per day (Ls) on clear days

Specific runoff discharge per day and specific runoff load per day were obtained from the data of the 24-hour observation conducted in Rio Macacu and Rio Acari on clear days.

River Name	Discharge (m^3/s/km^2)	BOD Load (t/d/km^2)	COD(Mn) Load t/d/km^2)	TN Load (t/d/km^2)	TP Load (t/d/km^2)	SS Load (t/d/km^2)
Rio Macacu	0.032	0.006	0.003	0.002	0.000	0.034
Rio Acari	0.108	0.444	0.046	0.116	0.020	0.861

(c) Runoff discharge (Qp) and runoff load (Pr) on rainy days

The runoff discharge and runoff amount on rainy days were obtained from the data of the observations conducted on the two model rivers, on rainy days.

Natural type river (Rio Macacu)

Precipitation (mm/day)	Discharge (m^3/s/km^2)	BOD Load (t/d/km^2)	COD(Mn) Load (t/d/km^2)	TN Load (t/d/km^2)	TP Load (t/d/km^2)	SS Load (t/d/km^2)
14.28	0.063	0.005	0.008	0.005	0.0005	0.203
16.75	0.094	0.008	0.035	0.008	0.001	0.432
24.08	0.119	0.016	0.074	0.016	0.001	1.014

Urban type river (Rio Acari)

Precipitation mm/day	Discharge (m^3/s/km^2)	BOD Load (t/d/km^2)	COD(Mn) Load (t/d/km^2)	TN Load (t/d/km^2)	TP Load (t/d/km^2)	SS Load (t/d/km$_2$)
12.00	0.177	0.567	0.157	0.106	0.018	1.089
24.08	0.481	0.990	0.772	0.165	0.013	11.264

(6) Precipitation (Pr) (Data obtained from the Petrobras observation station at Duque de Caxias, 1992)

Mean precipitation in the runoff period was classified by rainfall scales, and number of rainy days by rainfall scales was obtained (see **Table 9.3-1**).

(7) Basin area (A) and Population density (D)

Basin area covered by observation stations, uncovered area, whole basin area and population density are shown in **Table 9.3-2** and **9.3-3**.

Table 9.3- 1 Rainy Days during the Survey Period by Rainfall Scales

(1992)

	Rainy season			Dry season						Rainy season		
Precipetation	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
<10mm/d	19	26	27	27	29	30	29	30	28	23	15	28
10-20mm/d	4	0	3	0	2	0	2	0	0	5	5	0
20-30mm/d	8	3	1	3	0	0	0	0	0	3	7	3
30mm< /d	0	0	0	0	0	0	0	0	3	0	3	0
	31	29	31	30	31	30	31	30	31	31	30	31

Table 9.3- 2 Details of Basin Areas of the 25 Major Rivers Surveyed

NO	NAME	Basin Area NO.	Basin Area (A)=(B)+(C (A)km2	Covered Basin Area (B)km2	Uncovered Basin Area (C)km2	Population of Basin Area	Population Density (*10¯3/km2)
1 CI780	CANAL CANTO DO RIO	2	7.40	7.40	0.00	41,745	5.64
2 BM760	RIO BOMBA	5	26.20	3.40	22.80	183,099	6.99
3 IB810	RIO IMBOASSU	6	30.80	11.60	19.20	138,636	4.50
4 AN740	RIO ALCANTARA	8	144.60	58.50	68.80	470,420	3.25
5 MT820	RIO MUTONDO	8		5.50			
6 GX720	RIO GUAXINDIBA	8		11.80			
7 CC622	RIO CACEREBU	9	846.70	758.40	88.30	336,193	0.40
8 GP600	RIO GUAPIMIRIM	10	1253.10	1233.70	19.40	69,853	0.06
*9 MC967	RIO MACACU	10-3	256.00	256.00	0.00	18,577	0.07
*10 SB998	RIO SOBERBO	10-6	132.40	45.20	87.20	17,911	0.14
11 MG580	CANAL DE MAGE	11	18.30	4.60	13.70	8,458	0.46
12 RN560	RIO RONCADOR	12	111.40	107.00	4.40	36,370	0.33
13 IR540	RIO IRIRI	13	27.80	8.40	19.40	10,684	0.38
14 SR500	RIO SURUI	14	68.80	53.20	15.60	12,910	0.19
15 ES400	RIO ESTRELA	16	342.50	342.50	0.00	302,495	0.88
*16 IN460	RIO INHOMIRIN	16-2	139.00	139.00	0.00	84,106	0.61
*17 SC420	RIO SARACURUNA	16-3	186.00	186.00	0.00	194,173	1.04
18 IA260	RIO ICUACU	17-1¯5	562.80	544.20	18.60	758,010	1.35
19 SP300	RIO SARAPUI	17-6	165.50	159.80	5.70	1,012,275	6.12
20 SJ220	RIO S.J.DE MERITI	19	164.50	163.50	1.00	1,492,458	9.07
*21 AC241	RIO ACARI	19-2	57.90	57.90	0.00	438,076	7.57
22 IJ200	RIO IRAJA	20	35.70	27.30	8.40	500,276	14.01
23 PN180	CANAL DO PENHA	20	-	-	0.00		
24 CN100	CANAL DO CUNHA	21	63.60	60.50	3.10	815,389	12.82
25 MN000	CANAL DO MANGUE	23	42.80	42.80	0.00	500,876	11.70
	TOTAL		3912.50	3604.10	308.40	6,690,147	1,709.94

*:Tributary river (Excluded from Total amount)

Table 9.3- 3 Area, Population and Population Density by Sub-Basin

Name	Basin Area NO.	Basin Area (A)=(B)+(C) (A)km2	Covered Basin Area (B)km2	Uncovered Basin Area (C)km2	Covered Ratio(%) (B/A*100)	Population	Population Density (*10¯3/km2)
B.-CHARITAS	1	9.40	0.00	9.40	0	53,310	5.67
CANAL CANTO DO RIO	2	7.40	7.40	0.00	100	41,745	5.64
B.-CATEDRAR	3	7.80	0.00	7.80	0	37,458	4.80
B.-NORTE CENTRO	4	7.90	0.00	7.90	0	43,607	5.52
RIO BOMBA	5	26.20	3.40	22.80	13	183,099	6.99
RIO IMBOASSU	6	30.80	11.60	19.20	38	138,636	4.50
B.-ITAOCA	7	6.40	0.00	6.40	0	31,925	4.99
RIO ALCANTARA	8	144.60	75.80	68.80	52	470,420	3.25
RIO CACEREBU	9	846.70	758.40	88.30	90	336,193	0.40
RIO GUAPIMIRIM	10	1253.10	1233.70	19.40	98	69,853	0.06
CANAL DE MAGE	11	18.30	4.60	13.70	25	8,458	0.46
RIO RONCADOR	12	111.40	107.00	4.40	96	36,370	0.33
RIO IRIRI	13	27.80	8.40	19.40	30	10,684	0.38
RIO SURUI	14	68.80	53.20	15.60	77	12,910	0.19
B.-MAUA	15	28.90	0.00	28.90	0	8,541	0.30
RIO ESTRELA	16	342.50	342.50	0.00	100	302,495	0.88
RIO IGUACU	17-1¯5	562.80	544.20	18.60	97	758,010	1.35
RIO SARAPUI	17-6	165.50	159.80	5.70	97	1,012,275	6.12
B.-CABO DO BRITO	18	27.00	0.00	27.00	0	132,091	4.89
RIO S.J.DE MERITI	19	164.50	163.50	1.00	99	1,492,458	9.07
RIO IRAJA	20	35.70	27.30	8.40	76	500,276	14.01
CANAL DO CUNHA	21	63.60	60.50	3.10	95	815,389	12.82
B.-S.CRISTOVAO	22	6.60	0.00	6.60	0	60,011	9.09
CANAL DO MANGUE	23	42.80	42.80	0.00	100	500,876	11.70
B.-BOTAFOGO	24	26.00	0.00	26.00	0	358,622	13.79
I. DO GAVANADOR	25	38.20	0.00	38.20	0	153,903	4.03
I. DO FUNDAO	26	5.40	0.00	5.40	0	5,277	0.98
I. DE PAQUETA	27	1.70	0.00	1.70	0	3,254	1.91
I. DO ENGENHO	28	1.30	0.00	1.30	0	11,034	8.49
I. DE S.CRUZ	29	1.40	0.00	1.40	0	4,851	3.47
Total		4080.50	3604.10	476.40	88	7,594,031	

9.3.5 Calculation Results and its Validation

(1) Calculation results

The total runoff load of the 20 largest rivers (basin area covered: 3,604.1 km^2), determined using the parameters defined in 9.3.4 and following the steps described in **Fig.9.3-6**, is shown in **Fig. 9.3-8** and **Table 9.3-4**. The calculation was based on the precipitation data in 1992 and the population data in 1991. **Fig.9.3-9** and **Table 9.3-5** show the annual runoff loads on clear days and rainy days and in the rainy and dry seasons, and also the runoff load not influenced by precipitation and runoff load caused by precipitation.

The daily mean discharge of the 20 rivers directly flowing into the bay was estimated at 190.2 m^3/s, with a BOD load of 258.5 tons/day and a TN load of 91.9 tons/day.

40 to 50% of the annual discharge and BOD load, and 20% of the annual TN load were estimated to runoff from the basin during the rainy season (55 days in a year).

The runoff load ratio on rainy days was calculated based on the results of observations conducted after a short spell of rainfall of comparatively light intensity, hence, this ratio may be smaller than actuality. Yet the ratio of the runoff load in the rainy season to the annual load is significantly large.

By the way, the importance of the runoff load on rainy days was only recognized in Japan from the 1980s (the survey results are shown in the S/R).

(2) Comparison of the estimate value and measured value

Fig.9.3-10 compares of the estimate values and measured values. As far as this figure is concerned, the model used here closely reflects the measured values and the transition tendencies of the values. Accordingly, this model is effective in predicting runoff load from the basin.

(3) Estimation of runoff load from the entire basin area including uncovered basin area

Runoff loads for the rainy/dry season and annual runoff load in

1992 calculated by the estimation model are shown in **Table 9.3-6**.

(a) Annual runoff load

The mean runoff discharge per day from the entire basin (basin area covered: 4,080.5 km^2) was estimated at 230.2 m^3/s, and the BOD and TN loads in the runoff load are 330.6 tons/day and 116.2 tons/day respectively. **Fig. 9.3-11** shows the contribution ratio of each basin for various water quality items. BOD was observed to have been largely contributed by the Rio S.J.de Meriti (16.1%), Rio Sarapui (10.8%), Canal do Cunha (9.0%) and Rio Iguacu (7.8%). The runoff discharge and runoff load of each sub-basin are shown in **Fig. 9.3-12**.

(b) Runoff load during rainy and dry seasons

The ratio of the runoff loads in the rainy season and the dry season is of 6:4 in terms of BOD and TN. Yet, as aforementioned, the runoff discharge and runoff load during the rainy season; calculated based on the data from observations that were conducted (1) during a rainfall cycle preceded by a short period of clear days, (2) a light rainfall intensity of 25mm/day and (3) with a serious mistake of missing the measurement of the first flush; are likely to be smaller than the actual values.

On these grounds, the ratio of the rainy and dry seasons was revised to 7:3 in 1992.

TP load in the rainy and dry seasons had a ratio of 4:6, contrary to the other items, supposedly because data on water quality used in the calculation was obtained in the second rainfall observation, and the inorganic phosphorus concentration was not obtained as it was not detected during the first rainfall.

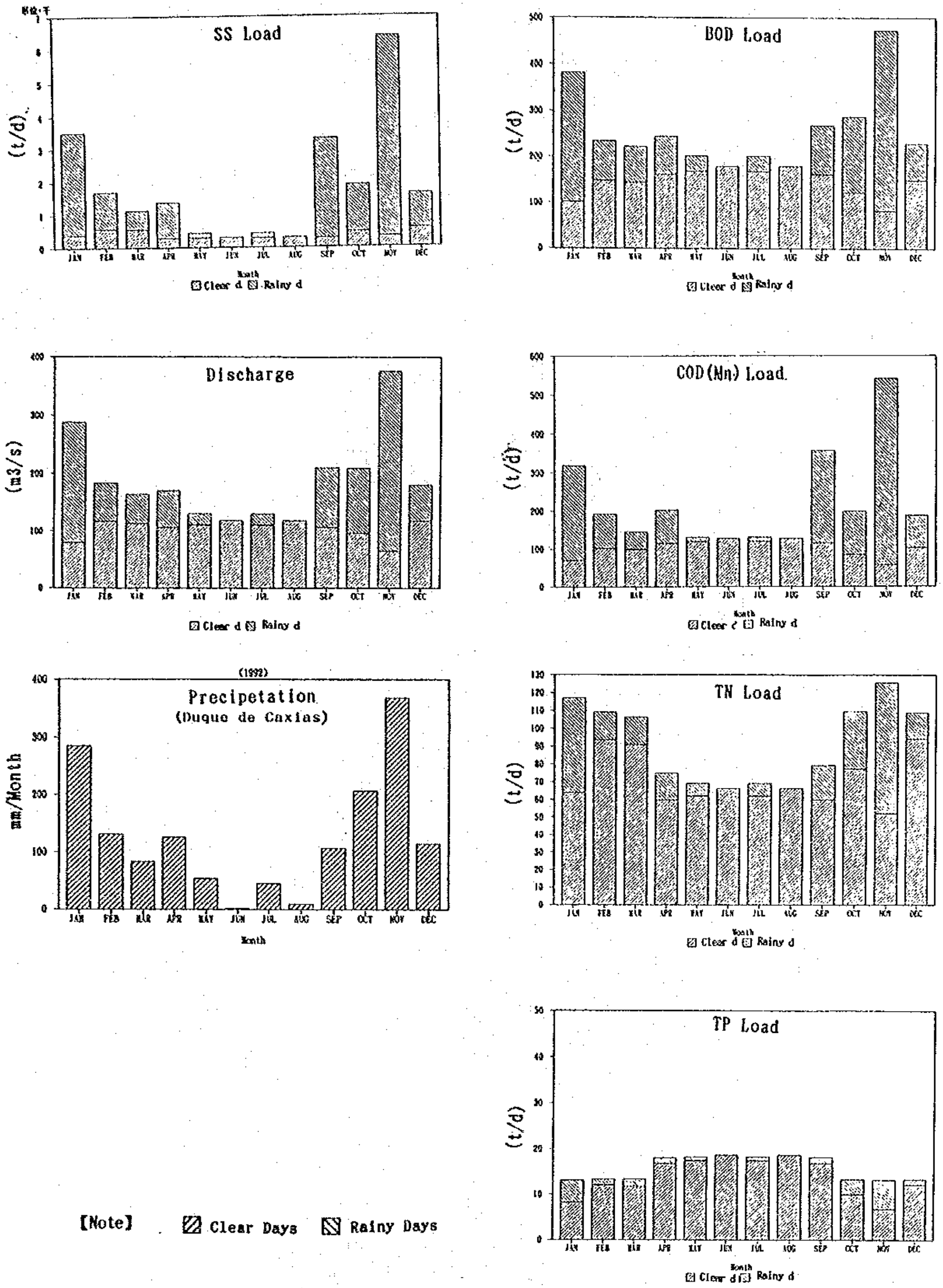


Fig. 9.3- 8 Estimated Monthly Runoff Load from the 20 Rivers

Table 9.3-4 Estimated Runoff Load from the 20 Rivers

No	Name	Covered Basin Area (Km2)	NO.	Basin Area (Km2)	Population	Population Density (p/Km2)	Land use Type	Rainy season Dischar (m3/s)	Rainy season BOD. Load (t/d)	Rainy season CODmn. Load (t/d)	Rainy season TN. Load (t/d)	Rainy season TP. Load (t/d)	Rainy season SS. Load (t/d)	Dry season Discharge (m3/s)	Dry season BOD. Load (t/d)	Dry season CODmn. Load (t/d)	Dry season TN. Load (t/d)	Dry season TP. Load (t/d)	Dry season SS. Load (t/d)	Mean Value Discharge (m3/s)	Mean Value BOD. Load (t/d)	Mean Value CODmn. Load (t/d)	Mean Value TN. Load (t/d)	Mean Value TP. Load (t/d)	Mean Value SS. Load (t/d)
1 C1780	CANAL CANTO DO RIO	7.40	2	7.40	41,745	5.64	Urb/S.T	1.10	2.15	1.70	0.73	0.10	16.60	0.73	1.54	1.27	0.52	0.14	6.19	0.92	1.84	1.49	0.62	0.12	11.40
2 BM760	RIO BOMBA	3.40	5	26.20	183,099	5.99	Urban	0.60	1.23	0.97	0.42	0.06	9.40	0.41	0.89	0.75	0.31	0.08	3.50	0.51	1.06	0.86	0.36	0.07	6.45
3 IB810	RIO IMBOASSU	11.60	6	30.80	138,635	4.50	Urban	1.45	2.67	2.13	0.91	0.12	21.01	0.96	1.90	1.57	0.64	0.17	7.84	1.21	2.29	1.85	0.77	0.15	14.43
4 AN740	RIO ALCANTARA	58.50	8	144.60	470,420	3.25	Urban	5.74	9.63	7.75	3.27	0.42	77.97	3.70	6.75	5.44	2.20	0.58	29.12	4.72	8.19	6.59	2.73	0.50	53.54
5 MT820	RIO MUTONDO	5.50	8			3.25	Urban	0.56	0.92	0.75	0.33	0.04	7.45	0.37	0.66	0.55	0.22	0.06	2.80	0.46	0.79	0.65	0.27	0.05	5.13
6 GX720	RIO GUAXINDIBA	11.80	8			3.25	Urban	1.19	1.96	1.60	0.69	0.09	15.89	0.78	1.39	1.15	0.47	0.12	5.97	0.98	1.68	1.37	0.58	0.11	10.93
7 CC622	RIO CACEREBU	758.40	9	846.70	336,193	0.40	N/A	30.91	16.05	20.07	9.09	0.66	223.35	18.76	10.49	10.94	3.62	0.77	90.27	24.84	13.27	15.51	6.36	0.72	156.81
8 GP600	RIO GUAPIMIRIM	1233.70	10	1253.10	69,353	0.06	N/A	40.30	5.84	17.66	8.52	0.31	215.06	23.43	3.36	7.89	1.87	0.21	92.27	31.87	4.60	12.77	5.20	0.26	153.66
*9 MC957	RIO MACACU	256.00	10-3	256.00	18,577	0.07	N/A	8.70	1.43	3.89	1.91	0.07	46.35	5.18	0.85	1.79	0.44	0.05	19.96	6.94	1.14	2.84	1.18	0.06	33.15
*10 SB998	RIO SOBERBO	45.20	10-6	132.40	17,911	0.14	N/A	1.66	0.39	0.81	0.40	0.02	9.24	1.02	0.25	0.40	0.11	0.02	3.95	1.34	0.32	0.60	0.25	0.02	6.60
11 MG580	CANAL DE MAGE	4.60	11	18.30	8,458	0.46	N/A	0.21	0.12	0.14	0.07	0.01	1.49	0.13	0.08	0.08	0.03	0.01	0.61	0.17	0.10	0.11	0.05	0.01	1.05
12 RN560	RIO RONCADOR	107.00	12	111.40	36,370	0.33	N/A	4.33	1.92	2.63	1.23	0.08	29.06	2.68	1.26	1.43	0.46	0.09	11.97	2.51	1.59	2.03	0.85	0.09	20.52
13 IR540	RIO IRIRI	8.40	13	27.80	10,684	0.38	N/A	0.36	0.18	0.23	0.11	0.01	2.48	0.23	0.12	0.13	0.04	0.01	1.03	0.30	0.15	0.18	0.08	0.01	1.75
14 SR500	RIO SURUI	53.20	14	68.80	12,910	0.19	N/A	2.01	0.60	1.05	0.51	0.03	11.86	1.24	0.38	0.54	0.16	0.03	5.02	1.63	0.49	0.79	0.33	0.03	8.44
15 ES400	RIO ESTRELA	342.50	16	342.50	302,495	0.88	N/A	17.40	15.43	15.05	6.55	0.63	160.29	10.79	10.40	9.14	3.37	0.82	62.39	14.10	12.92	12.09	4.96	0.72	111.33
*16 IN460	RIO INHOMIRIM	139.00	16-2	139.00	84,106	0.61	N/A	6.40	4.39	4.79	2.16	0.18	51.52	3.99	2.95	2.81	1.00	0.23	20.52	5.19	3.67	2.80	1.58	0.21	36.02
*17 SC420	RIO SARACURUNA	186.00	16-3	185.00	194,173	1.04	N/A	10.12	9.39	9.31	4.04	0.41	98.01	6.33	6.72	5.81	2.18	0.54	37.93	8.22	8.31	7.56	3.11	0.47	67.97
18 IA260	RIO IGUACU	544.20	17-1‾5	562.80	758,010	1.35	N/A	32.25	56.83	32.72	13.88	1.49	343.88	20.01	25.01	20.65	7.81	1.99	131.05	26.13	30.92	26.59	10.90	1.74	237.47
19 SP300	RIO SARAPUI	158.80	17-6	165.50	1,012,275	6.12	Urban	24.21	49.21	37.91	15.73	2.13	378.89	15.61	34.62	27.25	11.21	3.01	139.52	19.91	41.92	32.58	13.47	2.57	259.20
20 SJ220	RIO S.J.DE MERITI	163.50	19	164.50	1,492,458	9.07	Urban	34.07	74.90	56.98	23.63	3.28	565.28	22.13	52.99	41.77	17.31	4.69	207.43	28.10	63.94	49.38	20.47	3.98	386.36
*21 AC241	RIO ACARI	57.90	19-2	57.90	436,076	7.57	Urban	10.53	22.24	17.14	7.17	0.99	169.27	6.90	15.81	12.65	5.23	1.42	62.42	8.72	19.03	14.89	6.20	1.20	115.84
22 IJ200	RIO IRAJA	27.30	20	35.70	500,276	14.01	Urban	8.51	19.64	15.05	6.36	0.91	146.15	5.70	14.15	11.57	4.82	1.32	53.87	7.11	16.90	13.31	5.59	1.11	100.01
23 PX180	CANAL DO PENHA	-	20	-				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24 CN100	CANAL DO CUNHA	60.50	21	63.60	815,359	12.82	Urban	17.23	39.56	30.15	12.64	1.79	295.05	11.41	28.32	22.80	9.50	2.59	108.48	14.32	33.94	26.48	11.07	2.19	201.76
25 MN000	CANAL DO MANGUE	42.80	23	42.80	500,876	11.70	Urb/S.T	11.30	25.59	19.57	8.23	1.16	191.36	7.50	18.33	14.82	6.17	1.68	70.46	9.40	21.96	17.20	7.20	1.42	130.91
	TOTAL	3604.10		3912.50				233.77	304.43	264.12	112.88	13.31	2712.55	146.61	212.66	179.74	70.83	18.37	1029.78	190.19	258.54	221.93	91.85	15.84	1871.16

*:Tributary river(excluded from Total amount)

N/A : Natural and Agricultural use

Urban : Urban use

Urb/S.T: Urban Use with Sewage Treatments

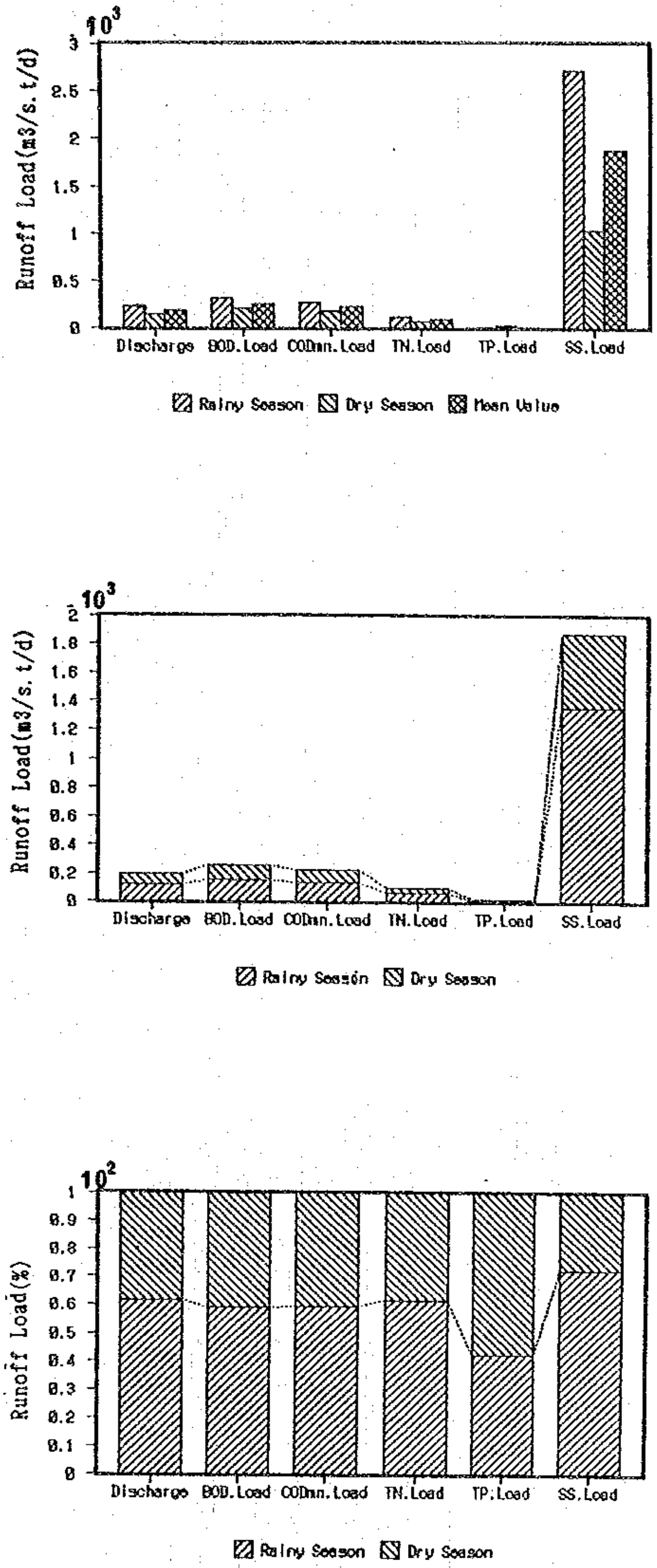


Fig. 9.3- 9 Difference in Estimated Runoff Load between Rainy Season and Dry Season

Table 9.3- 5 Estimated Total Runoff Load from the 20 Rivers

(Clear days/ Rainy days, Rainy season/Dry sesason, Runoff Load not influenced by Precipitation/ Runoff Load caused by precipitation)

Clear day /Rainy day

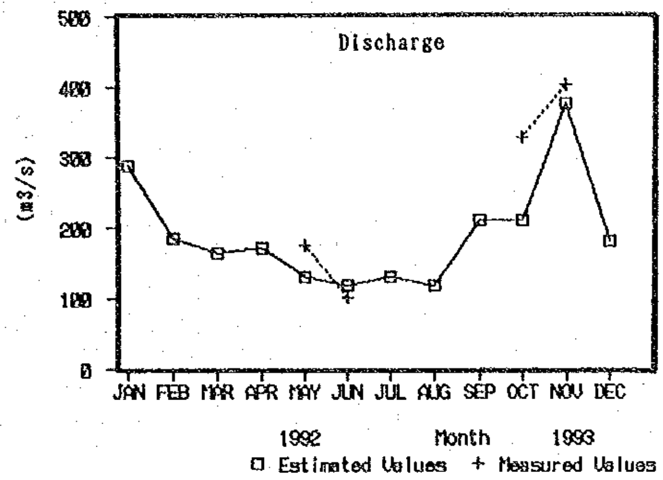
	Discharge		BOD Load		COD(Mn)Load		TN Load		TP Load		SS Load	
	(m3/s)	%	(t/day)	%	(t/day)	%	(t/day)	%	(t/day)	%	(t/day)	%
Clear day(<10mm/day):331days	105.18	55	147.29	57	103.51	47	70.71	77	13.91	88	384.23	21
Rainy day(10mm</day): 55days	85.01	45	111.26	43	118.42	53	21.14	23	1.93	12	1486.93	79
Mean Value	190.19	100	258.54	100	221.93	100	91.85	100	15.84	100	1871.16	100

Rainy season /Dry season

	Discharge		BOD Load		COD(Mn)Load		TN Load		TP Load		SS Load	
Season	(m3/s)	%	(t/day)	%	(t/day)	%	(t/day)	%	(t/day)	%	(t/day)	%
Rainy season(Oct-Mar,1992)	233.77	61	304.43	59	264.12	60	112.88	61	13.31	42	2712.55	72
Dry season (Apr-Sep.1992)	146.61	39	212.66	41	179.74	40	70.83	39	18.37	58	1029.78	28
Mean Value	190.19	100	258.54	100	221.93	100	91.85	100	15.84	100	1871.16	100

Runoff Load not influenced by precipitation /Runoff Load caused by precipitation

	Discharge		BOD Load		COD(Mn)Load		TN Load		TP Load		SS Load	
	(m3/s)	%	(t/day)	%	(t/day)	%	(t/day)	%	(t/day)	%	(t/day)	%
Runoff Load not influenced by precipitation	116.30	61	162.86	63	114.45	52	78.19	85	15.38	97	424.86	23
Runoff Load caused by precipitation	73.89	39	95.68	37	107.48	48	13.66	15	0.46	3	1446.31	77
	190.19	100	258.54	100	221.93	100	91.85	100	15.84	100	1871.16	100



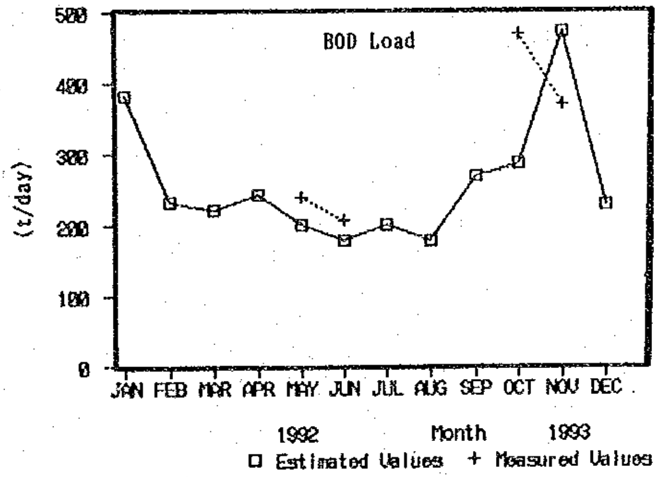


Fig. 9.3-10 Comparison of Estimated Runoff Load with Measured One

Table 9.3- 6 Estimated Runoff Loads from the Entire Basin (1991)

Basin No.		Name	Covered, Basin Area (Km^2)	NO.	Basin Area (Km^2)	Population	Population Density ($10^3/km^2$)	Land use Type	Mean Value Discharge (m^3/s)	BOD Load (t/d)	CODmn Load (t/d)	TN Load (t/d)	TP Load (t/d)	SS Load (t/d)
	1	B.-CHARITAS	9.40	1	9.40	53,310	5.67	Urban	1.17	2.35	1.89	0.79	0.15	14.52
Eastern	2	CANAL CANTO DO RIO	7.40	2	7.40	41,745	5.64	Urb/S.T	0.92	1.84	1.49	0.62	0.12	11.40
Basin	3	B.-CATEDRAR	7.80	3	7.80	37,458	4.80	Urban	0.86	1.65	1.33	0.56	0.11	10.33
	4	B.-NORTE CENTRO	7.90	4	7.90	43,607	5.52	Urban	0.96	1.92	1.55	0.65	0.12	11.91
	5	RIO BOMBA	26.20	5	26.20	183,099	6.99	Urban	3.75	8.00	6.33	2.65	0.51	48.90
	6	RIO IMBOASSU	30.80	6	30.80	138,636	4.50	Urban	3.14	6.02	4.81	2.00	0.38	38.02
	7	B.-ITAOCA	6.40	7	6.40	31,925	4.99	Urban	0.73	1.41	1.14	0.48	0.09	8.80
Northeastern	8	RIO ALCANTARA	144.60	8	144.60	470,420	3.25	Urban	11.48	20.07	16.01	6.60	1.20	131.48
Basin	9	RIO CACEREBU	846.70	9	846.70	336,193	0.40	N/A	27.67	14.80	17.28	7.08	0.80	174.97
	10	RIO GUAPIMIRIM	1253.10	10	1253.10	69,853	0.06	N/A	32.36	4.67	12.97	5.28	0.26	156.07
	11	CANAL DE MAGE	18.30	11	18.30	8,458	0.46	N/A	0.67	0.38	0.44	0.18	0.02	4.16
	12	RIO RONCADOR	111.40	12	111.40	36,370	0.33	N/A	3.65	1.66	2.11	0.88	0.09	21.36
	13	RIO IRIRI	27.80	13	27.80	10,684	0.38	N/A	0.97	0.49	0.59	0.25	0.03	5.77
	14	RIO SURUI	68.80	14	68.80	12,910	0.19	N/A	2.09	0.63	1.02	0.43	0.04	10.90
	15	B.-MAUA	28.90	15	28.90	8,541	0.30	N/A	0.96	0.40	0.53	0.22	0.02	5.36
Northwestern	16	RIO ESTRELA	342.50	16	342.50	302,495	0.88	N/A	14.10	12.92	12.09	4.96	0.72	111.33
Basin	17.1~5	RIO IGUACU	562.80	17-1~5	562.80	758,010	1.35	N/A	27.01	31.97	27.58	11.26	1.80	245.53
	17.6	RIO SARAPUI	165.50	17-6	165.50	1,012,275	6.12	Urban	20.61	43.40	33.72	13.94	2.66	268.38
	18	B.-CABO DO BRITO	27.00	18	27.00	132,091	4.89	Urban	2.93	5.75	4.58	1.91	0.36	36.03
	19	RIO S.J.DE MERITI	164.50	19	164.50	1,492,458	9.07	Urban	28.27	64.33	49.68	20.59	4.01	388.70
	20	RIO IRAJA	35.70	20	35.70	500,276	14.01	Urban	9.25	22.04	17.30	7.26	1.44	130.49
Western	21	CANAL DO CUNHA	63.60	21	63.60	815,389	12.82	Urban	15.04	35.66	27.80	11.62	2.30	212.01
Basin	22	B.-S.CRISTOVAO	6.60	22	6.60	60,011	9.09	Urban	1.21	2.67	2.14	0.90	0.18	16.04
	23	CANAL DO MANGUE	42.80	23	42.80	500,876	11.70	Urb/S.T	9.40	21.96	17.20	7.20	1.42	130.91
	24	B.-BOTAFOGO	26.00	24	26.00	358,622	13.79	Urban	6.68	15.84	12.48	5.24	1.04	93.81
	25	I. DO GAVANADOR	38.20	25	38.20	153,903	4.03	Urban	3.59	6.66	5.33	2.22	0.41	42.54
Island	26	I. DO FUNDAO	5.40	26	5.40	5,277	0.98	N/A	0.25	0.23	0.22	0.09	0.01	1.93
	27	I. DE PAQUETA	1.70	27	1.70	3,254	1.91	N/A	0.11	0.14	0.13	0.05	0.01	1.02
	28	I. DO ENGENHO	1.30	28	1.30	11,034	8.49	Urban	0.23	0.50	0.41	0.17	0.03	3.00
	29	I. DE S.CRUZ	1.40	29	1.40	4,851	3.47	Urban	0.13	0.22	0.18	0.08	0.01	1.40
		Total			4080.50	7,594,031			230.16	330.59	280.34	116.18	20.37	2337.07

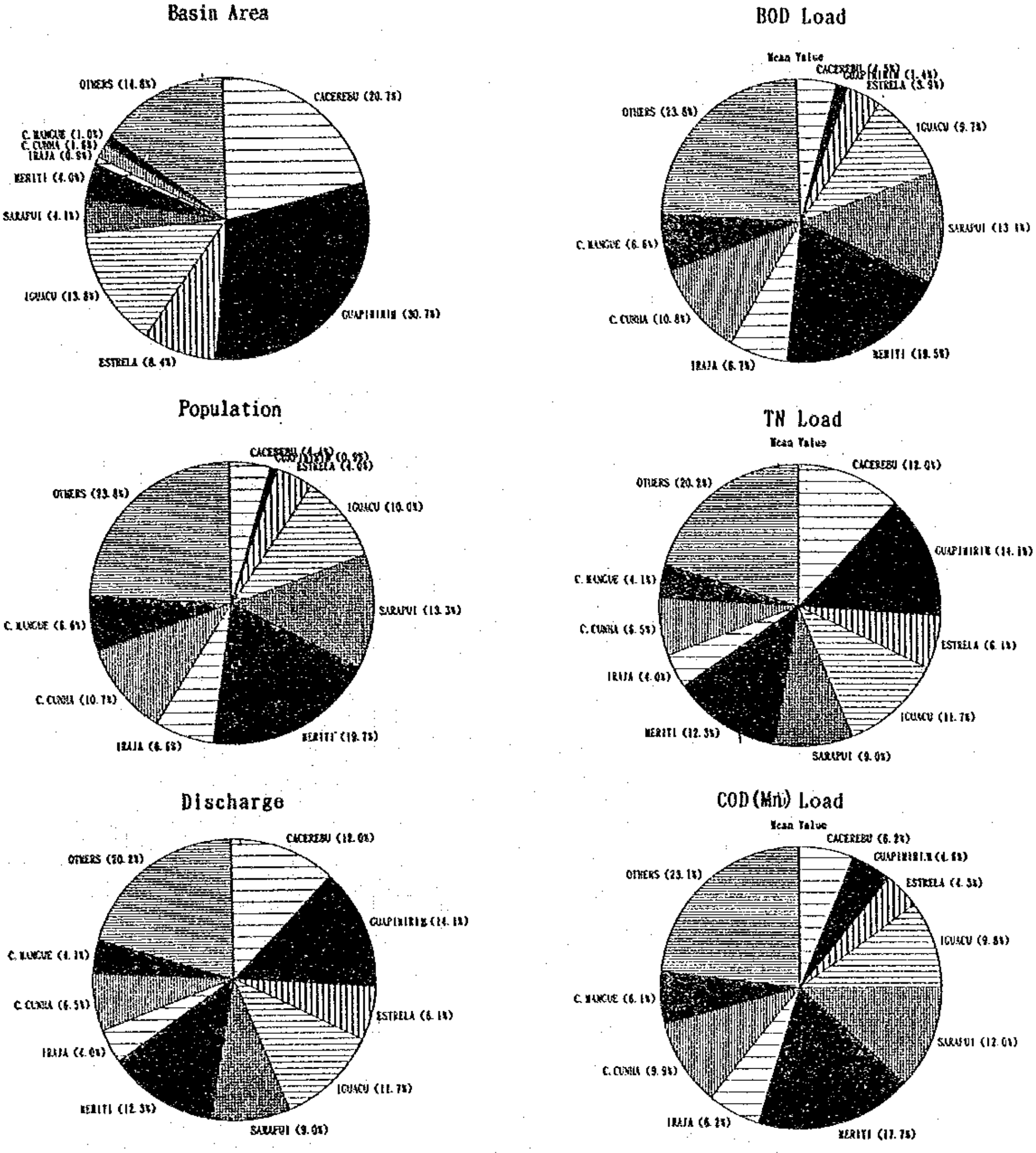


Fig. 9.3-11 Contribution Ratio of Estimated Runoff Load by River Basin

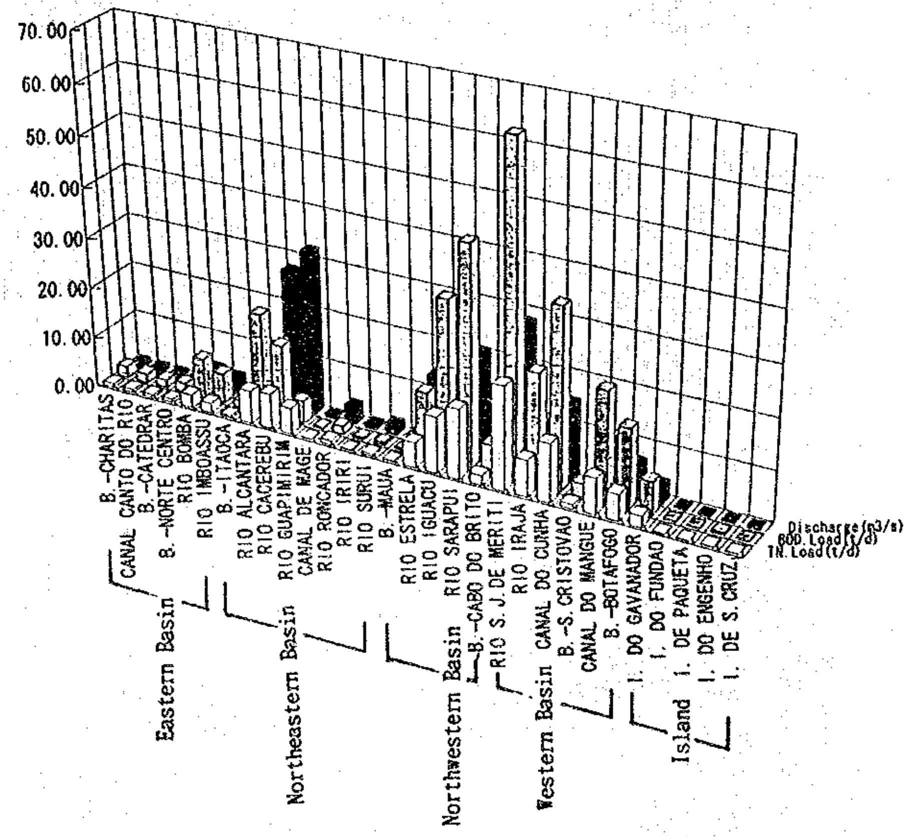


Fig. 9.3-12 Estimated Runoff Load from Each Sub-Basin

9.4 Details of Runoff Load from the Basin

Pollutants flow into the bay through various routes, some of them via rivers or stormwater drains, and some directly from the pollution sources (factories, waste treatment plants, sewage disposal plants, etc.). Here, the total runoff load is calculated after obtaining the runoff load of each route.

(1) Runoff load flowing into the Bay through rivers and stormwater drains

Fig.9.4-1 shows the runoff load flowing into the bay from each area. According to the position of their mouths in the bay, rivers were classified into the following five groups: eastern basin (sub-basin Nos.1 to 6), northeastern basin (sub-basin Nos.7 to 14), Northwestern basin (sub-basin Nos. 15 to 18), western basin (sub-basin Nos.19 to 24) island basin (sub-basin Nos. 25 through 29). Due to differences in water quality items, 45 to 51% of the total runoff load comes from the western basin and about 30% from the northwestern basin. 35% of the total runoff discharge is contributed by the northeastern basin, and although this amount is larger than the western or northwestern basins, it only supplies 12 to 18% of the total runoff load.

Besides the rivers, stormwater drains also discharge runoff load into the bay. Separate sewers were installed in Rio de Janeiro a century ago. Yet since the construction of treatment plants they were never upgraded, rain water drains were used as sewers and there are 5 open outlets around Rio de Janeiro port, and another one north of Niteroi.

CEDAE estimated the BOD load flowing into the bay directly from the five outlets was about 36 tons/day (no data was available for RSD-02). However, since this figure was calculated based on pump capacity, runoff ratio was not considered. No data on the discharge outlet in northern Niteroi, outside of Jurujuba Bay, was obtained.

(2) Runoff loads flowing into the bay directly from the pollution sources on the coastal areas

Among the various pollution sources along the coast of the bay, factories, that are located on the downstream side of the observation stations, discharge about 24 tons of BOD per day, sewage treatment plants (6 plants of Penha, ETEIG, ETEG, ETAR-AIRJ, ETAR-TECA and Icarai) discharge about 5.4 tons per day, and waste disposal plants (leachate), about 0.3 tons a day. The total BOD load totals approximately 30 tons a day.

Food factories (seafood processing factories among others) that are located between Niteroi and San Goncalo in the eastern area make up about 75% of the total load discharged by factories in the basin.

The total runoff load in terms of BOD load that flows into the bay was estimated as 360.53 tons a day by adding the runoff load of 330.59 tons/day from rivers and rain water drains to the runoff load of 29.94 tons/day from pollution sources on the coast.

Details are shown in **Table 9.4-1** and **Fig. 9.4-2**.

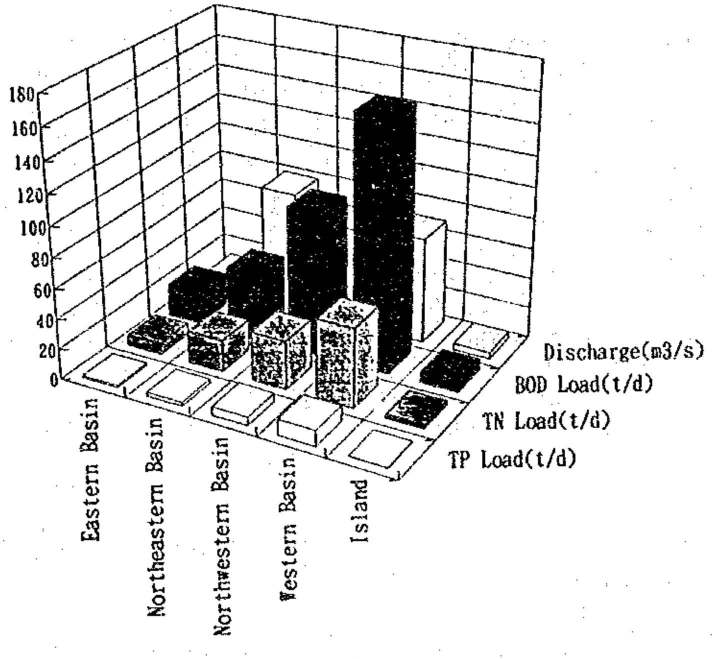


Fig. 9.4- 1 Details of Runoff Load (BOD) from the Basin

Table 9.4- 1 Details of BOD Load from the Basin

	Runoff Load from the basin(A)	Direct Runoff Load from Point Source(B)			Total (A)+(B)
	River(t/d)	Industry(t/d)	WWTP(t/d)	SWDS(t/d)	(t/day)
Eastern Basin (1-6)	21.79	18.32	1.63	---	41.74
Northeastern Basin (7-14)	44.11	--	--	--	44.11
Northwestern Basin (15-19)	94.43	4.11	--	0.30	98.84
Western Basin (20-24)	162.50 (RSD:36.00)	1.69	2.45	--	166.64
Island (25-29)	7.75	0.28	1.16	--	9.19
Total	330.59	24.40	5.24	0.30	360.53

Remarks
WWTP : Wastewater treatment plant
SWDS : Solid waste disposal site
RSD : Raw sewage drain-pipes

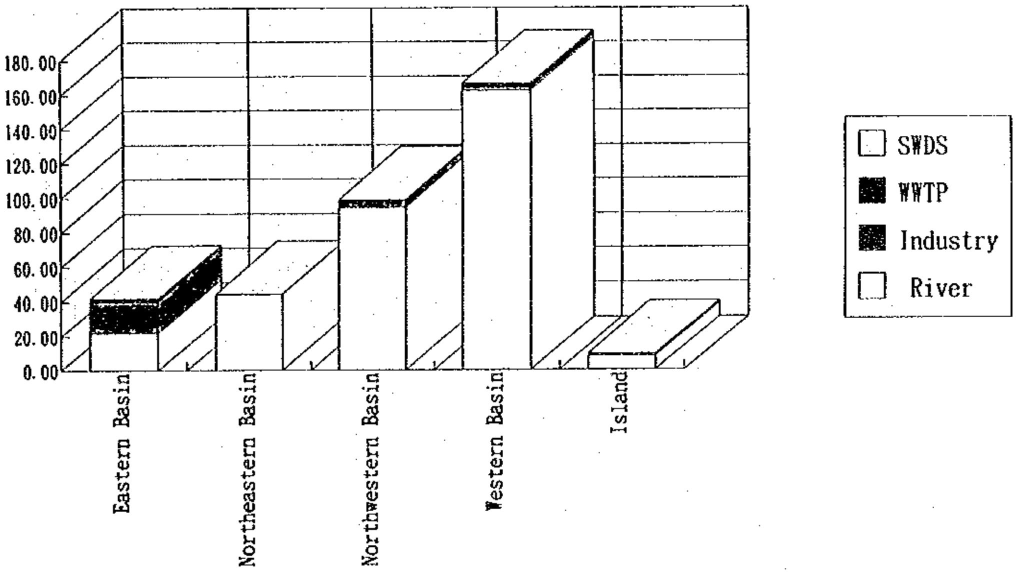


Fig. 9.4- 2 Estimated Runoff Load (BOD) from Each Area

PART V

DEVELOPMENT OF THE NUMERICAL SIMULATION MODEL

CHAPTER 10

NUMERICAL SIMULATION MODEL
OF
GUANABARA BAY

CHAPTER 10

NUMERICAL SIMULATION MODEL OF GUANABARA BAY

Numerical simulation models were developed as an effective tool for the study of the measures to be used in the recuperation of the ecosystem of Guanabara Bay.

This chapter explains the basic equations of the simulation models developed in this study; the Hydrodynamic Model, the Diffusion Model and the Eutrophication Model.

10.1 Structure of the Numerical Simulation Model

The numerical simulation of water quality in Guanabara Bay was carried out by the procedure shown in the flow-chart, **Fig. 10.1-1.** Three kinds of numerical models were used. The first was the Hydrodynamic Model which simulated water circulation caused by tidal phenomena, based on the results of the tidal current observations. The following water quality models were founded on this model.

The second was the Diffusion Model which was used to assess conservative substances such as salinity. Generally, this kind of model is used to estimate the water quality of conservative substances or substances regarded as conservative. In enclosed coastal seas, particularly in water areas where primary production is thriving and there is a high release from bottom sediments, the Eutrophication Model (see below) is better for assessing water quality. In this study, we used the Diffusion Model mainly to determine the diffusion coefficient.

The last was the Eutrophication Model, which is another form of the Diffusion Model. It assesses the release from bottom sediments as well as the primary production etc. as is described in detail later. We used this model for the estimation of water quality in the future and for the evaluation of the measures.

These numerical simulation models were built on the basis of the results of the field observations and laboratory experiments.

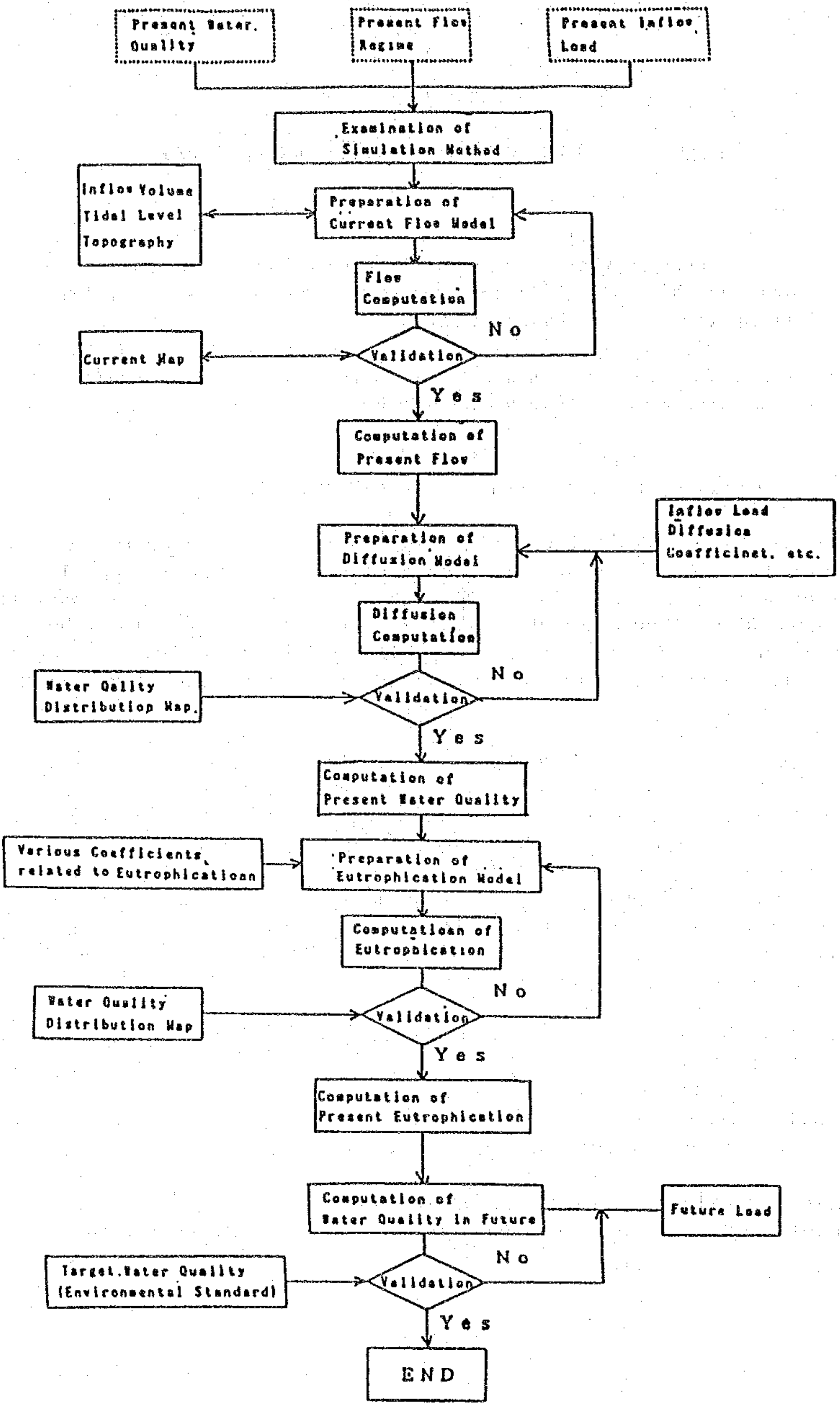


Fig.10.1-1 Numerical Simulation of Water Quality Analysis

10.2 Hydrodynamic Model

The substances discharged into the bay move by advection and dispersion in the bay. On reproducing the flow in a model, annual and seasonal mean flows are evaluated and several cases are considered with respect to vertical distribution. In this study, we used a two-level model which included the vertical velocity component as well as the two horizontal components. We took the upper layer to equal the photic layer.

The Hydrodynamic model was derived from the following Navior-Stokes Equation and Continuity Equation:

[Continuity Equation]

Upper Layer:

$$\frac{\partial \zeta}{\partial t} = w - \frac{\partial M_1}{\partial x} - \frac{\partial N_1}{\partial y}$$

Lower layer:

$$w = -\frac{\partial M_2}{\partial x} - \frac{\partial N_2}{\partial y}$$

[Motion Equation]

Upper Layer:

x-direction

$$\frac{\partial M_1}{\partial t} + \frac{\partial (u_1 M_1)}{\partial x} + \frac{\partial (v_1 M_1)}{\partial y} - (u \cdot w)_{z=h1} = fN_1 - g(\zeta + h_1)\frac{\partial \zeta}{\partial x} + A_h(\zeta + h_1)\left(\frac{\partial^2 u_1}{\partial x^2} + \frac{\partial^2 u_1}{\partial y^2}\right)$$

$$-\gamma_i^2 (u_1 - u_2)\sqrt{(u_1 - u_2)^2 + (v_1 - v_2)^2}$$

y-direction

$$\frac{\partial N_1}{\partial t} + \frac{\partial (u_1 N_1)}{\partial x} + \frac{\partial (v_1 N_1)}{\partial y} - (v \cdot w)_{z=h1} = -fM_1 - g(\zeta + h_1)\frac{\partial \zeta}{\partial y} + A_h(\zeta + h_1)\left(\frac{\partial^2 v_1}{\partial x^2} + \frac{\partial^2 v_1}{\partial y^2}\right)$$

$$-\gamma_i^2 (v_1 - v_2)\sqrt{(u_1 - u_2)^2 + (v_1 - v_2)^2}$$

Lower Layer:

x-direction

$$\frac{\partial M_2}{\partial t} + \frac{\partial (u_2 M_2)}{\partial x} + \frac{\partial (v_2 M_2)}{\partial y} + (u \cdot w)_{z=h1} = fN_2 - gh_2\frac{\partial \zeta}{\partial x} + A_h h_2\left(\frac{\partial^2 u_2}{\partial x^2} + \frac{\partial^2 u_2}{\partial y^2}\right)$$

$$+\gamma_i^2 (u_1 - u_2)\sqrt{(u_1 - u_2)^2 + (v_1 - v_2)^2} \; -\gamma_b^2 u_2\sqrt{u_2^2 + v_2^2}$$

y-direction

$$\frac{\partial N_2}{\partial t}+\frac{\partial (u_2N_2)}{\partial x}+\frac{\partial (v_2N_2)}{\partial y}+(v_*w)_{z=h1}=-fM_2-gh_2\frac{\partial \zeta}{\partial y}+A_hh_2\left(\frac{\partial^2 v_2}{\partial x^2}+\frac{\partial^2 v_2}{\partial y^2}\right)$$

$$+\gamma_1{}^2(v_1-v_2)\sqrt{(u_1-u_2)^2+(v_1-v_2)^2}-\gamma_b{}^2v_2\sqrt{u_2{}^2+v_2{}^2}$$

The parameters which contain asterrisk indicate that

$u_*=u_2,\ v_*=v_2$ for $w>0$,

$u_*=u_1,\ v_*=v_1$ for $w>0$,

respectively.

Parameters appeared in the equations are explained in **Fig.10.2-1** and as follows:

M_1, N_1 :flow per unit width in x,y direction of upper layer
M_2, N_2 :flow per unit width in x,y direction of lower layer
u_1, v_1 :horizontal velocity components of seawater circulation in upper layer
u_2, v_2 :horizontal velocity components of seawater circulation in lower layer
w :vertical velocity components of seawater circulation in the interface between the upper layer and lower layer
:water surface elevation
h_1 :thickness of upper layer
h_2 :thickness of lower layer
g :acceleration due to gravity
f :Coliolis coefficient
A_h :horizontal eddy viscosity coefficient
$r_1{}^2$:inner friction coefficient at the interface between the upper layer and lower layer
$r_b{}^2$:bottom friction coefficient

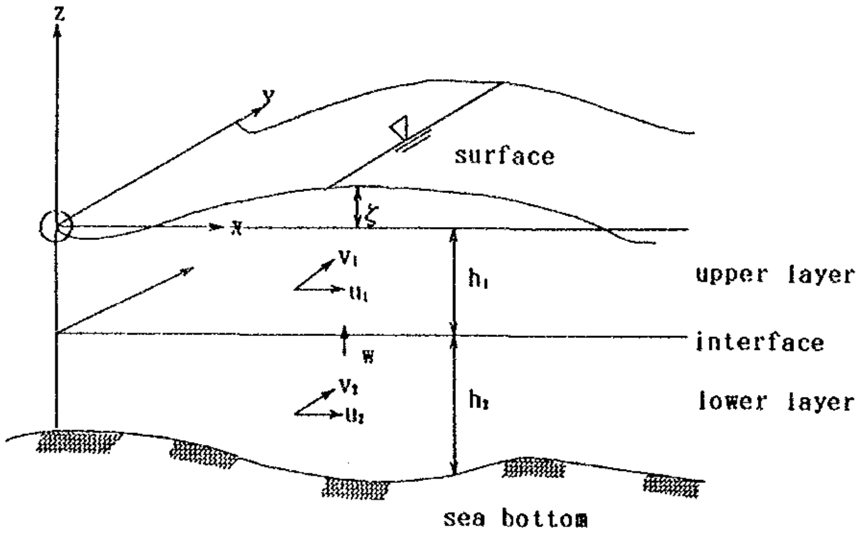


Fig.10.2-1 Definition of parameters in Two-level Model

10.3 Diffusion Model

Basic equations for the two-level diffusion model for conservative substances are expressed below. The concentration of water quality at each unit of time can be calculated by solving these equations using the finite difference method.

$$\underbrace{\frac{\partial C_1\cdot D_1}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(C_1\cdot u_1\cdot D_1) - \frac{\partial}{\partial y}(C_1\cdot v_1\cdot D_1)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}(K_hD_1\frac{\partial C_1}{\partial x}) + \frac{\partial}{\partial y}(K_hD_1\frac{\partial C_1}{\partial y})}_{\text{horizontal dispersion}}$$

$$\underbrace{+ w\cdot C^* - K_z(C_1-C_2)}_{\text{vertical advection \& dispersion}} \quad \underbrace{+ \ L}_{\text{external load}}$$

Lower Layer:

$$\underbrace{\frac{\partial C_2\cdot D_2}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(C_2\cdot u_2\cdot D_2) - \frac{\partial}{\partial y}(C_2\cdot v_2\cdot D_2)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}(K_hD_2\frac{\partial C_2}{\partial x}) + \frac{\partial}{\partial y} K_hD_2\frac{\partial C_2}{\partial y})}_{\text{horizontal dispersion}}$$

$$\underbrace{- w\cdot C^* + K_z(C_1-C_2)}_{\text{vertical advection \& dispersion}}$$

Parameters appeared in each equation are explained as follows:

C_1 : salinity concentration in upper layer
C_2 : salinity concentration in lower layer
L : external load
D_1 : thickness of upper layer
D_2 : thickness of lower layer
u_1, v_1 : horizontal velocity components of seawater circulation in upper layer calculated by Tidal Current Model
u_2, v_2 : horizontal velocity cimponents of seawater circulation in lower layer calculated by Tidal Current Model
w : vertical velocity components of seawater circulation in the interface between the upper layer and lower layer calculated by Tidal Current Model
K_h : horizontal dispersion coefficient
K_z : vertical dispersion coefficient

The parameters which contain asterisk indicate that

$$C^*=C_2 \quad \text{for } w \geqq 0,$$
$$C^*=C_1 \quad \text{for } w < 0,$$

respectively.

10.4 Eutrophication Model

On the formulation of a nutrient cycle between seawater and sediment, we assumed the following:

(1) The nutrient cycle process is controlled by the decomposition of O-P (organic phosphorus) into PO_4-P (phosphate phosphorus). DO (dissolved oxygen) and organic matter increase correspondingly to the level of primary production.

(2) The indices, COD (Chemical Oxygen Demand) and BOD (Biochemical Oxygen Demand) are used for the concentrations of organic matter as well as PO_4-P, O-P and DO.

(3) Vertically the area is divided into two layers the photic layer (upper layer) and the non-photic layer (lower layer). The growth of phytoplankton occurs only in the photic layer.

(4) COD, DO and nutrient salts vary through the process of growth, decomposition, settling and release etc., as well as inflow form rivers (**Fig. 10.4-1**).

(5) COD, DO and nutrient salts vary by advection and dispersion due to the tidal currents.

The variation over time in the two-level model is expressed by the following equations, and the concentration of water quality at each unit of time can be calculated by solving these equations using the finite difference method.

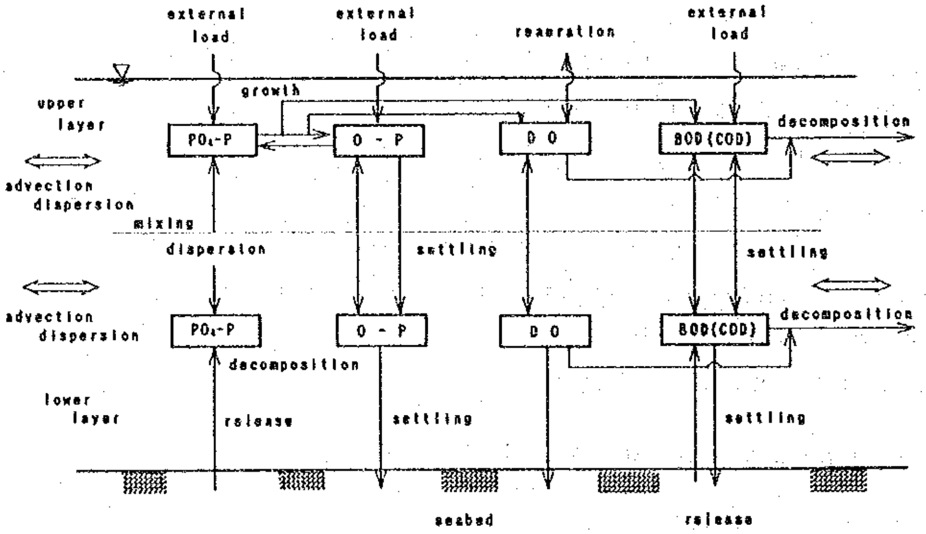


Fig.10.4-1 Nutrient Cycle Model

O−P

Upper layer :

$$\underbrace{\frac{\partial OP_1\cdot D_1}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(OP_1\cdot u_1\cdot D_1) - \frac{\partial}{\partial y}(OP_1\cdot v_1\cdot D_1)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_1 \frac{\partial OP_1}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_1 \frac{\partial OP_1}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$\underbrace{+\, w\cdot OP^* - K_z(OP_1 - OP_2)}_{\text{vertical advection \& dispersion}} \quad \underbrace{+\, G\cdot OPP_1\cdot D_1}_{\text{growth}} \underbrace{-\, B_1{}^P\cdot OP_1\cdot D_1}_{\text{decomposition}} \quad \underbrace{-\, S_1{}^P\cdot OP_1}_{\text{settling}}$$

$$\underbrace{+\, L_{OP}}_{\text{external load}}$$

Lower layer :

$$\underbrace{\frac{\partial OP_2\cdot D_2}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(OP_2\cdot u_2\cdot D_2) - \frac{\partial}{\partial y}(OP_2\cdot v_2\cdot D_2)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_2 \frac{\partial OP_2}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_2 \frac{\partial OP_2}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$\underbrace{-\, w\cdot OP^* + K_z(OP_1 - OP_2)}_{\text{vertical advection \& dispersion}} \quad \underbrace{-\, B_2{}^P\cdot OP_2\cdot D_2}_{\text{decomposition}} \underbrace{+\, S_1{}^P\cdot OP_1 - S_2{}^P\cdot OP_2}_{\text{settling}}$$

O−P (Inner Production)

Upper layer :

$$\underbrace{\frac{\partial OPP_1\cdot D_1}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(OPP_1\cdot u_1\cdot D_1) - \frac{\partial}{\partial y}(OPP_1\cdot v_1\cdot D_1)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_1 \frac{\partial OPP_1}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_1 \frac{\partial OPP_1}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$\underbrace{+\, w\cdot OPP^* - K_z(OPP_1 - OPP_2)}_{\text{vertical advection \& dispersion}} \quad \underbrace{+\, G\cdot OPP_1\cdot D_1}_{\text{growth}} \underbrace{-\, B_1{}^P\cdot OPP_1\cdot D_1}_{\text{decomposition}} \quad \underbrace{-\, S_1{}^P\cdot OPP_1}_{\text{settling}}$$

Lower layer :

$$\underbrace{\frac{\partial OPP_2\cdot D_2}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(OPP_2\cdot u_2\cdot D_2) - \frac{\partial}{\partial y}(OPP_2\cdot v_2\cdot D_2)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_2 \frac{\partial OPP_2}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_2 \frac{\partial OPP_2}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$\underbrace{-\, w\cdot OPP^* + K_z(OPP_1 - OPP_2)}_{\text{vertical advection \& dispersion}} \quad \underbrace{-\, B_2{}^P\cdot OPP_2\cdot D_2}_{\text{decomposition}} \underbrace{+\, S_1{}^P\cdot OPP_1 - S_2{}^P\cdot OPP_2}_{\text{settling}}$$

PO_4-P

Upper layer :

$$\underbrace{\frac{\partial IP_1\cdot D_1}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(IP_1\cdot u_1\cdot D_1) - \frac{\partial}{\partial y}(IP_1\cdot v_1\cdot D_1)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_1 \frac{\partial IP_1}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_1 \frac{\partial IP_1}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$\underbrace{+ w\cdot IP^* - K_z(IP_1-IP_2)}_{\text{vertical advection \& dispersion}} \underbrace{- G\cdot OPP_1\cdot D_1}_{\text{growth}} \underbrace{+ B_1{}^P\cdot OP_1\cdot D_1}_{\text{decomposition}} \underbrace{+ L_{IP}}_{\text{external load}}$$

lower layer :

$$\underbrace{\frac{\partial IP_2\cdot D_2}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(IP_2\cdot u_2\cdot D_2) - \frac{\partial}{\partial y}(IP_2\cdot v_2\cdot D_2)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_2 \frac{\partial IP_2}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_2 \frac{\partial IP_2}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$\underbrace{- w\cdot IP^* + K_z(IP_1-IP_2)}_{\text{vertical advection \& dispersion}} \underbrace{+ B_2{}^P\cdot OP_2\cdot D_2}_{\text{decomposition}} \underbrace{+ R_{IP}}_{\text{release}}$$

COD

Upper layer :

$$\underbrace{\frac{\partial COD_1\cdot D_1}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(COD_1\cdot u_1\cdot D_1) - \frac{\partial}{\partial y}(COD_1\cdot V_1\cdot D_1)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_1 \frac{\partial COD_1}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_1 \frac{\partial COD_1}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$\underbrace{+ w\cdot COD^* - K_z(COD_1-COD_2)}_{\text{vertical advection \& dispersion}} \underbrace{+ \beta\cdot G\cdot OPP_1\cdot D_1}_{\text{growth}} \underbrace{- B_1{}^C\cdot COD_1\cdot D_1}_{\text{decomposition}} \underbrace{- S_1{}^C\cdot COD_1}_{\text{settling}}$$

$$\underbrace{+ L_{COD}}_{\text{external load}}$$

Lower layer :

$$\underbrace{\frac{\partial COD_2\cdot D_2}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(COD_2\cdot u_2\cdot D_2) - \frac{\partial}{\partial y}(COD_2\cdot V_2\cdot D_2)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_2 \frac{\partial COD_2}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_2 \frac{\partial COD_2}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$+\underbrace{w\cdot COD^{*}-K_z(COD_1-COD_2)}_{\text{vertical advection \& dispersion}}\;\underbrace{-B_2{}^{C}\cdot COD_2\cdot D_2}_{\text{decomposition}}+\underbrace{S_1{}^{C}\cdot COD_1-S_2{}^{C}\cdot COD_2}_{\text{settling}}$$

$$+\underbrace{R_{COD}}_{\text{release}}$$

BOD

Upper layer :

$$\underbrace{\frac{\partial BOD_1\cdot D_1}{\partial t}}_{\text{time variation}}=\underbrace{-\frac{\partial}{\partial x}(BOD_1\cdot u_1\cdot D_1)-\frac{\partial}{\partial y}(BOD_1\cdot V_1\cdot D_1)}_{\text{horizontal advection}}+\underbrace{\frac{\partial}{\partial x}\left(K_hD_1\frac{\partial BOD_1}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_hD_1\frac{\partial BOD_1}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$+\underbrace{w\cdot BOD^{*}-K_z(BOD_1-BOD_2)}_{\text{vertical advection \& dispersion}}+\underbrace{\delta\cdot G\cdot OPP_1\cdot D_1}_{\text{growth}}-\underbrace{B_1{}^{B}\cdot BOD_1\cdot D_1}_{\text{decomposition}}-\underbrace{S_1{}^{B}\cdot BOD_1}_{\text{settling}}$$

$$+\underbrace{L_{BOD}}_{\text{external load}}$$

Lower layer :

$$\underbrace{\frac{\partial BOD_2\cdot D_2}{\partial t}}_{\text{time variation}}=\underbrace{-\frac{\partial}{\partial x}(BOD_2\cdot u_2\cdot D_2)-\frac{\partial}{\partial y}(BOD_2\cdot V_2\cdot D_2)}_{\text{horizontal advection}}+\underbrace{\frac{\partial}{\partial x}\left(K_hD_2\frac{\partial BOD_2}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_hD_2\frac{\partial BOD_2}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$+\underbrace{w\cdot BOD^{*}-K_z(BOD_1-BOD_2)}_{\text{vertical advection \& dispersion}}\;\underbrace{-B_2{}^{B}\cdot BOD_2\cdot D_2}_{\text{decomposition}}+\underbrace{S_1{}^{B}\cdot BOD_1-S_2{}^{B}\cdot BOD_2}_{\text{settling}}$$

$$+\underbrace{R_{BOD}}_{\text{release}}$$

DO

Upper layer :

$$\underbrace{\frac{\partial DO_1\cdot D_1}{\partial t}}_{\text{time variation}}=\underbrace{-\frac{\partial}{\partial x}(DO_1\cdot u_1\cdot D_1)-\frac{\partial}{\partial y}(DO_1\cdot v_1\cdot D_1)}_{\text{horizontal advection}}+\underbrace{\frac{\partial}{\partial x}\left(K_hD_1\frac{\partial DO_1}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_hD_1\frac{\partial DO_1}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$+\underbrace{w\cdot DO^{*} - K_z(DO_1-DO_2)}_{\text{vertical advection \& dispersion}} \quad + \underbrace{\gamma\cdot G\cdot OPP_1\cdot D_1}_{\text{growth}} - \underbrace{B_1{}^{O}\cdot COD_1\cdot D_1}_{\text{decomposition}}$$

$$+\underbrace{A(HOWA-DO_1)}_{\text{reaeration}}$$

Lower layer :

$$\underbrace{\frac{\partial DO_2\cdot D_2}{\partial t}}_{\text{time variation}} = \underbrace{-\frac{\partial}{\partial x}(DO_2\cdot u_2\cdot D_2) - \frac{\partial}{\partial y}(DO_2\cdot v_2\cdot D_2)}_{\text{horizontal advection}} + \underbrace{\frac{\partial}{\partial x}\left(K_h D_2\frac{\partial DO_2}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h D_2\frac{\partial DO_2}{\partial y}\right)}_{\text{horizontal dispersion}}$$

$$-\underbrace{w\cdot DO^{*} + K_z(DO_1-DO_2)}_{\text{vertical advection \& dispersion}} \quad - \underbrace{B_2{}^{O}\cdot COD_2\cdot D_2}_{\text{decomposition}} - \underbrace{DB}_{\text{uptake by sediment}}$$

Parameters appeared in each equation are explained as follows:

OP_1 : O-P concentration in upper layer
OPP_1 : O-P(Inner Production) concentration in upper layer
IP_1 : PO_4-P concentration in upper layer
COD_1 : COD concentration in upper layer
BOD_1 : BOD concentration in upper layer
DO_1 : DO concentration in upper layer
OP_2 : O-P concentration in lower layer
OPP_2 : O-P(Inner Production) concentration in lower layer
IP_2 : PO_4-P concentration in lower layer
COD_2 : COD concentration in lower layer
BOD_2 : BOD concentration in lower layer
DO_2 : DO concentration in lower layer
D_1 : thickness of upper layer
D_2 : thickness of lower layer
G : growth rate of phytoplankton
$B_1{}^{P}$: O-P decomposition rate in upper layer
$B_1{}^{C}$: COD decomposition rate in upper layer
$B_1{}^{B}$: BOD decomposition rate in upper layer
$B_1{}^{O}$: DO uptake rate by decomposition in upper layer
$S_1{}^{P}$: O-P settling rate in upper layer
$S_1{}^{C}$: COD settling rate in upper layer

S_1^B : BOD settling rate in upper layer
B_2^P : O-P decomposition rate in lower layer
B_2^C : COD decomposition rate in lower layer
B_2^B : BOD decomposition rate in lower layer
B_2^O : DO uptake rate by decomposition in lower layer
S_2^P : O-P settling rate in lower layer
S_2^C : COD settling rate in lower layer
S_2^B : BOD settling rate in lower layer
R_{IP} : PO_4-P release rate
R_{COD} : COD release rate
R_{BOD} : BOD release rate
L_{OP} : O-P external load
L_{IP} : PO_4-P external load
L_{COD} : COD external load
L_{BOD} : BOD external load
DB : oxygen uptake rate by seabed sediment
A : reaeration constant
$HOWA$: saturated oxygen concentration
β : COD conversion factor from O-P
δ : BOD conversion factor from O-P
γ : DO conversion factor from O-P
u_1, v_1 : horizontal velocity components of seawater circulation in upper layer calculated by Tidal Current Model
u_2, v_2 : horizontal velocity components of seawater circulation in lower layer calculated by Tidal Current Model
w : vertical velocity components of seawater circulation in the interface between the upper layer and lower layer calculated by Tidal Current Model
K_h : horizontal dispersion coefficient
K_z : vertical dispersion coefficient

The parameters which contain asterisk indicate that

$$OP^*=OP_2,\ OPP^*=OPP_2,\ IP^*=IP_2,\ COD^*=COD_2,\ BOD^*=BOD_2,\ DO^*=DO_2 \text{ for } w \geqq 0,$$
$$OP^*=OP_1,\ OPP^*=OPP_1,\ IP^*=IP_1,\ COD^*=COD_1,\ BOD^*=BOD_1,\ DO^*=DO_1 \text{ for } w < 0,$$

respectively.

CHAPTER 11

VERIFICATION TEST OF THE SIMULATION MODEL

CHAPTER 11

VERIFICATION TEST OF THE SIMULATION MODEL

After the numerical simulation models have been developed, it is very important to verify the calculation results obtained using the models by comparing them with the data of water quality obtained on site.

Verification of the results obtained from the "Hydrodynamic Model", "Diffusion Model" and "Eutrophication Model" developed in Chapter 10 was carried out in this chapter.

11.1 Calculation Index and Calculation Condition

11.1.1 Calculation Index

On the assumptions mentioned in the previous chapter, we calculated the following indices by numerical simulation in this study:

Hydrodynamic Model	: Two horizontal velocity components in both the upper and lower layers.
Diffusion Model	: Salinity for calibration of dispersion coefficient.
Eutrophication Model:	BOD and COD for the concentration of organic matter. DO for the amount of dissolved oxygen PO_4-P and O-P as nutrient salts.

On the formulation of a eutrophication model, there is much argument about indices. Phosphorus and nitrogen compounds are the most important nutrients, they control organic matter pollution in the seawater. The content of phosphorus and nitrogen in organic matter generally stays at a certain ratio, but this ratio differs between species of organisms and at different stages of their growth. Through this, the daily nutrient uptake is determined for both phosphorus and nitrogen.

The structure of the prediction model, however, becomes very complicated if the behavior of both phosphorus and nitrogen are evaluated. Thus, evaluating the nutrient cycle of only phosphorus is preferable for the reason that phosphorus is the limiting factor in the nutrient cycle in a eutrophic bay.

11.1.2 Calculation Condition

(1) Hydrodynamic Model

The calculation of tidal currents in Guanabara Bay was performed for the area shown in **Fig. 11.1-1** using a two-level model with 500 meter lattice intervals in the mean spring tides.

Calculation conditions applied in the Hydrodynamic Model are summarized in **Table 11.1-1.**

Table 11.1-1 Calculation Conditions for the Hydrodynamic Model

Item	Condition
Target season	Dry season, Rainy season, Annual mean
Model	Two-level Model
Lattice interval	500 m
Calculation area	**Fig. 11-1-1**
Topography	**Fig. 11.1-2**
Tidal condition	$M_2 + S_2$
Mean water level	M.S.L.
Thickness of upper layer	3.0 m This value is based on the observed results of the vertical profile and transparency.
Time step	15 sec
Horizontal eddy viscosity	10^4 cm^2/s
Bottom friction coefficient	0.0026
Inner friction coefficient	0.001
Acceleration due to gravity	9.8 m/s^2
Coriolis coefficient	$-5.64*10^{-5}$
Open boundary condition	The tidal height at all open boundaries is 45 cm and the difference between the eastern and western boundary is 1.38°
Calculation time	for 5 tidal repetitions

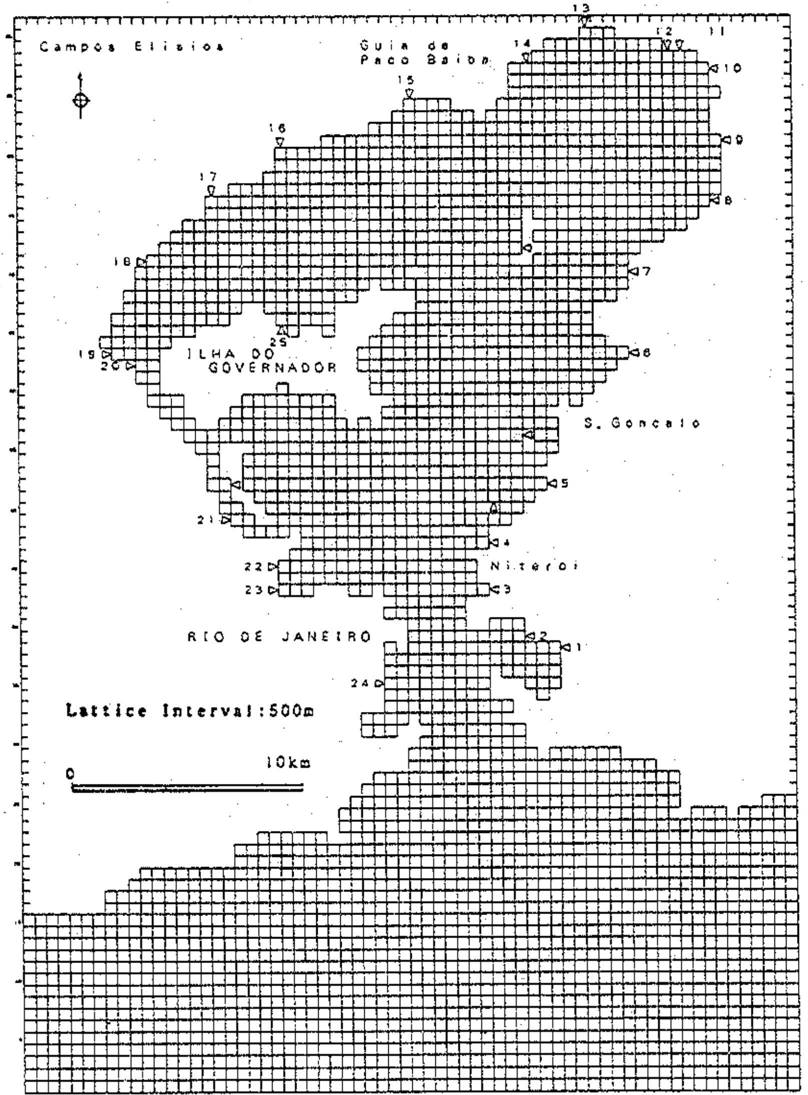


Fig.11.1-1 Simulation Lattice Map and River Inflow Points

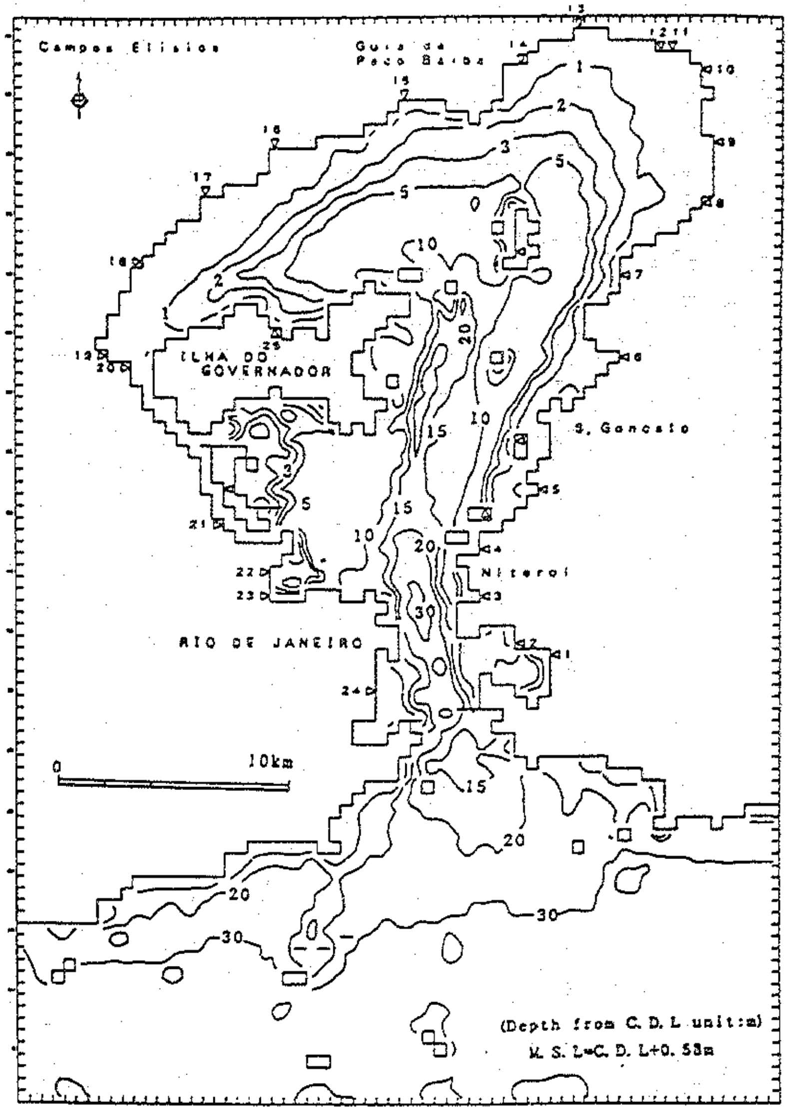


Fig.11.1-2 Water Depths used for simulation Model

(2) Diffusion Model

The calculation for the diffusion and dispersion of conservative substances in the bay was performed to determine the dispersion coefficients using salinity as a conservative substance both in the dry season and the rainy season.

Calculation conditions applied in the Diffusion Model are summarized in **Table 11.1-2.**

Table 11.1-2 Calculation Conditions for the Diffusion Model

Item	Condition
Target season	Dry season, Rainy season Annual mean
Index	Salinity
Tidal condition	$M_2' + S_2$
Thickness of upper layer	3.0 m
Computational area	**Fig. 11.1-1**
Horizontal dispersion coefficient	1.0×10^6 cm^2/s, and 5.0×10^4 & 1.0×10^4 cm^2/s for limited areas
Vertical dispersion coefficient	0.0 cm^2/s
Discharge of rivers	**Table 11.1-4**
Initial value	inner of the bay 30 % outer of the bay 35 %
Open boundary concentration	35 %
Time step	150 seconds
Computation time	for 120 tidal repetitions

(3) Eutrophication Model

On calculating the concentrations of organic matter and nutrient salts in regard to the eutrophic phenomena, values need to be determined for various parameters by referring to data obtained in the field and in recent literature.

The method and criteria for the determination of parameters are described below and the calculation conditions applied in the eutrophication model are summarized in **Table 11.1-3.**

a) Thickness of the Upper Layer

We assumed the thickness of the upper layer to be equal to the photic layer. Generally, there is correlation between the transparency (T) and the compensation depth (C_D), that is $C_D = 2.5 \times T$.

The average transparency in all areas of Guanabara Bay was about one meter according to observations except in the bay mouth area.

Therefore, we set 3.0 meters as the thickness of the upper layer.

b) Growth Rate

The growth rate of phytoplankton is expressed as the increase of O-P in the model and the increase of BOD (COD) corresponds to that of O-P.

Generally, the growth rate of phytoplankton can be determined in relation to water temperature, light intensity and concentration of nutrient salts such as N and P; and the growth rate of O-P (G) can be expressed in terms of concentration of PO_4-P (IP), if we assume water temperature and light intensity to be constant.

$$G = u_{max} \times IP / (K_{IP} + IP)$$

u_{max} : maximum specific growth rate of O-P
IP : concentration of PO_4-P
K_{IP} : semi-saturation constant of PO_4-P

Table 11.1-3 Calculation Conditions for the Eutrophication Model

Item	Sign	Value
Target season		Dry sason, Rainy season, Annual mean
Index		COD, BOD, O-P, PO_4-P, DO
Computational area		Fig. 11.1-1
Tidal condition		$M_2 + S_2$
a) Thickness of upper		3.0 m
b) Growth rate (1/day)	G	$0.70 * (IP_1/0.012 + IP_1)$
Maximum specific growth rate	u_{max}	0.700
PO_4-P Semi-saturation constant	K_{1p}	0.012
c) Decomposition rate (1/day)		
upper O-P	B_1^P	0.10
COD	B_1^C	0.10
BOD	B_1^B	0.10
lower O-P	B_2^P	0.10
COD	B_2^C	0.10
BOD	B_2^B	0.10
d) Settling (1/day)		
upper O-P	S_1^P	0.30
COD	S_1^C	0.30
BOD	S_1^B	0.30
lower O-P	S_2^P	0.45
COD	S_2^C	0.45
BOD	S_2^B	0.45
e) Release rate ($mg/m^2/day$)		
COD	R_{COD}	167.0
BOD	R_{BOD}	262.0
PO_4-P	R_{IP}	11.0 ~ 20.0
f) Conversion factor		
COD/O-P	β	16.4
BOD/O-P	δ	25.6
DO/O-P	γ	143
g) Parameters concerned with DO		
Uptake rate by decomposition(1/day)		
Upper	B_1^O	0.60
Lower	B_2^O	0.60
Uptake rate by sediment($mg/m^2/day$)	DB	690 ~ 1670
Reaeration constant(1/day)	A	0.8
Staturated DO concentration	HOWA	6.8 mg/l
h) Dispersion Coefficient		
Horizontal	K_H	1.0×10^4 ~ 1.0×10^6 cm^2/s
Vertical	K_Z	0.0 cm^2/s
i) External load	L_{COD} L_{BOD} L_{IP}	Table 11.1-4
j) Initial value		The value based on the observation
k) Open boundary condition		Open boundary concentration is fixed as shown below COD 0.6 mg/l BOD 1.0 mg/l PO_4-P 0.02 mg/l O-P 0.02 mg/l DO 7.8 mg/l
Time interval		120 second
Computation time		for 120 tidal repetitions

The value of u_{max} was 0.70 according to the experiment for primary production and that of K_{IP} was 0.012 according to the experiment for <u>Oscillatoria</u>. We set these values as constant for both seasons because of the lack of data for both seasons, though there is a possibility that the values will not remain constant.

In the western area, we confirmed that the above values were too large to reproduce the present state of water quality by the calibration test. It is thought to be because the amount of primary production is extremely small compared with the external PO_4-P loads in this area. Therefore, we decreased the growth rate of O-P (G) in proportion to the ratio of the transparency to the thickness of the upper layer (3 m).

c) Decomposition Rate

The decomposition is considered for BOD (COD) and for O-P to PO_4-P in the model. Generally, the decomposition rate changes depending on water temperature. The variation of temperature, however, was not considered in this model and we did not collect any data in Brazil.

Therefore, we set the constant values shown in **Table 11.1-3** as the decomposition rates through calibration tests, referring to the following data obtained in Japan.

COD : 0.01 to 0.1 (1/day)
O-P : 0.01 to 0.2 (1/day)

d) Settling Velocity

Settling was considered for O-P and BOD (COD) in the model. Generally, the settling amount is proportional to the concentration.

We set constant values shown in **Table 11.1-3** as the settling velocity in this model through calibration tests, referring to the experiment results.

e) Release Rate

The release rate from sediments was determined as a function of water temperature, DO concentration and sediment characteristics.

It is more than likely that the release rate in the western part of the bay is larger than that in the other part. However, we do not have any data to confirm this.

Therefore, we set the same values all over the bay as shown in **Table 11.1-3** as release rates based on the experiment results. In the outside of the bay, we assumed the release rate to be zero.

f) Conversion Factor

The ratio of DO to O-P (DO/O-P) can be obtained by the following chemical equation which is well known as the chemical equation for photosynthesis;

$$106CO_2 + 16HNO_3 + H_3PO_4 + 122H_2O = (CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2$$

$$DO/O\text{-}P = 138 \times O/P = 138 \times 16 \times 2 \div 31 = 143$$

On the other hand, we set 25.6 as the ratio of BOD to O-P and 16.4 for COD to O-P according to the observation data.

g) Parameters concerned with DO

(1) Uptake Rate by Decomposition

The uptake rate by decomposition was determined through calibration tests, because there was no data obtain on site.

(2) Uptake Rate by Sediment

We set 690 - 810 $mg/m^2/day$ in all areas except the western area as the uptake rate by sediment, which was the average value of all the stations.
In the western area, we set a value two times that of the above, considering that low DO concentration was observed in the area and the fact that the uptake rate by sediment is approximately ten times of release rate, generally.

(3) Reaeration Constant

Generally, the reaeration constant is between 0.1 and 0.8 1/day. We finally set it at 0.9 1/day through calibration tests.

(4) Saturated DO Concentration

It was set at 6.8 mg/l, according to the observation data.

h) Dispersion Coefficient

We set 10^6 cm^2/sec as the horizontal dispersion coefficient. This was based on the results of calibration tests by the Diffusion Model for most of the bay area, and (1.0 - 5.0) X 10^4 cm^2/sec was set in limited areas.

Regarding the vertical dispersion coefficient, we set it at zero, on the assumption that vertical movement is controlled by vertical advection.

i) External Load

The present external loads used for the model are shown in **Table 11.1-4** for effluent loads through rivers, and direct loads into the bay.

To estimate PO_4-P and O-P loads, we assumed the relation PO_4-P/T-P = 0.4, based on the result of the river surveys, because we only calculated T-P loads for each river basically. O-P was calculated as the difference between T-P and O-P.

Regarding the direct loads, we assessed only BOD loads in the model.

j) Initial Value

The initial values for the distribution of concentrations of each index were given using the concentrations observed.

Also, we did a trial pre-calculation using the above concentrations for the period of 120 tidals and the result of the precalculation was used as the initial value in the final calculation.

k) Open Boundary Concentration

The concentration of each index at the open boundaries was obtained using the concentrations observed outside the bay (St. 1).

Table 11.1-4(1) External Load at Present (Dry Season)

RIVER INFLOW Dry Season in 1991

NO	NAME	I	J	Discharge (m3/s)	BOD (t/day)	COD (t/day)	PO_4-P (t/day)	O-P (t/day)
River load								
1	B.-CHARITAS	46	38	0.93	1.96	1.61	0.072	0.108
2	CANAL CANTO DO RIO	43	39	0.73	1.54	1.27	0.056	0.084
3	B.-CATEDRAR	40	43	0.68	1.38	1.14	0.052	0.078
4	B.-NORTE CENTRO	40	47	0.77	1.61	1.33	0.060	0.090
5	RIO BOMBA	45	52	2.99	6.67	5.40	0.240	0.360
6	RIO IMBOASSU	52	63	2.48	4.99	4.04	0.176	0.264
Eastern Sub Total				8.58	18.15	14.79	0.656	0.984
7	B.-ITAOCA	52	70	0.58	1.18	0.98	0.044	0.066
8	RIO ALCANTARA	59	76	8.94	16.49	13.10	0.560	0.840
9	RIO CACEREBU	60	81	20.89	11.70	12.19	0.344	0.516
10	RIO GUAPIMIRIM	59	87	23.79	3.41	8.01	0.084	0.126
11	CANAL DE MAGE	57	88	0.52	0.31	0.32	0.008	0.012
12	RIO RONCADOR	56	88	2.79	1.31	1.49	0.040	0.060
13	RIO IRIRI	49	90	0.75	0.39	0.42	0.012	0.018
14	RIO SURUI	44	87	1.60	0.50	0.69	0.016	0.024
Northeastern Sub Total				59.86	35.29	37.2	1.108	1.662
15	B.-MAUA	34	84	0.74	0.32	0.37	0.008	0.012
16	RIO ESTRELA	23	80	10.79	10.40	9.14	0.328	0.492
171	RIO IGUACU	17	76	20.68	25.86	21.34	0.820	1.230
172	RIO SARAPUI	17	76	16.15	35.84	28.19	1.248	1.872
18	B.-CABO DO BRITO	12	71	2.32	4.77	3.87	0.172	0.258
Northwestern Sub Total				50.68	77.19	62.91	2.576	3.864
19	RIO S.J.DE MERITI	9	63	22.26	53.31	42.02	1.884	2.826
20	RIO IRAJA	11	62	7.41	18.43	15.00	0.684	1.026
21	CANAL DO CUNHA	19	49	11.98	29.75	23.93	1.088	1.632
22	B.-S.CRISTOVAO	23	45	0.97	2.24	1.86	0.084	0.126
23	CANAL DO MANGUE	23	43	7.50	18.33	14.82	0.672	1.008
24	B.-BOTAFOGO	32	35	5.36	13.27	10.85	0.496	0.744
Western Sub Total				55.48	135.33	108.48	4.908	7.362
25	I.DO GAVANADOR	23	66	2.83	5.51	4.45	0.192	0.288
26	I.DO FUNDAO	18	52	0.20	0.19	0.18	0.008	0.012
27	I.DE PAQUETA	43	72	0.09	0.12	0.10	0.004	0.006
28	I.DO ENGENHO	43	56	0.19	0.42	0.36	0.016	0.024
29	I.DE S.CRUZ	41	51	0.10	0.18	0.15	0.008	0.012
Islands Sub Total				3.41	6.42	5.24	0.228	0.342
River load Total				178.01	272.38	228.62	9.476	14.214
Direct Load								
007		43	36	-	2.13	-	-	-
001		46	55	-	6.70	-	-	-
004		46	56	-	2.40	-	-	-
008		44	51	-	2.10	-	-	-
009		40	47	-	1.94	-	-	-
027		45	52	-	0.80	-	-	-
034		46	57	-	0.66	-	-	-
044		46	57	-	0.51	-	-	-
047		46	57	-	0.48	-	-	-
062		48	59	-	0.38	-	-	-
113		51	62	-	0.22	-	-	-
Eastern Sub Total				-	18.32	-	-	-
015		17	76	-	1.32	-	-	-
018		17	76	-	1.20	-	-	-
075		17	76	-	0.33	-	-	-
029		17	76	-	0.79	-	-	-
086		17	76	-	0.31	-	-	-
137		10	68	-	0.16	-	-	-
Northwestern Sub Total				-	4.11	-	-	-
030		11	62	-	0.72	-	-	-
042		11	62	-	0.52	-	-	-
051		32	36	-	0.45	-	-	-
Western Sub Total				-	1.69	-	-	-
Direct Load Sub Total				-	24.11	-	-	-
Total				178.01	296.49	228.62	9.476	14.214

Table 11.1-4(2) External Load at Present (Rainy Season)

RIVER INFLOW — Rainy Season in 1991

NO	NAME	I	J	Discharge (m3/s)	BOD (t/day)	COD (t/day)	PO_4-P (t/day)	O-P (t/day)
River load								
1	B.-CHARITAS	46	38	1.40	2.74	2.16	0.048	0.072
2	CANAL CANTO DO RIO	43	39	1.10	2.15	1.70	0.040	0.060
3	B.-CATEDRAR	40	43	1.03	1.92	1.53	0.036	0.054
4	B.-NORTE CENTRO	40	47	1.15	2.24	1.77	0.040	0.060
5	RIO BOMBA	45	52	4.52	9.34	7.26	0.168	0.252
6	RIO IMBOASSU	52	63	3.80	7.05	5.58	0.124	0.186
Eastern Sub Total				13.00	25.44	20.00	0.456	0.684
7	B.-ITAOCA	52	70	0.87	1.64	1.31	0.032	0.048
8	RIO ALCANTARA	59	76	14.01	23.66	18.91	0.400	0.600
9	RIO CACERBBU	60	81	34.45	17.91	22.38	0.292	0.438
10	RIO GUAPIMIRIM	59	87	40.93	5.93	17.94	0.124	0.186
11	CANAL DE MAGE	57	88	0.82	0.46	0.55	0.008	0.012
12	RIO RONCADOR	56	88	4.51	2.00	2.74	0.036	0.054
13	RIO IRIRI	49	90	1.18	0.58	0.75	0.012	0.018
14	RIO SURUI	44	87	2.59	0.77	1.36	0.012	0.018
Northeastern Sub Total				99.36	52.95	65.94	0.916	1.374
15	B.-MAUA	34	84	1.18	0.48	0.69	0.008	0.012
16	RIO ESTRELA	23	80	17.40	15.43	15.05	0.252	0.378
171	RIO IGUACU	17	76	33.34	38.08	33.82	0.616	0.924
172	RIO SARAPUI	17	76	25.06	50.96	39.24	0.880	1.320
18	B.-CABO DO BRITO	12	71	3.54	6.73	5.30	0.120	0.180
Northwestern Sub Total				80.52	111.68	94.10	1.876	2.814
19	RIO S.J.DE MERITI	9	63	34.28	75.35	57.33	1.320	1.980
20	RIO IRAJA	11	62	11.09	25.64	19.60	0.472	0.708
21	CANAL DO CUNHA	19	49	18.10	41.58	31.67	0.752	1.128
22	B.-S.CRISTOVAO	23	45	1.44	3.10	2.42	0.060	0.090
23	CANAL DO MANGUE	23	43	11.30	25.59	19.57	0.464	0.696
24	B.-BOTAFOGO	32	35	8.00	18.42	14.12	0.340	0.510
Western Sub Total				84.21	189.68	144.71	3.408	5.112
25	I.DO GAVANADOR	23	66	4.35	7.81	6.21	0.136	0.204
26	I.DO FUNDAO	18	52	0.30	0.28	0.27	0.004	0.006
27	I.DE PAQUETA	43	72	0.13	0.17	0.15	0.004	0.006
28	I.DO ENGENHO	43	56	0.27	0.58	0.46	0.012	0.018
29	I.DE S.CRUZ	41	51	0.15	0.25	0.21	0.004	0.006
Islands Sub Total				5.20	9.09	7.30	0.160	0.240
River load Total				282.29	388.84	332.05	6.816	10.224
Direct Load								
007		43	36	-	2.13	-	-	-
001		46	55	-	6.70	-	-	-
004		46	56	-	2.40	-	-	-
008		44	51	-	2.10	-	-	-
009		40	47	-	1.94	-	-	-
027		45	52	-	0.80	-	-	-
034		46	57	-	0.66	-	-	-
044		46	57	-	0.51	-	-	-
047		46	57	-	0.48	-	-	-
062		48	59	-	0.38	-	-	-
113		51	62	-	0.22	-	-	-
Eastern Sub Total				-	18.32	-	-	-
015		17	76	-	1.32	-	-	-
018		17	76	-	1.20	-	-	-
075		17	76	-	0.33	-	-	-
029		17	76	-	0.79	-	-	-
086		17	76	-	0.31	-	-	-
137		10	68	-	0.16	-	-	-
Northwestern Sub Total				-	4.11	-	-	-
030		11	62	-	0.72	-	-	-
042		11	62	-	0.52	-	-	-
051		32	36	-	0.45	-	-	-
Western Sub Total				-	1.69	-	-	-
Direct Load Sub Total				-	24.11	-	-	-
Total				282.29	412.95	332.05	6.816	10.224