3.2 Demographic Characteristics

3.2.1 Population Distribution by Municipality

Demographic census presenting data on population and housing characteristics are taken at 10-year intervals in Brazil. Definitive data is available from demographic census taken in 1950, 1960, 1970 and 1980. The 1990 Census was delayed until 1991.

Table 3.2-1 shows the area and population of the municipalities included in the Guanabara Bay basin.

The total area and the total population was taken from 1991 demographic census, while the area within the Guanabara Bay basin was measured from topographical maps, scale of 1:50,000.

Fig. 3.2-1 shows that the ratio of population and area per municipality is about 80 % in the western district and about 60 % in the northeastern district.

The population density differs largely by municipality. Sao Joao de Meriti has 11,997 people/km^2, the highest, while Cachoeiras de Macacu has 44/km^2, the lowest in the basin.

3.2.2 Population Growth and Population Migration

Details of population growth by municipality between 1980 and 1991 are shown in **Table 3.2.2.**

A comparison between the population growth rates corresponding to the 1980s and the past three decades showed that the population growth rates have been continuously declining, except for Itaborai which had an upsurge during the 1970s (5.62%) and kept growing at a high 3.16% during the 1980s.

The above described pattern of population growth suggests that the urban areas around the city of Rio de Janeiro are saturated, implying high costs of living, thereby forcing population expansion into rural areas. Hence, population growth in the future is likely to be concentrated in those Municipalities with a significant proportion of rural population, namely, Itaborai, Rio Bonito and Cachoeiras de Macacu.

Expected population growth in Itaborai and Rio Bonito would be a natural extension of the population growth that is expected to take place in Sao Goncalo, where despite all its population being classified as urban, still a lot of large urbanizations and housing developments are planned within its municipal boundaries. On the other hand, Cachoeiras de Macacu is completing establishment of an Industrial District, with eight industries committed as of October 1992, which is expected to attract people seeking employment.

Table 3.2-1 Area and Population of the Municipalities included in the Guanabara Bay Basin

	Area (km^2)		Population ($x10^3$)		Pop. Density
	Total	G.B. basin	Total	G.B. basin	G.B. basin
W District	2,457	1,298.6	8,015	5,916.9	4,591
Rio de Janeiro	1,171	388.2	5,473	3,825.3	9,854
Nova Iguacu	764	390.2	1,294	888.7	2,278
Duque de Caxias	466	465.5	665	665.3	1,429
Sao Joao de Meriti	34	35.4	425	424.7	11,997
Nilopolis	22	19.3	158	157.9	8,181
E District	358	328.0	1,215	1,148.7	3,502
Sao Goncalo	228	245.8	779	778.8	3,168
Niterol	130	82.2	436	369.9	4,500
NE District	2,835	2,453.8	437	483.3	197
Mage	746	745.8	191	191.2	256
Itaborai	572	571.5	161	161.4	282
Cachoeiras de Macacu	1,055	899.5	40	39.6	44
Rio Bonito	462	197.0	45	43.1	219
Petropolis	--	40.0	--	48.0	1,200
Total		4,080.4		7,594.0	1,861

Remarks

(1) Total area and total population is taken from 1991 demographic census.

(2) Area in the Guanabara Bay basin was measured from topographical maps.

(3) Mage was divided into Mage and Guapimirim, quiet recently. Mage is 373 km^2 and Guapimirim is 345 km^2 in area respectively

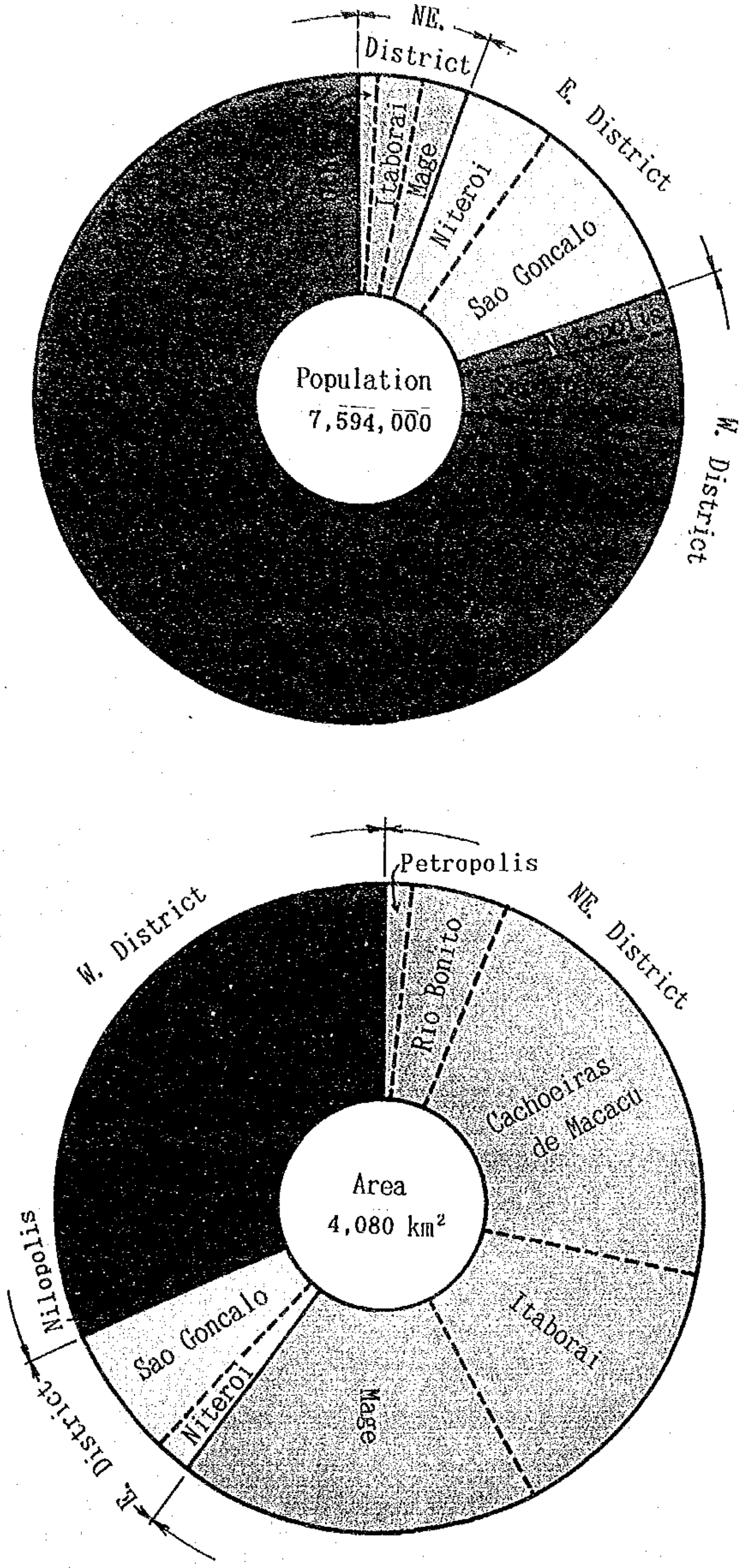
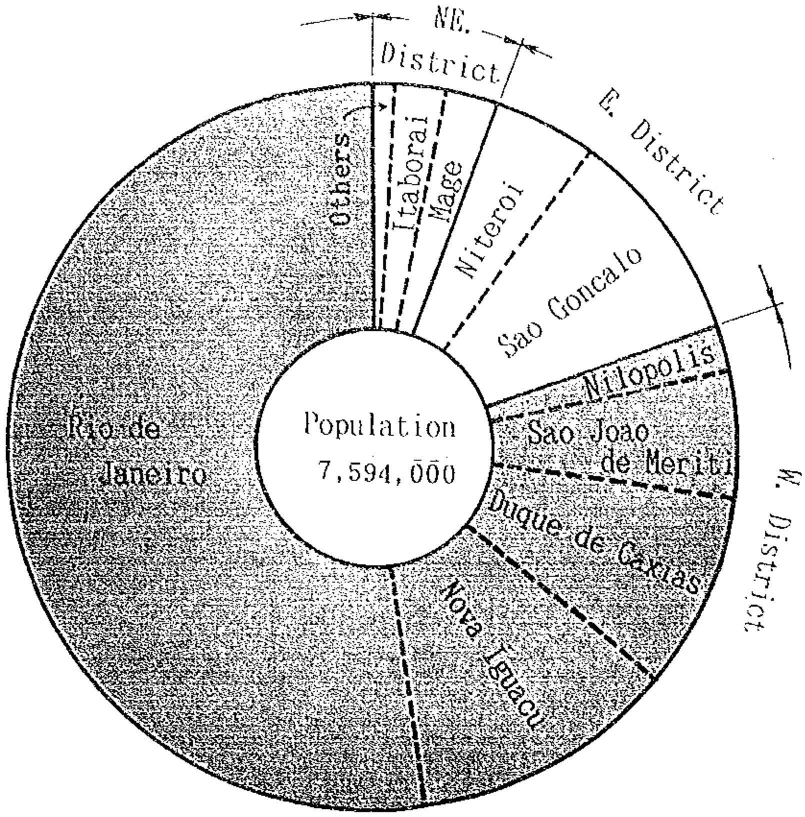


Fig. 3.2- 1 Ratio of Population and Area per Municipality



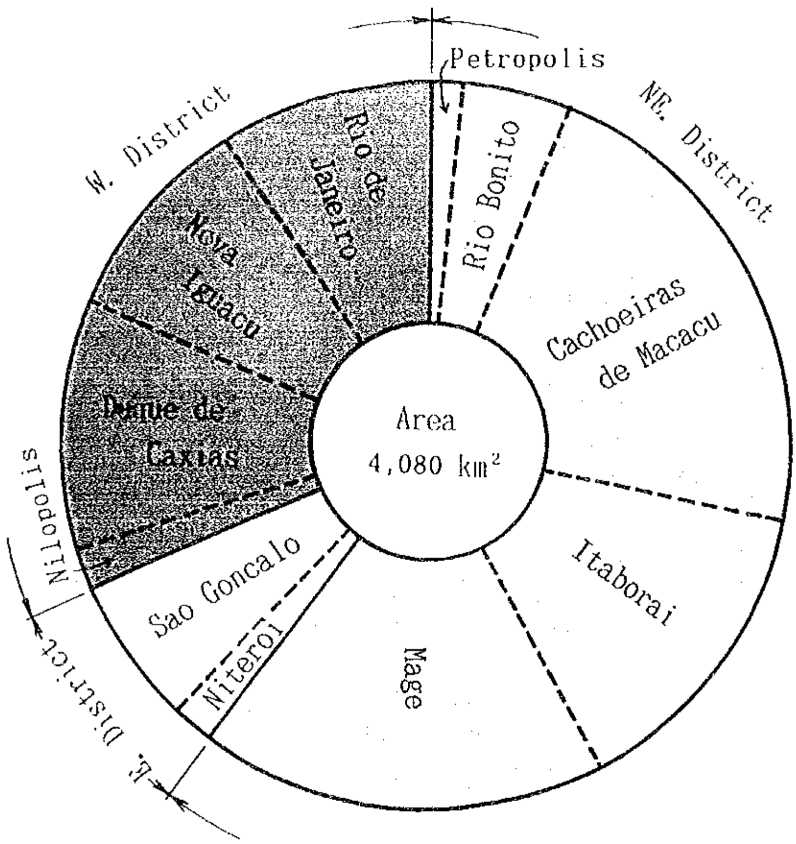


Fig. 3.2-1 Ratio of Population and Area per Municipality

Table 3.2-2 Population Growth between 1980 and 1991

Municipality	Population 1980	Population 1991	Annual Growth (%)
Rio de Janeiro	5,090,700	5,336,179	0.43
Nova Iguacu	1,094,805	1,286,337	1.48
D. de Caxias	575,814	665,643	1.31
S.J. de Meriti	398,826	425,038	0.58
Nilopolis	151,588	157,819	0.37
Sao Goncalo	615,352	747,891	1.79
Niteroi	397,123	416,123	0.43
Mage	166,602	191,359	1.27
Itaborai	114,540	161,274	3.16
Cach. de Macacu	35,867	40,195	1.04
Rio Bonito	40,036	45,093	1.09
Total	8,681,253	9,472,951	0.80

Source : 1980 and 1991 Population Census.

3.2.3 Favela Population

In the Study Area, there are many favelas which have their own peculiar characteristics concerning population density, sanitation facilities and collection of solid wastes. Since these characteristics are quite different from those in other areas, the favela population was obtained from the 1991 Demographic Census and summarized as shown in **Table 3.2.3.**

The favela population and area of Rio de Janeiro Municipality are grasped by IPLANRIO (Instituto de Planejamento Municipal). **Table 3.2-4** shows it by sub-basin.

The favela population in 1980 and 1991 numbers 570,928 and 799,549 respectively, consequently it increased 40 % during the past ten years.

The total favela area in Rio de Janeiro Municipality is 2,433 ha in 1991, that is only 6 % of the total area of the municipality, however, the population ratio amount to 19 % of the total population of the municipality.

In the study area, the area ratio of favela is 4.5 % and the population ratio of favela amount to 24 %. Favela population density in the study area is 46,011 per square kilometer.

Table 3.2-3 Favela Population by Municipality

Municipality	Municipal Population	G.B. Basin Population	Favela Population
Cach. de Macacu	40,181	40,181	0
Duque de Caxias	665,338	665,338	51,179
Itaborai	161,398	161,398	0
Mage	191,249	191,249	8,968
Nilopolis	157,936	157,936	2,261
Niteroi	435,658	369,933	24,843
Nova Iguacu	1,293,611	824,028	40,784
Rio Bonito	45,093	43,069	0
Rio de Janeiro	5,472,967	3,352,326	877,738
Sao Goncalo	778,820	778,820	0
S.J. de Meriti	424,689	424,689	13,726
Total	9,666,940	7,008,967	1,019,499

Source:

Table 3.2-4 Favela Population and Area by Sub-Basin included in the Study Area

Sub-basin No.	Number	1980 Population	1980 Dwellings	1991 Population	1991 Dwellings	Area (ha)
17-6RJ	21	8,148	1,835	33,343	7,547	77.93
19-1RJ	67	104,880	23,699	157,201	34,540	379.69
19-2RJ	36	13,554	3,062	27,469	5,749	80.52
20RJ	44	139,216	31,775	164,116	37,797	303.00
21RJ	104	154,806	35,440	205,864	45,964	444.97
22RJ	8	15,276	3,694	19,567	4,533	25.16
23RJ	48	88,359	20,128	27,592	6,296	285.04
24RJ	19	16,111	3,725	27,592	6,296	37.37
25RJ	22	30,578	6,750	51,304	12,074	104.06
Total	369 (Favelas)	570,928	130,108	799,549	179,083	1,737.74

Source:

Total favela of Rio de Janeiro Municipality by IPLANRIO

Total number of favelas ; about 600

Total favela population ; 1,045,721

Total number of houses ; 233,997

Total favela area ; 2,433.61 ha

3.3 Agriculture, Fishery and Forestry

3.3.1 Agriculture

As shown in **Table 3.3-1**, crop land area is very limited, about 10 % of the total area of the Guanabara Bay Basin.
About 70 % of the crop land is included in the Northeastern area of the Basin and it is scarcely found in Sao Joande Meriti, Niropolis and Niteroi.

Principal crops are orange, banana, cassava etc, from the view point of cropland area, and agricultural chemicals are scarcely used.

3.3.2 Fishery

During the two phases of the study, the main fishing techniques, fish production, commercialization of the main fish species, physical condition of the fishermen and the behavior of fish the Bay as a nursery ground were analysed.

Today, about 5,000 fishermen using boats and canoes are estimated to be working in the Bay. They are grouped into four fishermen colonies. Some of the main fishing techniques used within the Bay are "set nets", "trap nets", "bamboo screens", "hand lines" and "sand trawls".

The total income by set nets and bamboo screens was estimated to be between US$200 to US$400 per month.

Even though there is no historical statistical data, fish production reduction is evident, recently, causing serious anxiety among the fishermen. According to our investigation, the main reason for the fish production decadence has to be owed, mainly, to predatory fishing practices that are being practiced lately to maximize profits. Further, water quality deterioration, without a doubt, has affected the fish population composition and production.

One of the best available solutions, that would meet the fishermen's requirements, and at the same time maintain fish communities according to the Bay's original function would be to practice artificial breeding for commercial use, for example mussels, oysters can be farmed and regenerate etc. without damaging the fundamental function of Guranabara Bay as a nursery ground.

3.3.3 Forestry

Analitical result of the landsat image says that the ratio of forests in the Guanabara Bay Basin is 31 % and about 70 % of it distributes in the basins of Rio Macacu, Rio Guapimirim etc., the northeastern district.

About 95 km^2 of forest decreased during seven years, between 1984 and 1991, especially in Sao Goncalo and Itaborai. Only 2 % of the forests in the Guanabara Bay Basin are artificial.

Table 3.3-1 Crop Land and Forest

	Total Area (km^2)	Crop Land		Planted Area (km^2)						Forest (km^2)		Number of Milking Cows
		Total	(%)	Oranges	Bananas	Cassavas	Rice	Corn	Sugar	Natural	Artificial	
Western District	2,433	147	(6.0)	1.5	23.8	19.0	7.1	4.7	8.4	62.6	2.3	10,985
Rio de Janeiro	1,171	69	(5.9)	0.6	11.1	10.6	4.0	0.0	3.3	27.8	1.4	3,763
Nova Iguacu	764	51	(6.7)	0.7	8.5	5.2	3.0	4.5	3.4	11.0	0.8	5,388
Duque de Caxias	442	26	(5.9)	0.2	4.2	3.2	0.1	0.2	1.7	23.8	0.1	1,656
Sao Joan de Meriti	34	0	(0.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	125
Nilopolis	22	0	(0.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53
Eastern District	358	14	(3.9)	4.1	0.2	1.3	0.0	0.0	0.0	5.2	0.1	716
San Goncalo	228	13	(5.7)	4.0	0.0	1.3	0.0	0.0	0.0	2.4	0.0	621
Niteroi	130	1	(0.8)	0.1	0.2	0.0	0.0	0.0	0.0	2.8	0.1	95
Northeastern District	2,761	407	(14.7)	167.3	46.2	22.7	12.4	11.4	0.3	396.8	6.9	14,845
Mage	718	46	(6.4)	0.4	8.4	7.0	11.4	2.3	0.1	83.2	0.7	2,202
Itaborai	526	149	(28.8)	89.4	0.9	2.7	0.1	0.2	0.1	38.6	0.7	4,506
Cachoeiras de Macacu	1,055	108	(10.2)	8.6	22.6	8.5	0.9	7.1	0.1	202.8	3.4	5,484
Rio Bonito	462	104	(22.5)	68.9	14.3	4.5	0.0	1.8	0.0	72.2	2.1	2,653
Total	5,552	568	(10.2)	172.9	70.1	42.9	19.6	16.1	8.8	464.5	9.3	26,546

Remarks:

*1 The area of crop land includes perenial use and is taken from IBGE (1990) Censo Agropecuario 1985, No. 20.

*2 Planted area is taken from IBGE (1990) Producao Agropeucrio Minicipio 1988, Vol. 15, t-3.

3.4 Industry

3.4.1 Industry Characteristics

In terms of economic activities causing pollution of water bodies, the industrial sector is likely to be one of the most significant factors in the Guanabara Bay basin.

Industrial data for Rio de Janeiro State in 1985 were analyzed in terms of selected criteria: (1) number of industries, (2) number of employees and (3) gross value of production. These data show that the municipalities comprising the Guanabara Bay basin accounted for 74% of the number of industries, 77% of the number of employees, and 72% of the value of industrial production. In absolute figures, these Municipalities accounted for 12,492 out of 16,892 industrial firms, 405,344 out of 528,657 employees, and 78,724,100 out of 108,914,900 Million Cruzeiros worth of industrial production.

Details by municipality are shown in **Tables 3.4-1** and **3.4-2**.

As shown in **Table 3.4-2**, industrial firms with less than 10 employees comprised 61% of the total number of firms, but accounted for only 7% of employees devoted to production. The medium size industries, those employing between 10 and 49 employees, were more even in terms of the share in the number of industrial firms (28%) and the number of employees (21%). Finally, 11% of industrial firms, each employing 50 or more employees, accounted for 72% of total employees in production. Very clearly seen here is the highly skewed industry size structure, in which a small number of large industrial firms dominate employment in the manufacturing sector in such a way that small firms have little influence on the overall picture.

Table 3.4-1 Number of Industrial Firms and Employees by Municipality

State and Municipality	No. of Industries	No. of Employees	%
Rio de Janeiro State	16,892	528,657	100.0
Rio de Janeiro	8,959	320,820	60.7
Nova Iguacu	619	16,657	3.2
Duque de Caxias	807	23,302	4.4
Sao Joao de Meriti	446	5,568	1.1
Nilopolis	126	1,207	0.2
Sao Goncalo	594	12,536	2.4
Niteroi	498	15,729	3.0
Mage	144	5,075	1.0
Itaborai	179	3,007	0.6
Cachoeiras de Macacu	40	248	0.1
Rio Bonito	80	1,195	0.2

Source: 1985 Industrial Census.

Table 3.4-2 Size of Firms in the State of Rio de Janeiro

Personnel Size	Industries		Employees			
	Number	%	Total	%	Production	%
1 - 4	5,210	35.6	15,440	3.6	7,148	2.0
5 - 9	3,672	25.1	26,520	6.2	18,549	5.1
10 - 19	2,422	16.5	35,505	8.3	28,291	7.8
20 - 49	1,741	11.9	57,203	13.4	47,550	13.1
50 - 99	736	5.0	54,150	12.6	46,328	12.8
100 - 249	559	3.8	89,774	21.0	78,448	21.7
250 - 499	210	1.4	73,723	17.2	65,812	18.2
≥ 500	76	0.5	76,074	17.8	69,646	19.3
n.a.	24	0.2	-	-	-	-
Total	14,650	100.0	428,389	100.0	361,772	100.0

Source: 1985 Industrial Census.

3.4.2 Industry Types

Industry types were ranked by Municipality, according to the production values in 1985 as shown in **Tables 3.4.3**.

Municipalities belonging to the western district, most especially Rio de Janeiro, covers more than 90 % of the overall industrial production. The eastern district covers about 3.4 % and the northeastern district covers less than 1 % of the overall production.

The ratio according to type of industry shows that the chemical industry accounts for 35 %, metallurgical industry 8.0 %, and food industry 7.0 %, of the total production.

3.4.3 Industrial Pollution

A comparative analysis of the industrial sector by Municipality between 1980 and 1985 give the impression of an economic sector in decline. However, in the interpretation of these results, careful consideration should be given to the difficulties faced by the Brazilian economy during the 1980s.

Important to note from the viewpoint of pollution in the Guanabara Bay are the strength and widespread distribution of chemical industries, among which the sheer size and complexity of REDUC (Refinaria Duque de Casias) is a motive for concern. Other important industries appear to be metallurgical, clothing, textiles, and food processing. The concentration of about half of industrial establishments in Rio de Janeiro Municipality is also a matter of concern. Food processing industries, particularly fish canneries, although mostly localized in Niteroi and Sao Goncalo, are known to discharge untreated organic wastes.

Table 3.4- 3 Gross Value of Industrial Production by Industry Type

unit:Billon Cr$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	Total
Western District	45.4	5.9	8.3	261.5	7.4	18.7	23.8	19.5	13.5	59.3	29.2	46.6	2.6	170.2	711.8
Rio de Janeiro	39.6	5.9	8.3	69.7	7.4	13.2	23.8	16.5	13.5	52.1	27.6	46.6	2.6	147.4	474.2
Nova Iguacu	2.7	-	-	15.9	-	-	-	-	-	7.2	1.6	-	-	7.5	34.9
Duque de Caxias	2.0	-	-	175.9	-	-	-	3.0	-	-	-	-	-	13.0	193.9
Sao Joan de Meriti	0.9	-	-	-	-	5.4	-	-	-	-	-	-	-	2.0	8.3
Nilopolis	0.2	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.5
Eastern District	7.2	-	-	2.4	-	-	1.0	1.0	-	2.6	-	-	-	12.1	26.3
San Goncalo	4.0	-	-	2.4	-	-	1.0	-	-	1.9	-	-	-	4.9	14.2
Niteroi	3.2	-	-	-	-	-	-	1.0	-	0.7	-	-	-	7.2	12.1
Northeastern District	0.3	-	0.6	0.9	-	-	-	1.6	-	-	0.1	-	-	2.5	6.0
Mage	-	-	0.6	-	-	-	-	1.6	-	-	0.1	-	-	1.0	3.3
Itaborai	0.3	-	-	0.9	-	-	-	-	-	-	-	-	-	0.6	1.8
Cachoeiras de Macacu-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.1	
Rio Bonito	-	-	-	-	-	-	-	-	-	-	-	-	-	0.8	0.8
Total	53.0	5.9	8.9	264.9	7.4	18.7	24.7	22.1	13.5	61.9	29.4	46.6	2.6	207.4	767.0

Source : IBGE (1991) Censos Economic de 1985, Vel. 1.

(1) Food (2) Beverage (3) Paper (4) Chemical (5) Rubber
(6) Plasticse (7) Pharmaceuticals (8) Textile (9) Non-metallic (10) Metallurgical
(11) Mechanical (12) Mineral Extraction (13) Leather and Hide (14) Others

3.5 Sanitation Infrastructure

The following discussion on sanitation is based on the 1980 Census data, which is the latest census containing such data.

3.5.1 Water Supply

Indoor piped water supply was available in 80% of dwellings of the State in 1980, but wide variations occurred between Municipalities, ranging from 45% in Itaborai to 91% in Rio de Janeiro. Water supply systems were classified into public systems, wells/springs, and others. Water supply systems have an effect on the waste water generated and discharged from households or dwellings, especially if considered in conjunction with the types of toilet facilities.

Looking at the dwellings without indoor piped water supply, some of them showed water supplied by the public system. These are presumably yard taps. In the case of dwellings without indoor piped water supply, wells or springs were the predominant water sources.

Types of water supply systems by Municipality in 1980, expressed as percentage of dwellings, are shown in **Table 3.5.1.**

3.5.2 Sewer System

As already mentioned, important from the sanitation viewpoint are water supplied by indoor piping and facilities available in dwellings for the disposal of domestic refuse including human excreta. An critical issue in the sewer system in the Guanabara Bay basin concerns the final treatment of sewage. The issue stems from the insufficient capacity of sewage treatment plants, even in cities with infrastructure of sewer networks such as Rio de Janeiro and Niteroi.

The 1980 Population Census divided toilet facilities into those used exclusively by the dwelling and those shared with other dwellings, as shown in **Table 3.5.2**, expressed in terms of percentage of dwellings. Toilet facilities shared by several dwellings were more prevalent in rural Municipalities.

Table 3.5-1 Types of Water Supply Systems

Unit: % of dwellings

Municipality	Public System	Well/ Spring	Others	Total
Rio de Janeiro	88(4)	2 (2)	1(3)	91 (9)
Nova Iguacu	38(5)	23(28)	2(4)	63(37)
Duque de Caxias	37(7)	22(26)	2(6)	61(39)
Sao Joao de Meriti	62(9)	10(11)	2(6)	74(26)
Nilopolis	85(4)	3 (4)	1(3)	89(11)
Sao Goncalo	60(4)	12(15)	3(6)	75(25)
Niteroi	70(3)	9(10)	2(6)	81(19)
Mage	34(3)	22(36)	1(4)	57(43)
Itaborai	21(3)	22(51)	1(2)	44(56)
Cachoeiras de Macacu	45(4)	15(30)	2(4)	62(38)
Rio Bonito	40(2)	17(38)	-(3)	57(43)

No parentheses: with indoor pipes
In parentheses: without indoor pipes
Source : 1980 Population Census.

Table 3.5-2 Toilet Facilities

Unit: % of dwellings

Municipality	Public Sewer	Cess-pool	Simple Pits	Others	Total
Rio de Janeiro	78(5)	2(--)	5(1)	4 (5)	89(11)
Nova Iguacu	30(3)	39 (4)	9(1)	7 (7)	85(15)
Duque de Caxias	--	68(10)	8(1)	5 (8)	81(19)
S.J. de Meriti	--	68 (9)	9(2)	7 (5)	84(16)
Nilopolis	66(4)	16 (2)	3(1)	3 (4)	89(11)
Sao Goncalo	8(1)	1(--)	70(6)	6 (8)	85(15)
Niteroi	65(2)	14 (1)	7(1)	3 (7)	89(11)
Mage	--	46 (3)	22(2)	14(13)	82(18)
Itaborai	9(1)	2(--)	59(4)	3(22)	73(27)
Cach. de Macacu	--	7(--)	19(1)	47(26)	73(27)
Rio Bonito	25(1)	--	36(1)	5(32)	66(34)

No parenthesis: exclusive use of the dwelling
In parenthesis: shared use by several dwellings
Source : 1980 Population Census.

3.5.3 Sanitation and Water Pollution

From the water pollution viewpoint, attention should be paid to the following Municipalities.

* Dwellings without connection to public sewer systems

  Cachoeiras de Macacu
  Duque de Caxias
  Mage
  Sao Joao de Meriti

* High proportion of dwellings without toilet facilities

Cachoeiras de Macacu	23%
Itaborai	18%
Rio Bonito	28%

* High proportion of dwellings dependent on cesspools or septic tanks

Duque de Caxias	78%
Mage	49%
Nova Iguacu	44%
Sao Joao de Meriti	78%

* High proportion of dwellings dependent on simple pits

Cachoeiras de Macacu	20%
Itaborai	62%
Mage	24%
Rio Bonito	37%
Sao Goncalo	76%

It can be concluded from the above analysis that Municipalities requiring some kind of urgent sewer improvements are Cachoeiras de Macacu, Duque de Caxias, Itaborai, Mage, Nova Iguacu, Rio Bonito, Sao Goncalo and Sao Joao de Meriti, that is, eight of the eleven Municipalities in the Guanabara Bay basin.

Table 3.5- 3 Collection and Disposal of Urban Solid Waste

	Unit[1] (kg/cap/day)	Population (x10000)	Total (ton/day)	Collection[2] (ton/day)	Coll.Rate (%)	Disposal Site		(ton/day)
Western District								
Rio de Janeiro	1.510	5,473	8,246	5,500	66.6	Iraja	(Recycling/composting)	200
						Bangu	(Landfill)	700
						Jacarepagua	(Landfill)	700
						Itaguai	(Landfill)	80
						Caju	(Landfill)	1,100
						Gramacho	(Landfill)	3,820
Nova Iguacu	1.169	1,294	1,513	410	27.1	Gramacho	(Landfill)	700
Duque de Caxias	1.096	665	729	265	36.3	Gramacho	(Landfill)	
Sao Joao de Meriti	1.137	425	483	211	43.7	Gramacho	(Landfill)	
Nilopolis	1.113	158	176	74	42.0	Gramacho	(Landfill)	
Eastern District								
Sao Goncalo	0.974	779	759	160	21.0	Itaoca	(Landfill)	
Niteroi	1.396	436	609	270	44.3	Morro de Ceu	(Landfill)	
Northeastern District								
Mage	1.169	191	223	35	15.7	?	(Dump)	
Itaborai	1.169	161	188	30	16.0	?	(Dump)	
Cachoeiras de Macacu	?	40	?	30	?	Ferma	(Dump)	
Rio Bonito	?	45	?	22	?			
Total	7.007+?		12,926+?	7,007				

(Remarks)

1) Data on the Generation unit of solid waste (Domestic + Others) is taken from IBGE (1990) Revista Brasileira de Geografia, Vol. 52, No. 1.

2) Collection volume and disposal site are taken from FEEMA (1992).

3.6 Finance of the State Government and Municipalities

The relative importance attached to environmental matters by the Rio de Janeiro State and the Municipalities comprising the Guanabara Bay basin can be gleaned from the examination of budgets appropriations. The amount appropriated for environmental programs and its trend, as compared with the budges total, can give a useful indication on the possible commitment of State and local authorities to environmental improvement.

Budge data were examined at the State and Municipal levels in relation to expense appropriations for the respective Secretariats of the Environment. These data were available only for the State and the Municipality of Rio de Janeiro. Data on expense appropriations for broad expenditure groups were available for every Municipality, but none of the groups referred to the environment.

3.6.1 Rio de Janeiro State Finances

The State Government is organized under the classical division of power into three branches: Legislative, Judicial and Executive. However, expense appropriations for the Executive Branch during the three years of the available data accounted for 94 % of the State expense budget. Within the Executive Branch, the Secretariat for the Environment had expense appropriations since 1987, but they amounted to very low proportions of the budgets for the State and the Executive Branch, as shown in the table below.

Budget Item	Budgets Amount 1987 (1)	(Million Cz$) 1988 (1)	1989 (2)
R.J. State	110,423	908,270	11,351
Legislative	2,805	17,164	321
Judicial	4,868	32,095	328
Executive	102,750	859,011	10,702
Environment Secretariat	123	12,216	163
% of State	0.11	1.34	1.44
% of Executive	0.12	1.42	1.52

(1) Million Cruzados
(2) Million Cruzados Novos
Source:

More recent data are expected to show large increases in environmental budgets, in light to the tremendous importance granted lately to the environment, which culminated with the U.N. sponsored Conference on Conservation and Development, or the Earth Summit, held in Rio de Janeiro in June 1992 with the attendance of world political leaders and environmental experts.

According to FEEMA, the 1992 budget appropriations for the different government agencies of the Rio de Janeiro State, calculated at the exchange rate of CR$8,460.00 per US$1.00, amount to the following.

Government Agency	1992 Budget (US$)
SEMANP	1,111,000
IEF	1,832,000
FEEMA	5,447,000
SERLA	15,279,000
FECAM	1,709,000
Total	25,377,000

In the appropriated 1992 budget, the structure of expense categories was quite different for every government agency, as can be seen below.

Government Agency	Current Expenses (%)	Capital Expenses (%)
SEMANP	99.6	0.4
IEF	43.0	57.0
FEEMA	87.6	12.4
SERLA	24.6	75.4
FECAM	0.6	99.4
Total	41.1	58.9

3.6.2 Rio de Janeiro City Finances

The budget for the city of Rio de Janeiro showed appropriations for the Municipal Secretariat for Urban and Environmental Matters only starting in 1989. Similar to the State, the amounts appropriated in 1989 and 1990 were small, not reaching half a percent of the total municipal budget. However, while the 1989 expense budget was assigned to Housing and Urbanization, the 1990 expense budget was assigned to Education and Culture, presumably environmental education.

The total and environmental budgets appropriated by the City of Rio de Janeiro in 1989 and 1990 are shown in the following table.

Budget Item	Budget Amount(Million Cr$) 1989	1990
R.J. Municipality	3,869	123,220
Urban and Environmental Secretariat	18	608
% of Total	0.48	0.49

PART III

ENVIRONMENT AND UTILIZATION

OF

GUANABARA BAY

CHAPTER 4

OCEANOGRAPHIC CONDITIONS

CHAPTER 4

OCEANOGRAPHIC CONDITIONS

The water quality in the bay is mainly determined by three factors; physical condition (tidal currents), chemical condition (inflowing pollutants) and biological condition (in particular primary prodution). The physical condition is a basic one contributing to advection and diffusion in the bay. The currents in the bay are controlled not only by the topography but also by the tides.

Therefore, tides and tidal currents were studied in this chapter in order to help us understand the pollution mechanism of the Bay.

The physical characteristics of bed sediments, including the thickness of sediment layer and the rate of sedimentation were also studied.

4.1 Coastal and Submarine Topography

4.1.1 Coastline

The area of Guanabara Bay is about 400 km^2, including 48 km^2 of islands and islets, the major islands being, Ilha do Governador, Ilha do Fundao and Ilha de Paqueta.

The coastline of the Bay is about 131 km in length and is partially covered with mangroves, in particular the north-east area.

4.1.2 Submarine Topography

Main features of the Bay are its shallow water depth, 5.7 m on average, and narrow mouth, 1.6 km in width at the entrance of the Bay. Therefore, the Bay is a typical enclosed coastal sea.

The submarine topography of the Bay is complicated by many reefs. The maximum water depth at the mouth of the Bay is 51 m. A twenty meter contour line indents until the Rio-Niteroi Bridge and there is an area deeper than twenty meters off the eastern side of Ilha do Governador as shown in **Fig. 4.1-1**. A contour line of ten meters penetrates far into the inner part from the mouth of the Bay at about 2.5 km in width and extends to Ilha de Paqueta, located in the inner part of the bay.

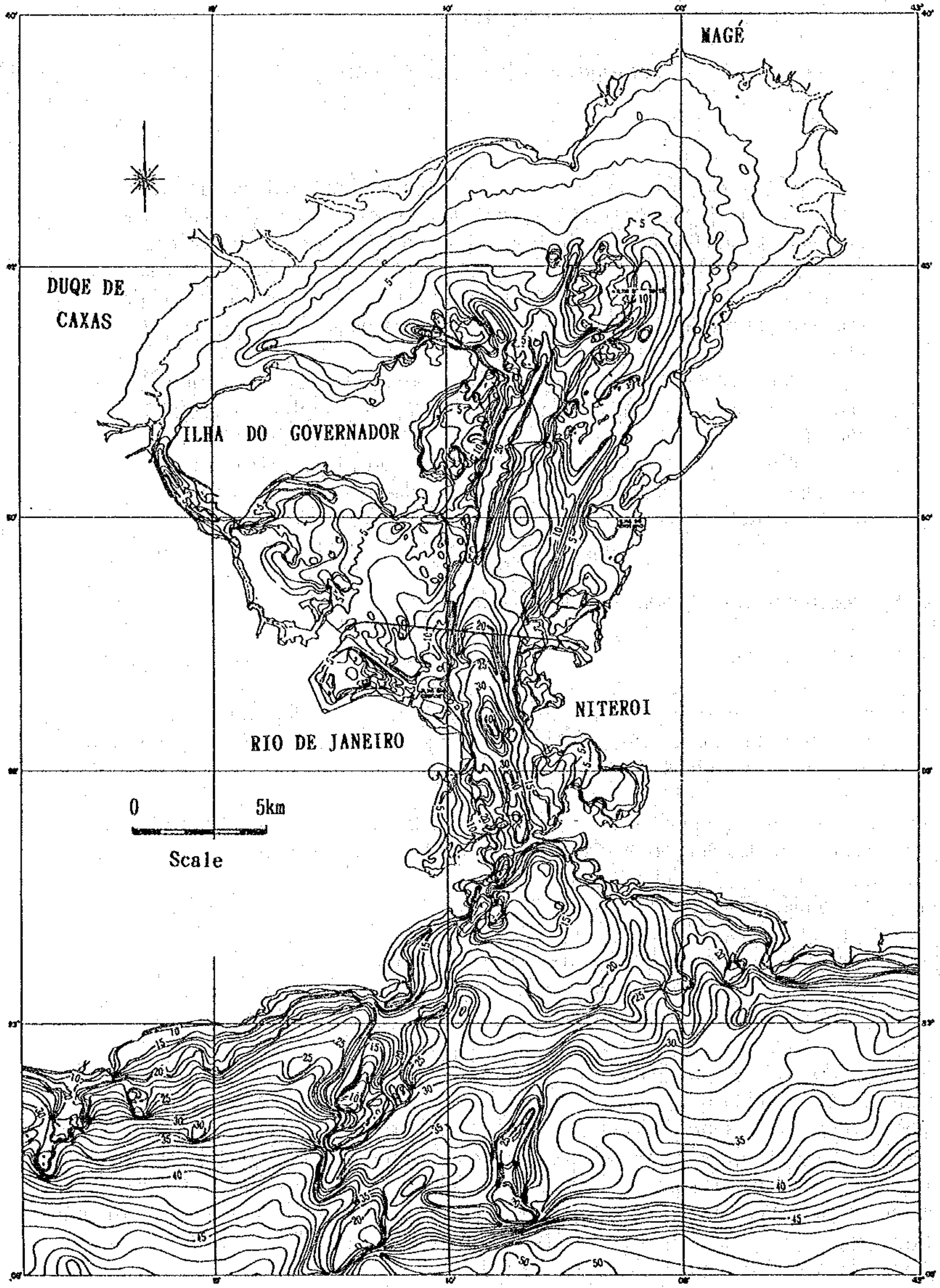


Fig. 4.1- 1 Submarine Topography of Guanabara Bay

4.1.3 Water Volume

The water volume of the Bay, which was calculated using the mesh data from an existing chart published in 1992, is shown in **Table 4.1-1.** The average water volume is estimated at 2.2 $\times 10^9$ m^3.

Table 4.1-1 Water Volume of Guanabara Bay

Tide	Water Volume below Water Level	Water Level
Mean High Water Springs	2.39×10^9 m^3	MSL + 48.8 cm
Mean High Water Neaps	2.25×10^9 m^3	MSL + 13.0 cm
Mean Low Water Neaps	2.15×10^9 m^3	MSL - 13.0 cm
Mean Low Water Springs	2.02×10^9 m^3	MSL - 48.8 cm
Lowest Low Water	1.95×10^9 m^3	MSL - 69.0 cm

4.2 Sea Bed Sediments

4.2.1 Grain Size Distribution

Fig. 4.2-1 shows the grain size distribution of the bed sediments in Guanabara Bay reffering to Amador (1992) and the records of acoustic survey carried out in the Study.

This shows that fine sediments(mud) are widely distributed in the inner part and in the coastal area of the central part of the Bay. On the other hand, coarse sediments are distributed along the deeper parts in the center of the Bay and in the area between Ilha do Governador and Ilha do Fundao.

The study team collected fifteen samples of surface sediments in the Bay. Twelve of them contained more than 90 % clay and silt. This result does not contradict Amador (1992).

4.2.2 Thickness of Bed Sediment Layer

The thickness of soft sediments (clay to fine silt) varies irregularly in the Bay depending on the topography and flow regime. It was confirmed, to be partially more than 10 meters thick in the northern part, through acoustic prospecting using low frequencies (7, 10, 12 KHz).

Fig. 4.2-2 shows the typical acoustic profiles obtained in this study.

4.2.3 Determination of Rate of Sedimentation

Using undisturbed core samples collected in the Bay, the rate of sedimentation was calculated by using the method for determining the concentration of ^{210}Pb.

The results of the measurement for ^{210}Pb concentration of samples at the locations shown in **Fig. 4.2-3**, using a low-background gas-flow counter have deviations from regularity, which is thought to have been caused by disturbances due to various reasons.

The sedimentation speed, however, was calculated to be 2.0 cm/year in recent years and 0.5 cm/year in past years as shown in **Fig. 4.2-3**.

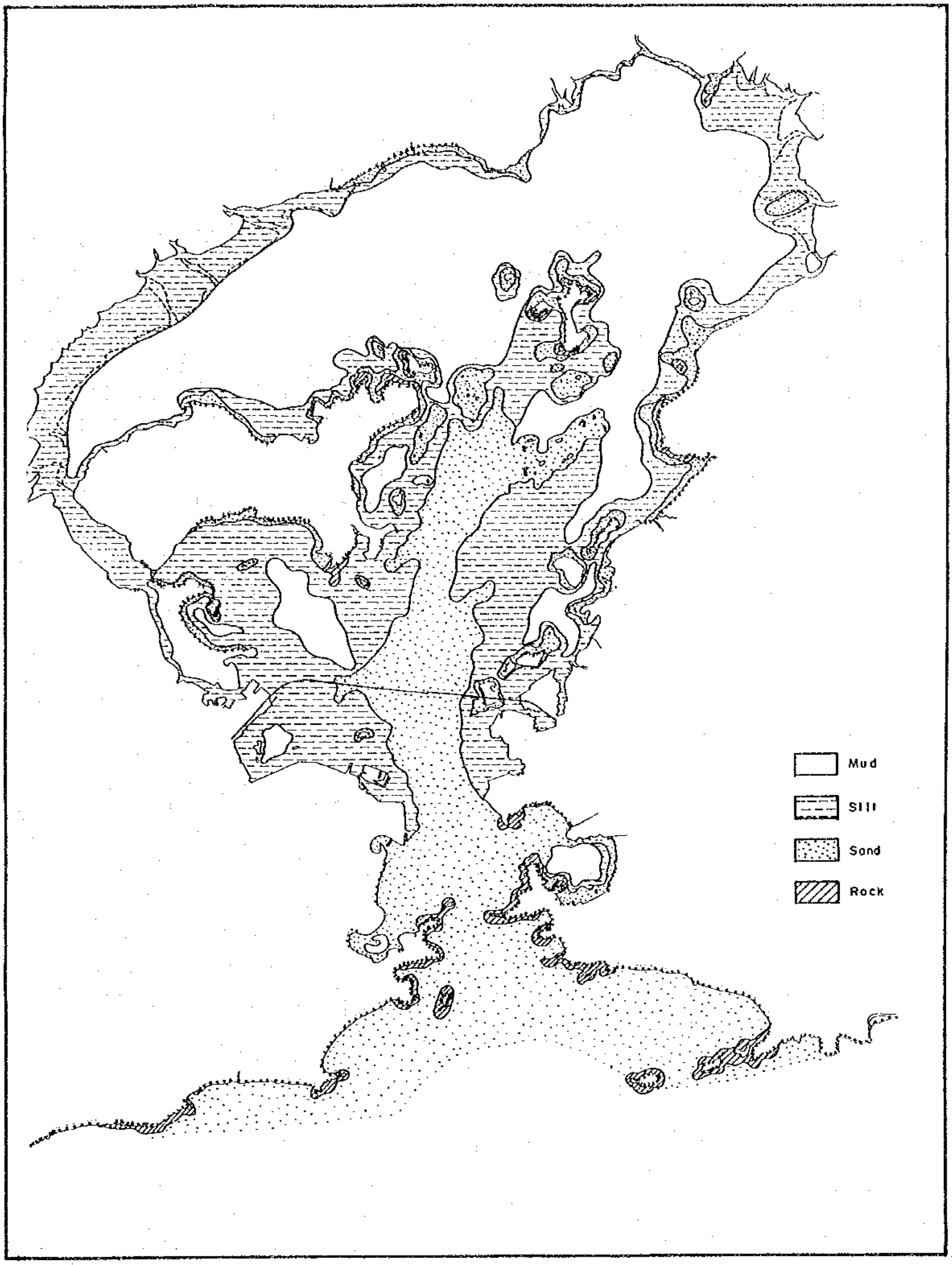
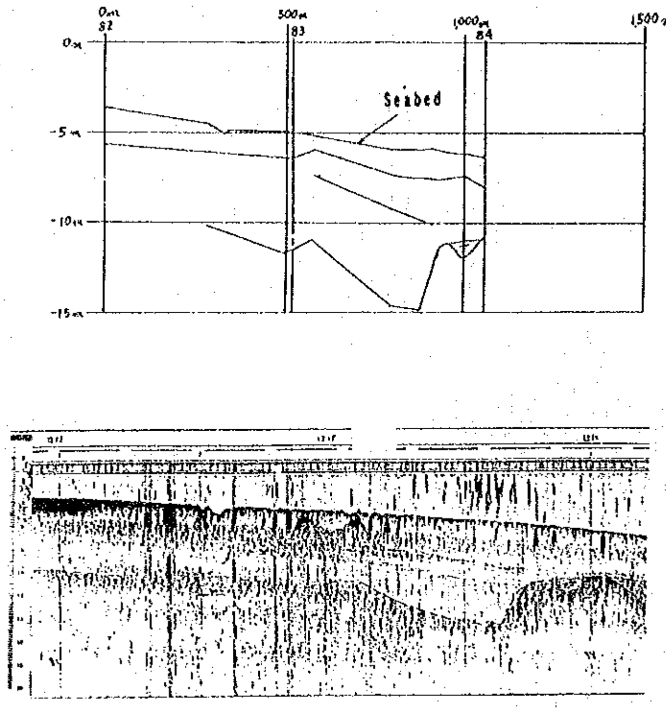
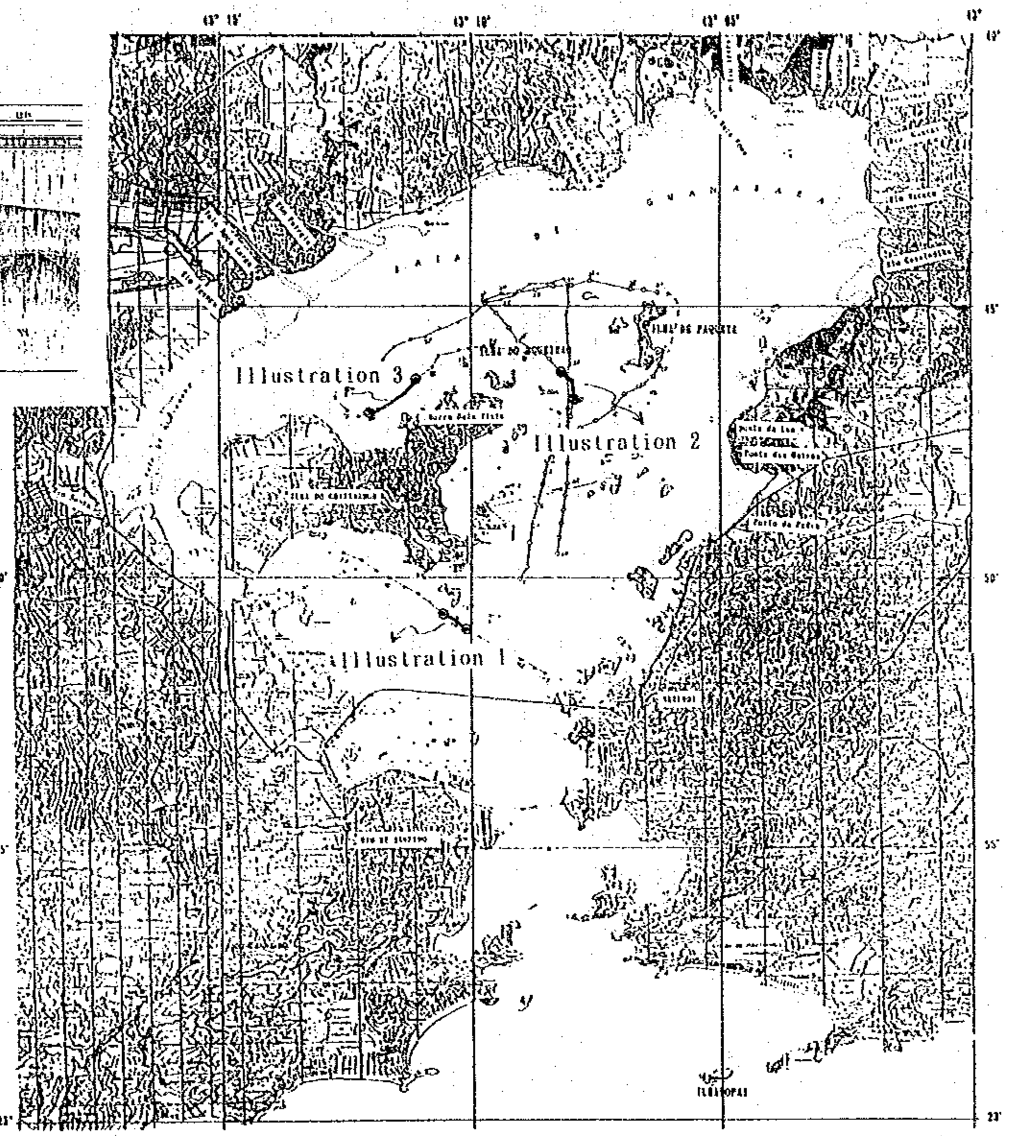


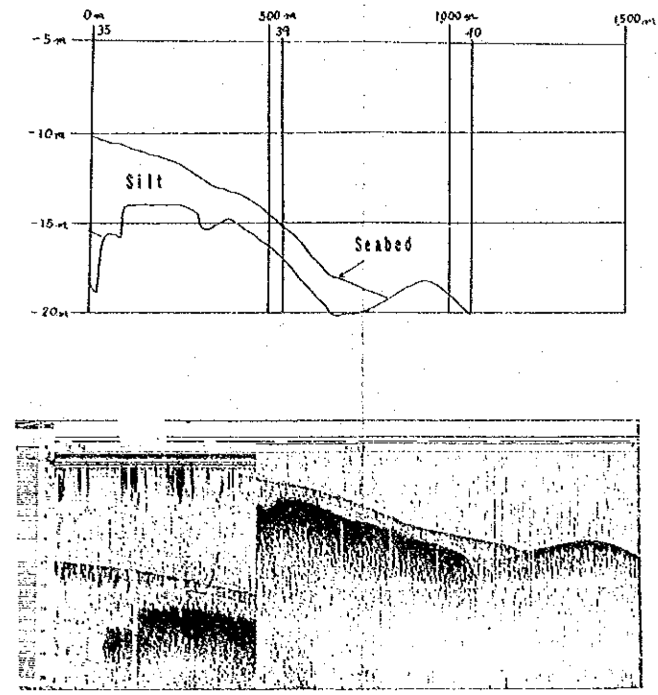
Fig.4.2-1 Distribution of the Bed Material in Guanabara Bay

【 Illustration-3 】





【 Illustration-2 】



【 Illustration-1 】

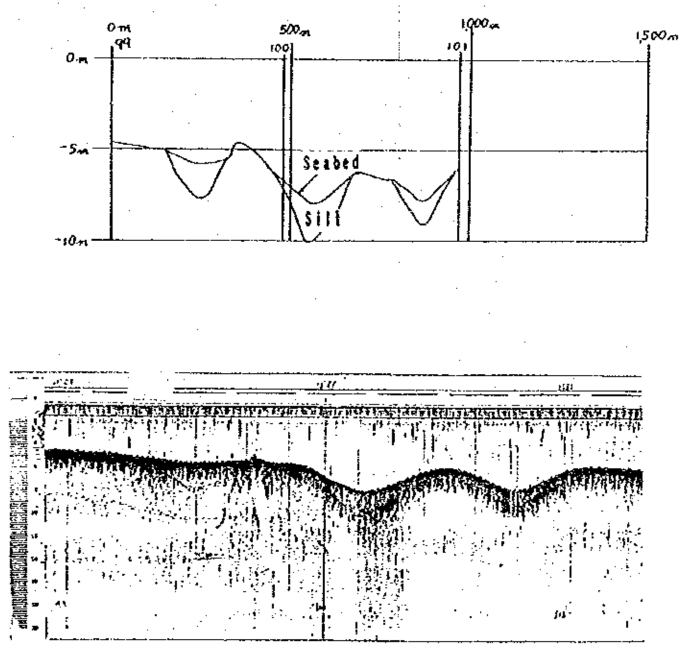
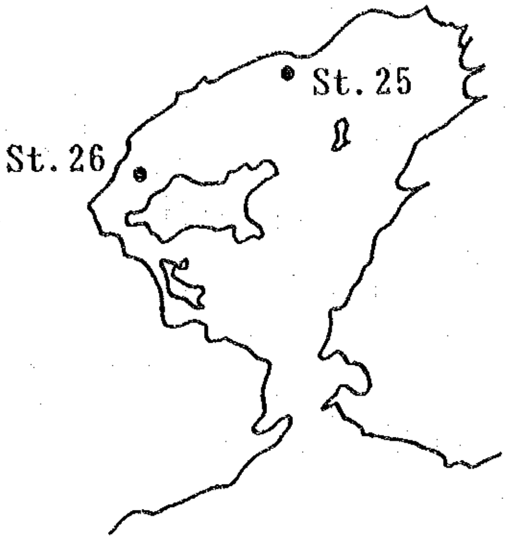


Fig. 4.2- 2　Typical Acoustic Profiles within Guanabara Bay



[Sampling Sites]

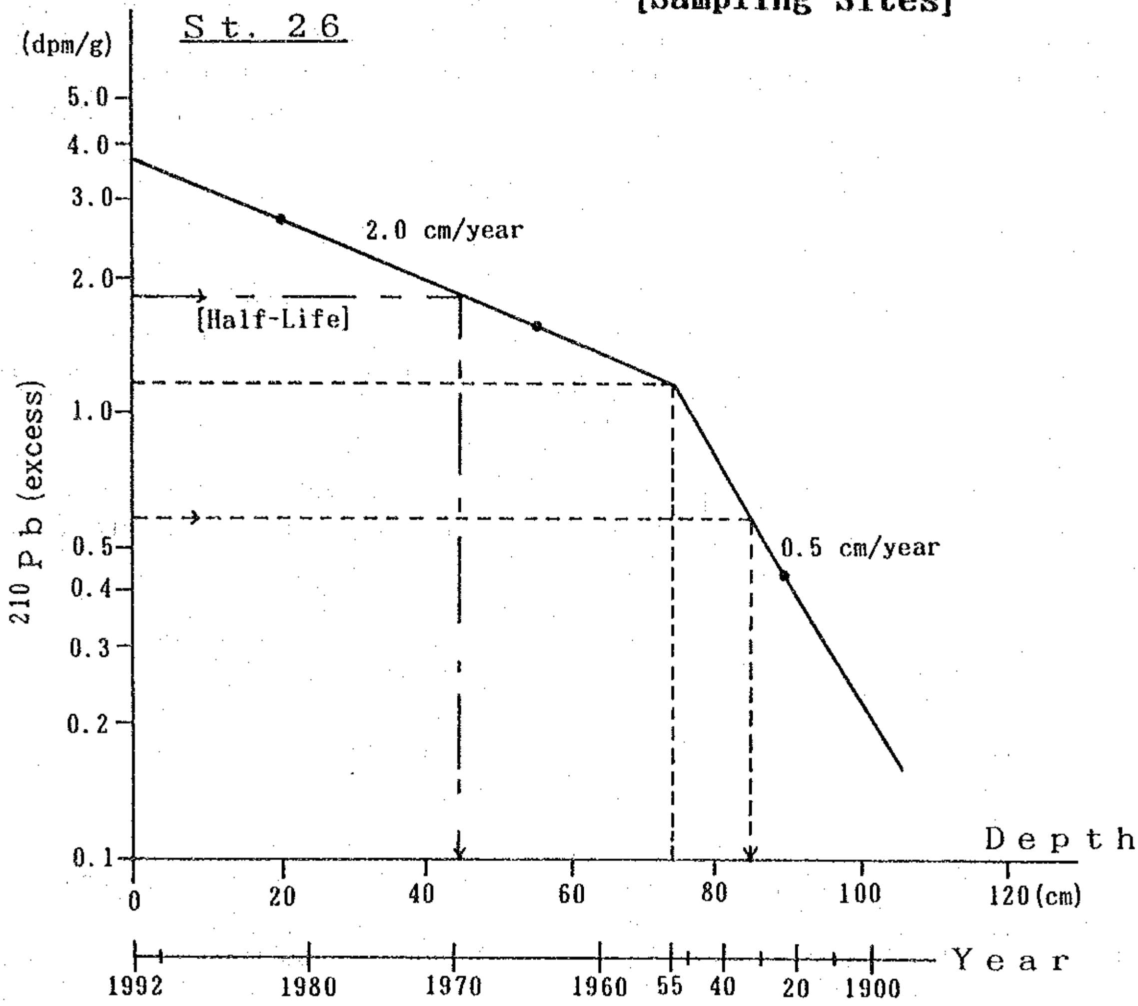


Fig.4.2-3 Sedimentation Rate at Station 26

4.3 Tides

4.3.1 Tidal Diagram

The tidal diagram at Ilha Fiscal (see **Fig. 4.3-1**), which is the standard of the Port of Rio de Janeiro, is shown in **Fig. 4.3-2** using the data for the year March 19, 1991 to March 18, 1992.

The maximum and mean tidal spring range was 1.46 m and 1.25 m, respectively. The Highest High Water was recorded to be 99.0 cm above Mean Sea Level and the Lowest Low Water was 94.0 cm below Mean Sea Level.

Fig. 4.3-3 is the tidal diagram for Ponta da Armacao, near the mouth of the Bay, and for Ilha de Paqueta, in the inner part of the Bay (see **Fig. 4.3-1**), conducted simultaneously for one month from October 25, 1992, to November 24, 1992. The diagrams show that there was a difference of 16 cm in the Highest High Water between the two locations.

4.3.2 Harmonic Constants of Tides

The harmonic constants of the principal four constituents, M_2, S_2, K_1 and O_1, at the four stations in the Bay are shown in **Table 4.3-1**.

For Guanabara Bay, the constants, M_2 and S_2, predominate, meaning that the tide period in the Bay is semi-diurnal, namely about 12.5 hours.

Table 4.3-1 Harmonic Constants of the Principal Four Constituents

Station	Coordinates	Constituent (Height in cm)				$H=H_m+H_s+H'+H_o$	Remarks
		$M_2(Hm)$	$S_2(Hs)$	$K_1(H')$	$O_1(H_o)$		
Fiscal	22° 53'47"S 43° 09'57"W	30.9	17.9	5.8	10.5	65.1 cm	DHN, 1986 (1 year)
Santa Cruz	22° 56'12"S 43° 07'48"W	31.6	17.4	6.5	10.5	66.0 cm	DHN, 1979 (1 month)
Armacao	22° 52'59"S 43° 08'05"W	34.1	16.7	5.4	10.2	66.4 cm	JICA, 1992 (1 month)
Paqueta	22° 45'43"S 43° 06'26"W	38.8	19.7	6.0	10.6	75.0 cm	JICA, 1992 (1 month)

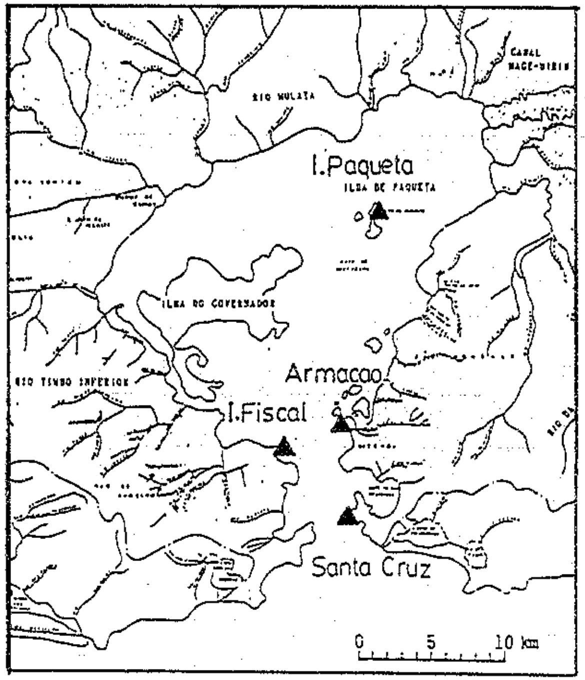


Fig. 4.3- 1 Location of Tidal Stations

Ilha Fiscal (Rio de Janeiro Port)

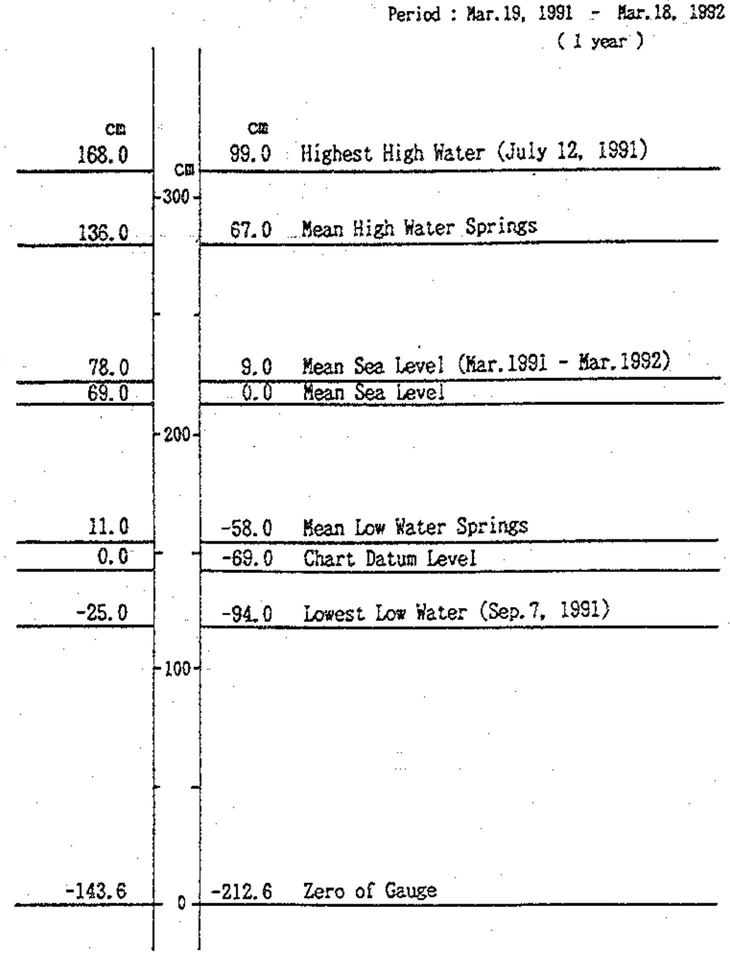


Fig. 4.3-2 Tidal Diagram for Ilha Fiscal

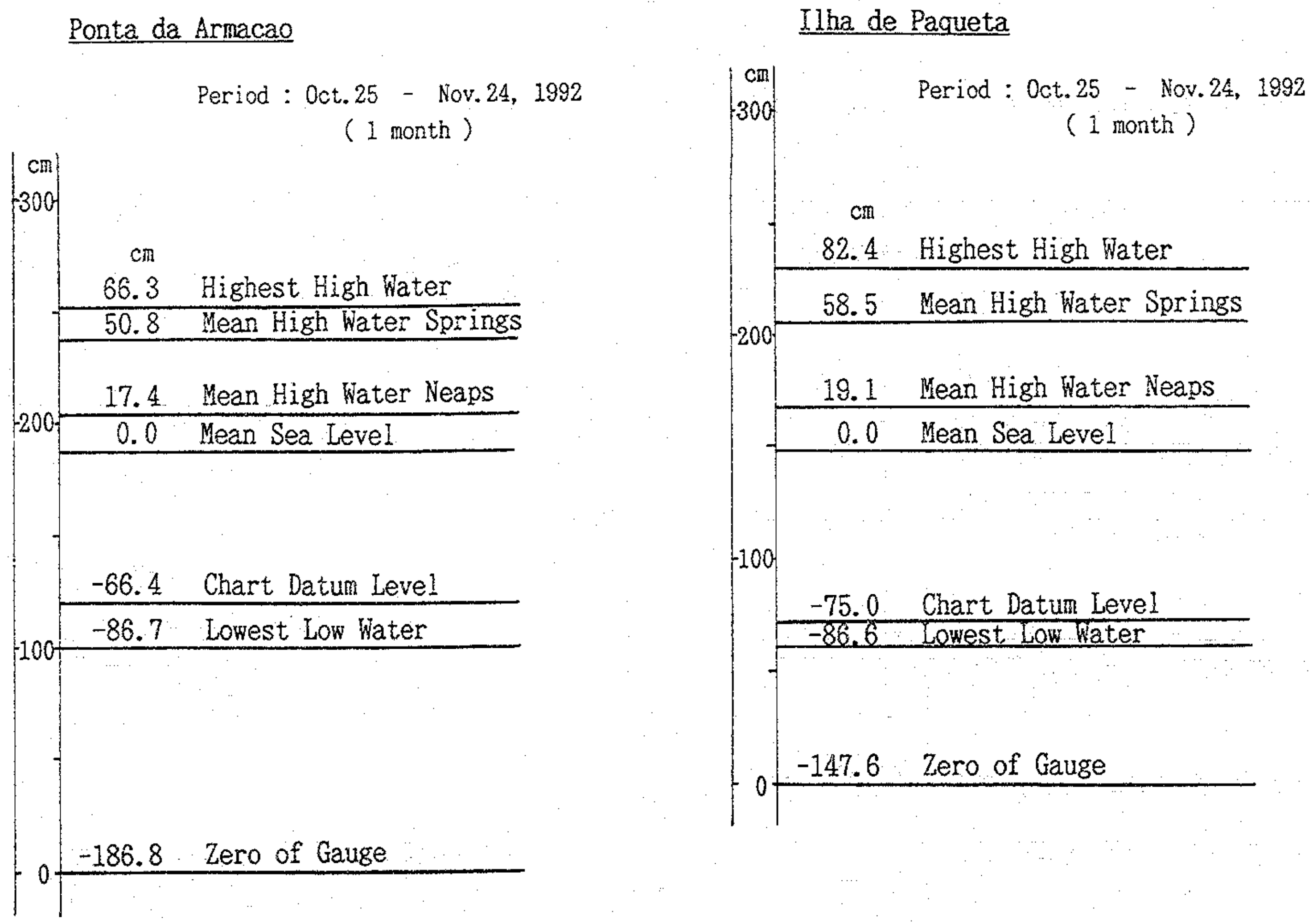


Fig. 4.3-3 Tidal Diagram for Armacao and Paqueta

4.3.3 Comparison of Tides in the Bay

Fig. 4.3-4 shows the tidal curves for Ponta da Armacao near the mouth of the Bay and Ilha de Paqueta in the northern part of the Bay on November 10, 1992.

By comparing the two curves for spring tides, the range of the tide at Paqueta is 12 to 13 cm larger than at Armacao.

On the other hand, the time of high water and low water tends to be faster at Paqueta and Armacao, respectively and the high and low water intervals seem to be almost the same.

This tendency is also seen in the tidal diagram and the harmonic constants (**Fig. 4.3-3** and **Table 4.3-1**).

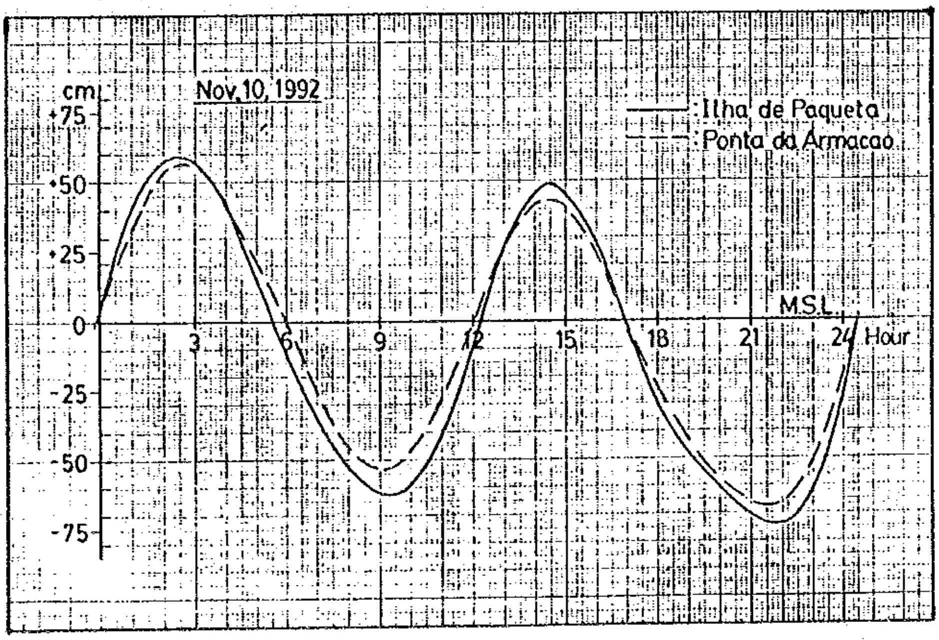


Fig. 4.3- 4 Comparison of Tidal Curves between Ilha de Paqueta and Ponta da Armacao

4.4 Tidal Currents

4.4.1 Tidal Current Observation

Tidal current observations were performed in different seasons, June 1992 (Phase 1), October to November 1992 (Phase 2) and in March 1993 (Phase 3) as a supplemental survey using self-recording type current meters (RCM-7). Ten observation stations were used.

The location of the tidal current observation stations and other information is shown in **Table 4.4-1** and **Fig. 4.4-1.**

The maximum speeds observed for flood and ebb currents at each station are summarized in **Table 4.4-2** together with the direction.

High speeds were observed at the mouth of the Bay (particularly at St. B) and in the channel behind Ilha do Governador (St. H). The highest speed recorded was more than 150 cm/sec in the upper layer at St. B and at St. H.

The speed of tidal currents in the Bay tends to weaken as we move further from the mouth of the Bay except, as mentioned above, in the channel behind Ilha do Governador, e.g. 50 - 70 cm/sec in the center of the Bay, 30 - 50 cm/sec around Ilha de Paqueta and 20 - 30 cm/sec off the northern shore of Ilha do Governador, were the maximum speeds observed. Outside the Bay, the maximum speed was 31 cm/sec.

4.4.2 Harmonic Constants of Tidal Currents

The principal harmonic constants and the velocity of the major axis of tidal ellipses, at each station obtained by harmonic analysis of tidal currents are summarized in **Table 4.4-3**.

The results show that semi-diurnal currents (M_2 and S_2) are predominant in the area from the mouth to the center of the Bay (Sts. A, B, C and D). In the northern part of the Bay (Sts. E, F and G), the diurnal currents (K_1 and O_1) are also large showing a mixed tidal current.

The currents at St. H in the channel behind Ilha do Governador and St. I located outside the Bay, however, take on a different appearance. Shallowwater tidal currents (M_4 and MS_4) having a six-hour period are large at St. H. while diurnal and constant currents are predominant at St. I.

Table 4.4-1 Station and Period of Tidal Current Observation

Station	No. of Layers	Coordinate	Water Depth (m)	Observation Period		
				Phase 1 (1992)	Phase 2 (1992)	Phase 3 (1993)
A	2	22° 54.3' S 43° 09.2' W	31	June 15-June 16	Oct.28-Nov.13	-
B	2	22° 54.3' S 43° 08.5' W	22	- ditto -	- ditto -	-
C	1	22° 51.9' S 43° 10.0' W	11	June 16-June 17	Oct.24-Oct.25	-
D	1	22° 50.0 S 43° 09.2' W	23	- ditto -	Oct.28-Nov.13	-
E	1	22° 46.5' S 43° 07.7' W	12	-	Oct.24-Oct.25	-
F	1	22° 44.4' S 43° 05.8' W	7	June 17-June 18	- ditto -	-
G	1	22° 46.0' S 43° 11.7' W	6	-	-	-
H	1	22° 48.7' S 43° 16.1' W	6	-	-	Mar.23-Mar.26
I	1	23° 01.0' S 43° 09.1' W	30	-	-	-
J	1	22° 50.0' S 43° 15.1' W	8	-	-	Mar.23-Mar.26

[Note]
one layer : 3.0 m below sea surface
two layers
upper layer: 3.0 m below sea surface
lower layer: 5.0 m above sea bottom

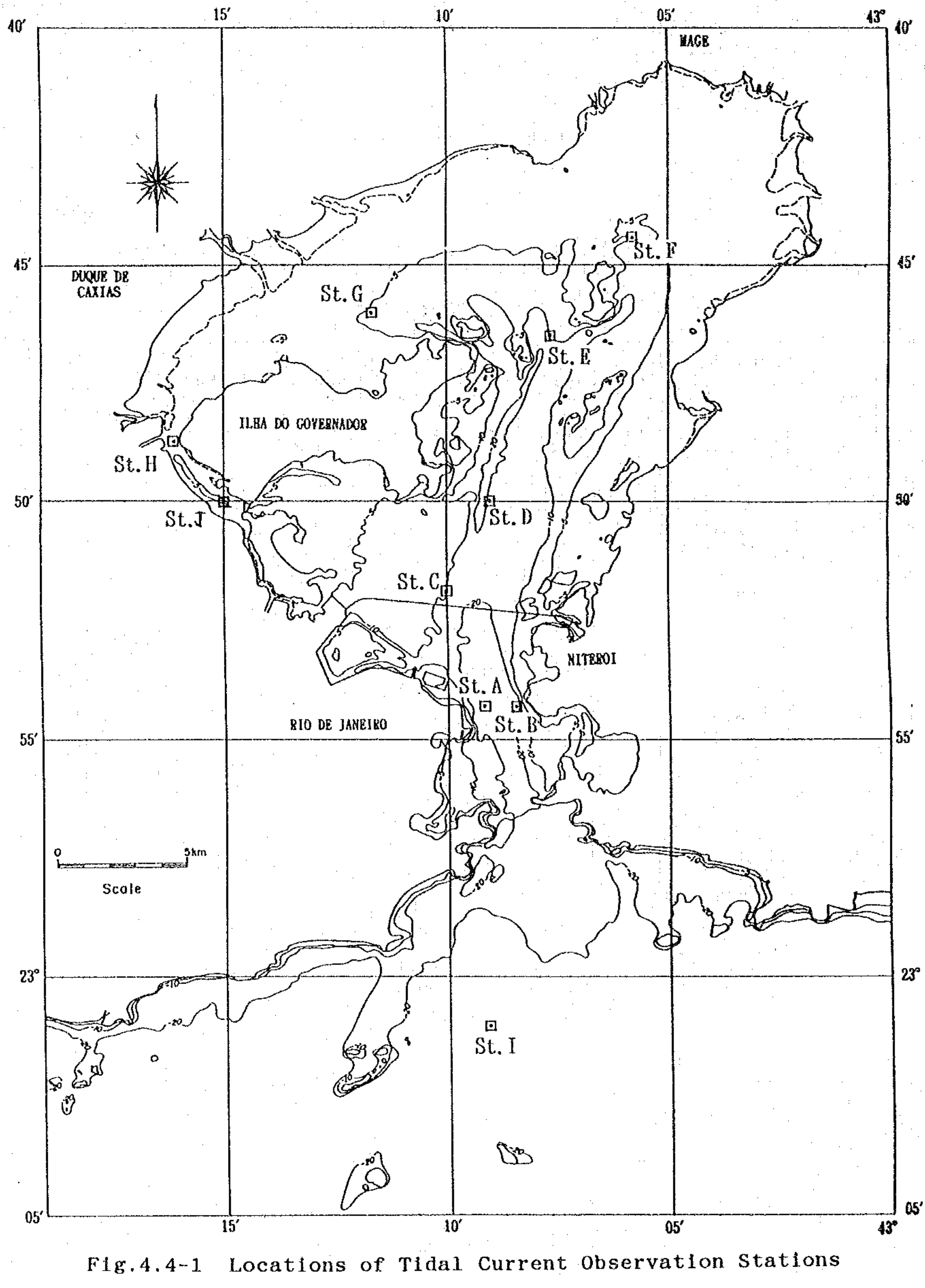


Fig.4.4-1 Locations of Tidal Current Observation Stations

Table 4.4-2 Maximum Speed of Tidal Currents

St.	Layer	Flood/ Ebb	June/1992 Max.Speed (cm/sec)	June/1992 Dir. (°)	Oct-Nov/1992 Max.Speed (cm/sec)	Oct-Nov/1992 Dir. (°)	March/1993 Max.Speed (cm/sec)	March/1993 Dir. (°)
A	upper	Flood	49	350°	85	19°	-	-
		Ebb	65	148	65	169	-	-
	lower	Flood	75	356	96	2	-	-
		Ebb	40	158	57	188	-	-
B	upper	Flood	67	346°	156	358°	-	-
		Ebb	68	171	137	203	-	-
	lower	Flood	52	338	105	3	-	-
		Ebb	54	167	53	197	-	-
C	upper	Flood	52	359°	54	342°	-	-
		Ebb	48	194	44	158	-	-
D	upper	Flood	56	23°	62	42°	-	-
		Ebb	45	200	57	201	-	-
E	upper	Flood	-	-	42	5°	-	-
		Ebb	-	-	21	132	-	-
F	upper	Flood	31	2°	48	356°	-	-
		Ebb	16	231	19	199	-	-
G	upper	Flood	-	-	24	110°	-	-
		Ebb	-	-	32	262	-	-
H	upper	Flood	-	-	100	20°	123	10°
		Ebb	-	-	57	183	157	197
I	upper	Flood	-	-	10	44°	-	-
		Ebb	-	-	31	213	-	-
J	upper	Flood	-	-	-	-	43	299°
		Ebb	-	-	-	-	43	124°

[Note] Dir.: Current direction of Max. Speed

(Clockwise from True North)

Table 4.4- 3 Harmonic Constants of Tidal Currents

(unit : cm/sec)

St. Layer	Velocity along Major Axis							Remarks
	V_o	K_1	O_1	M_2	S_2	M_4	MS_4	
June/1992								
A upper	15.4	2.2	3.8	24.9	14.9	7.6	9.2	
lower	8.6	2.2	3.7	31.2	18.7	5.5	6.7	
B upper	8.9	1.8	2.9	34.1	20.4	9.0	11.0	
lower	3.1	1.2	2.0	28.7	17.2	5.8	7.1	
C	2.2	2.9	5.0	23.0	13.8	5.3	6.5	
D	5.4	3.2	5.3	26.1	15.7	6.5	8.0	
F	5.4	1.4	2.2	11.6	7.0	2.5	3.0	
Oct.-Nov./1992								General Direction
A upper	5.0	1.4	5.5	27.8	15.5	12.2	3.0	+159°, - 339°
lower	3.2	1.3	1.8	19.7	14.0	10.2	6.5	+166°, - 346°
B upper	12.6	2.9	10.1	56.4	33.4	24.9	8.7	+167°, - 347°
lower	2.7	3.8	4.6	23.6	11.9	13.2	9.4	+163°, - 343°
C	3.4	6.3	10.6	19.3	11.6	4.5	5.4	
D	3.8	2.5	5.4	24.0	14.0	9.8	4.0	+ 18°, - 198°
E	6.7	5.6	9.4	12.9	7.7	2.8	3.4	
F	3.9	8.3	14.1	10.5	6.3	3.0	3.6	
G	1.1	4.5	7.6	9.7	5.8	1.8	2.2	
H	6.7	9.2	15.6	27.1	16.2	11.7	14.3	
I	10.3	11.0	18.6	6.0	3.6	1.9	2.4	
(March/1993)								
H	3.1	5.0	8.5	57.6	34.5	15.0	18.3	
J	0.6	3.4	5.7	8.4	5.0	2.9	3.5	

[Note] V_o : Constant Current (Residual Current)

4.4.3 Vertical Change of Tidal Currents

Fig. 4.4-2 shows the results of the two-layer observation performed at St. A and St. B at the mouth of the Bay. The duration of the flood current is considerably shorter than that of the ebb current on the surface, that is the flood current lasted for 4.5 hours while the ebb current lasted 8 hours. On the other hand, for the lower layer, the duration of the flood and ebb currents is almost the same, being about 6 hours, at both stations.

Regarding the current speed, the maximum speed at St. B was observed to be faster on the surface than at the bottom, while that at St. A it was the same order on the surface and at the bottom. The difference in the speed of the flood and ebb currents was clearly observed in November when the flood current was faster than the ebb current.

4.4.4 Seasonal Change of Tidal Currents

The tidal current observations were performed twice at the same points in June and from October to November 1992. The frequency distribution and the maximum speed observed show that the speed in the October to November period was faster than in June.

For example, the maximum speed in the October to November period at St. F situated off the northeast shore of Ilha de Paqueta was about 1.5 times of that observed in June.

As for the current direction, there was not a large difference between June and October-November.

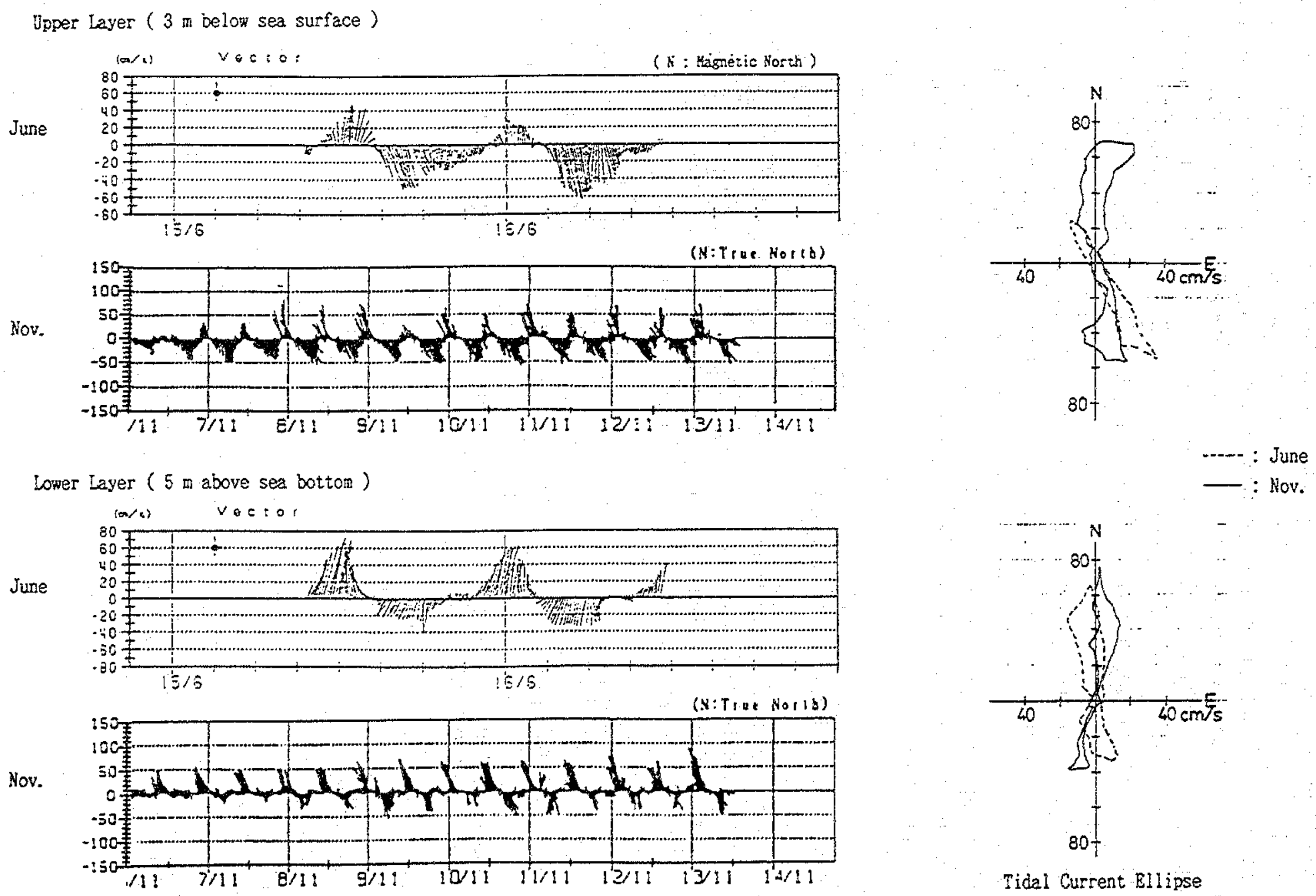


Fig. 4.4-2(1) Vertical Change of Tidal Currents at the Bay Mouth (St. A)

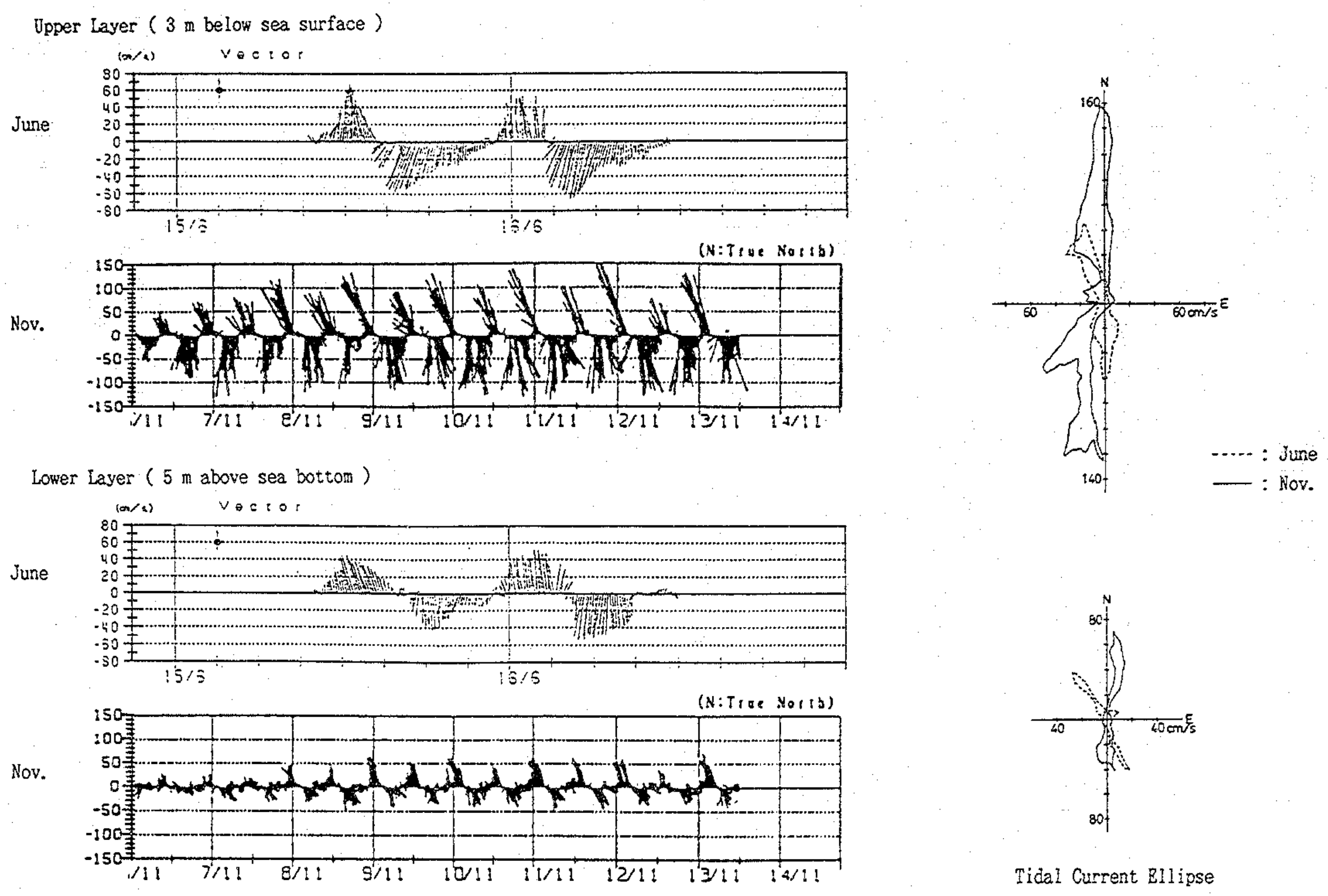


Fig. 4.4-2(2) Vertical Change of Tidal Current at the Bay Mouth (St. B)

4.4.5 Current Map in the Bay

The annual average distribution of the constant currents is shown in **Fig. 4.4-3** and the distribution of the predicted hourly tidal currents is shown in **Fig. 4.4-4** of the mean spring tides with the lunar hour after high water at Ilha Fiscal (Port of Rio de Janeiro).

The strongest ebb current comes about three hours after high water at Ilha Fiscal in the waters from the mouth to the central part of the Bay, and the strongest flood current can be observed one to two hours before high water in this area.

It should be noted that the velocity in **Fig. 4.4-4** is the speed of the mean spring tides. The maximum speed in a year, is estimated by multiplying the speed of the mean spring tides by about 1.3 for the central part of the bay to about 1.7 for the mouth and inner parts of the Bay.

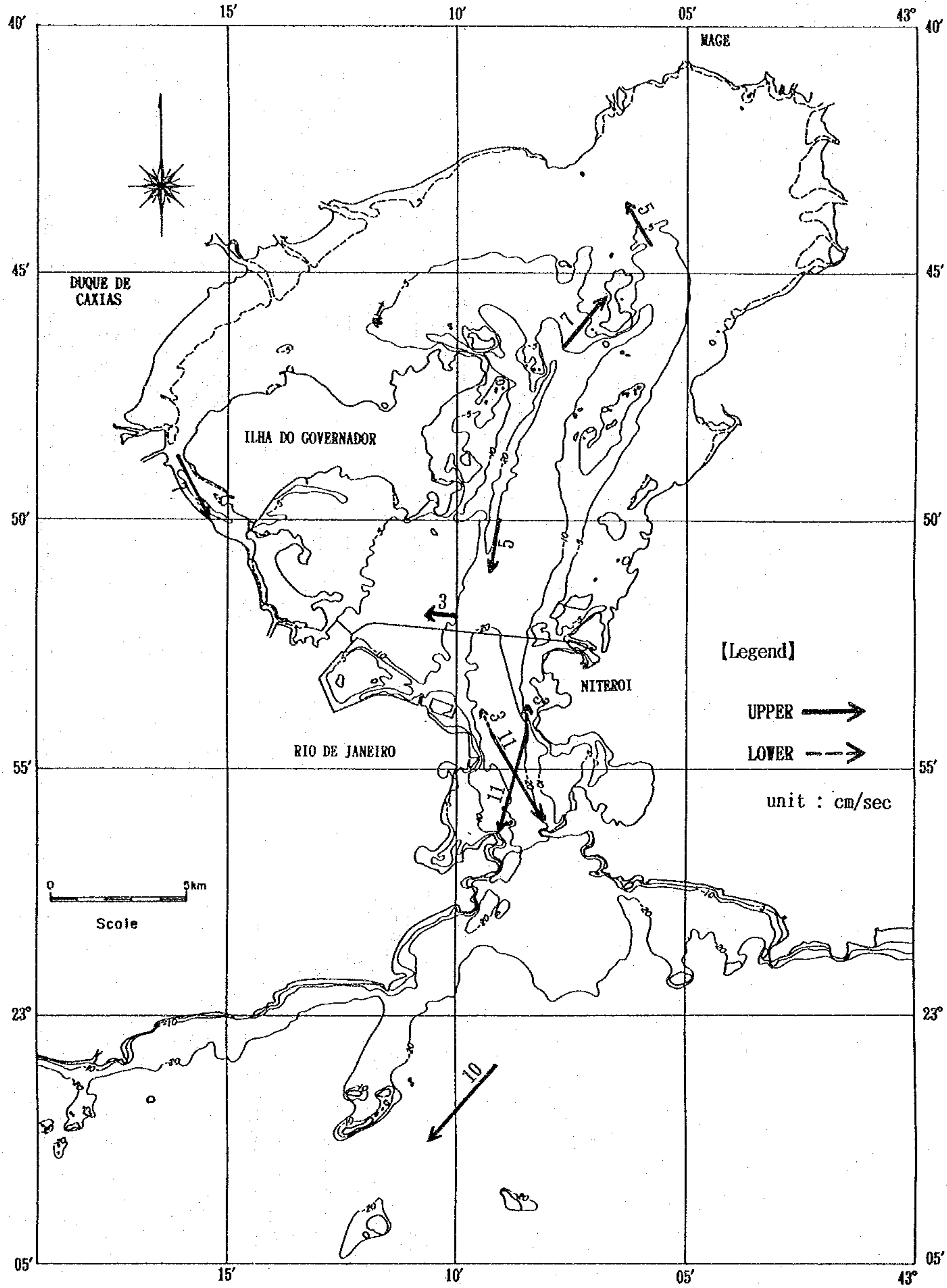


Fig. 4.4- 3 Distribution of Constant Currents

T = 0 (High Water)

T = 1 (1 hour after H.W.)

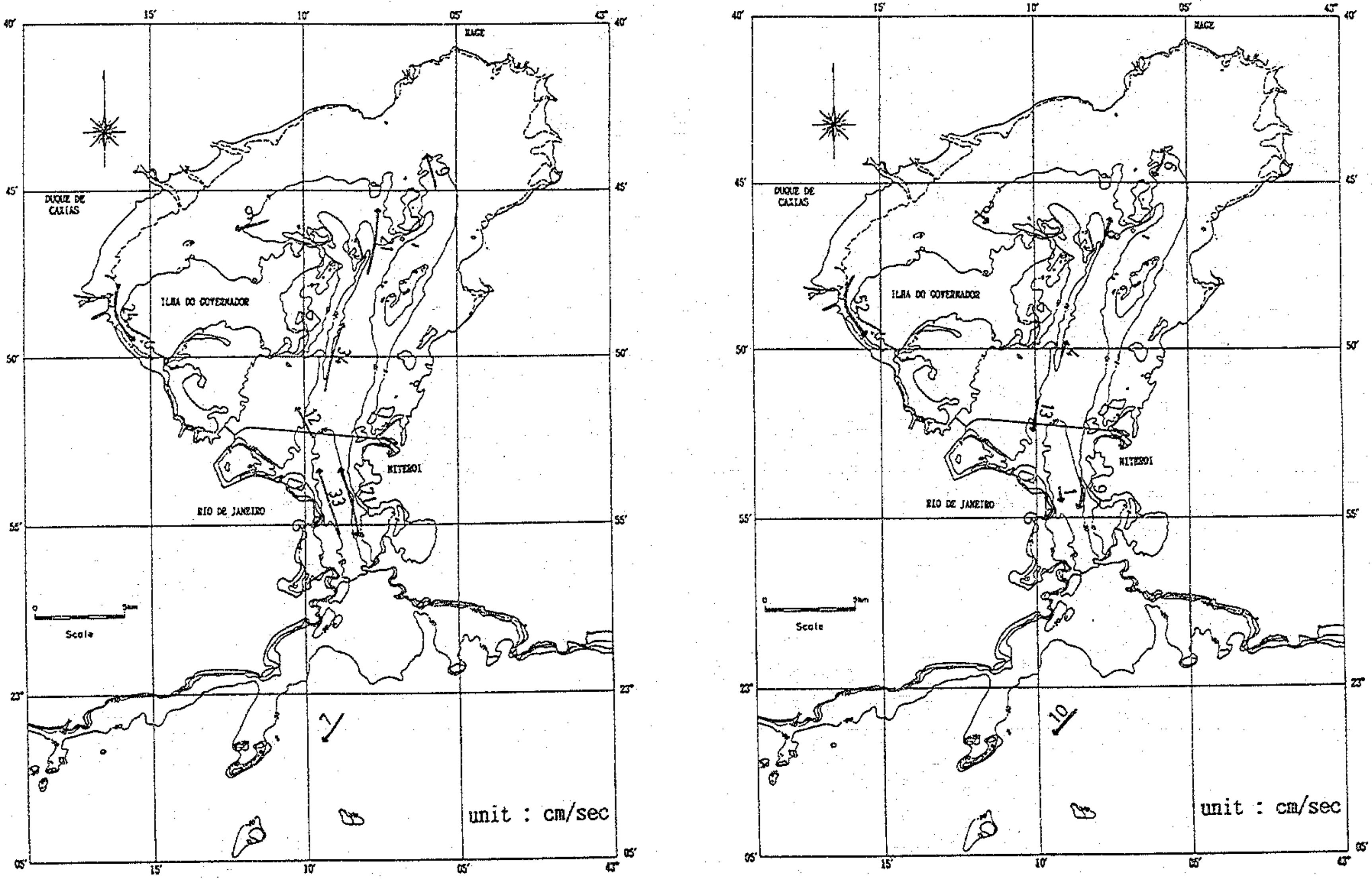
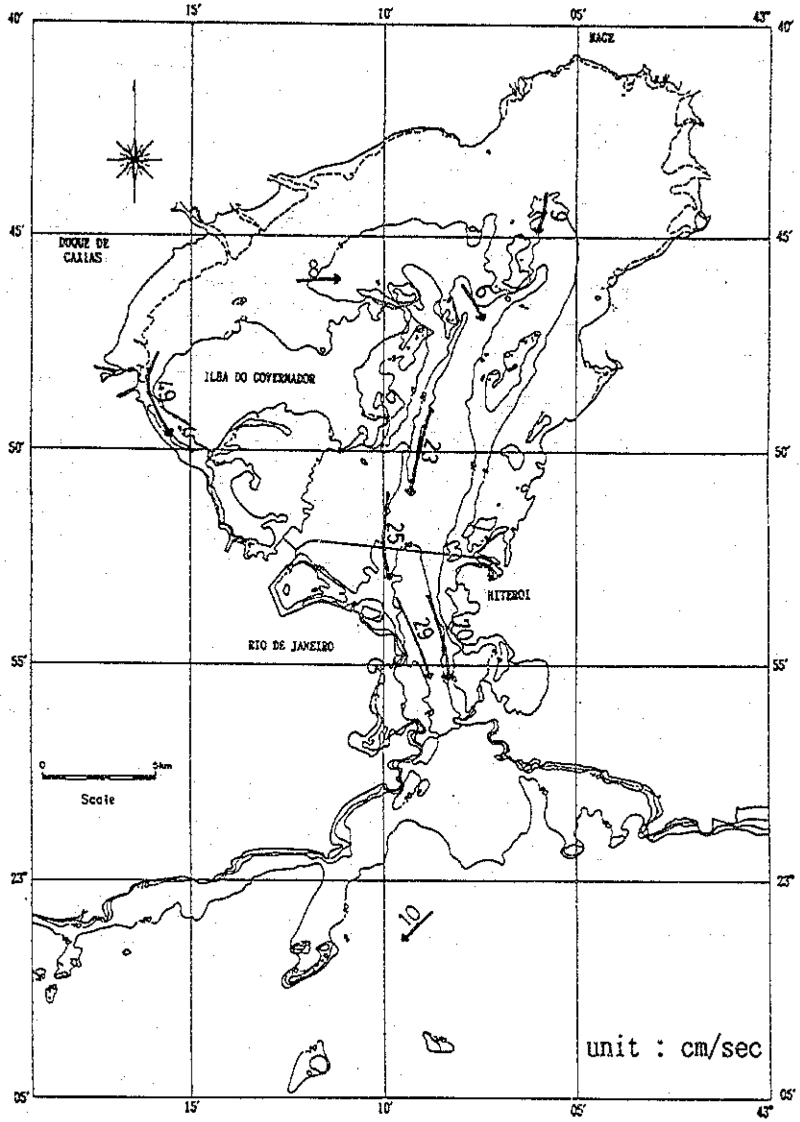


Fig. 4.4-4(1) Hourly Change of Tidal Current of the Mean Spring Tides

T = 2 (2 hours after H.W.)



T = 3 (3 hours after H.W.)

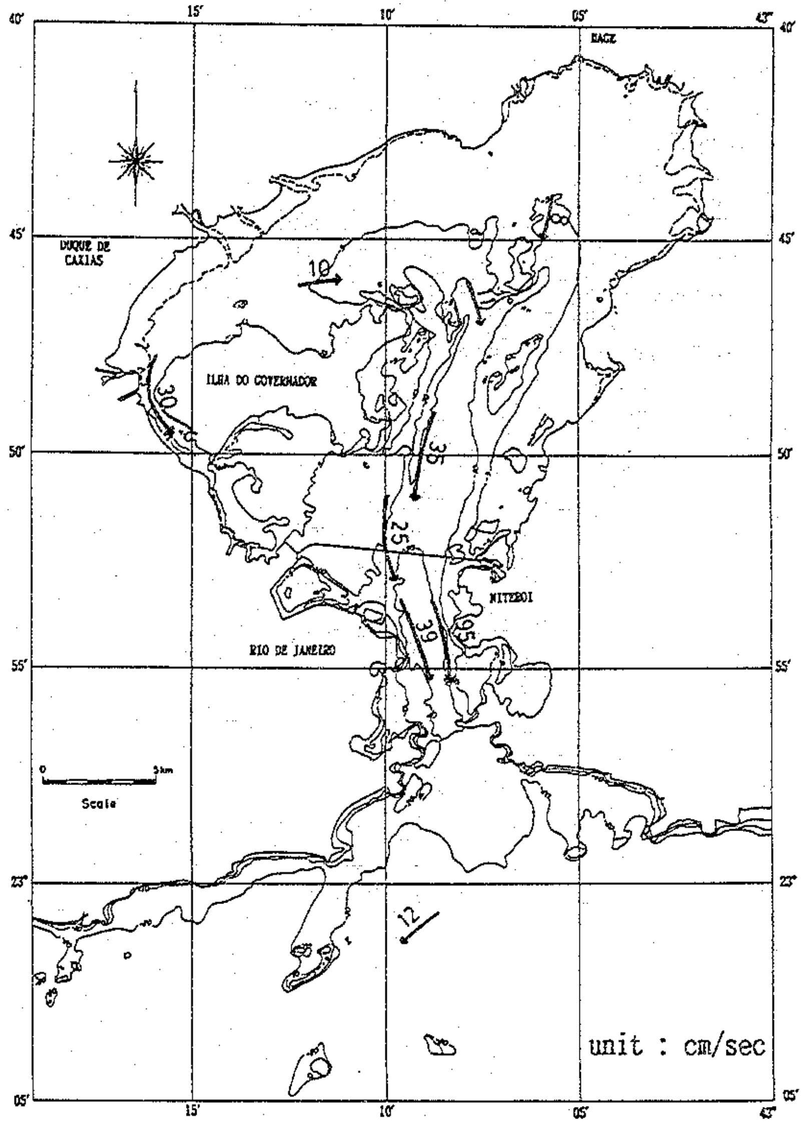
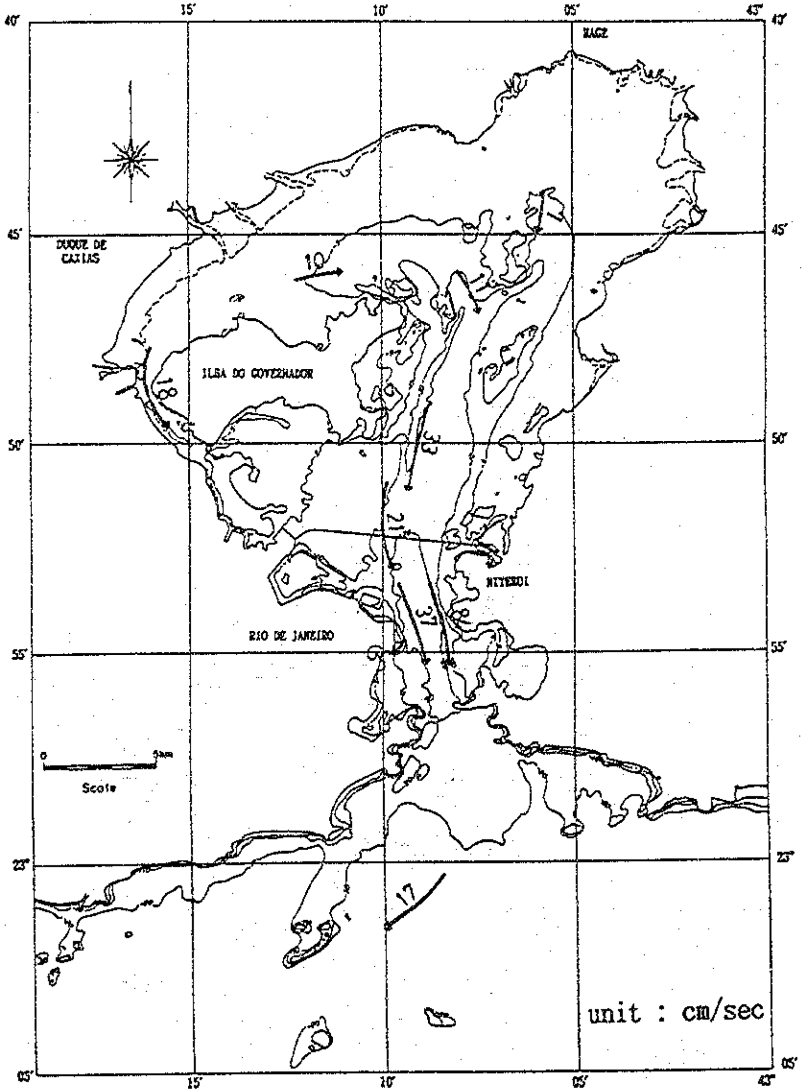


Fig. 4.4-4(2) Hourly Change of Tidal Current of the Mean Spring Tides

T = 4 (2 hours before L.W.)



T = 5 (1 hour before L.W.)

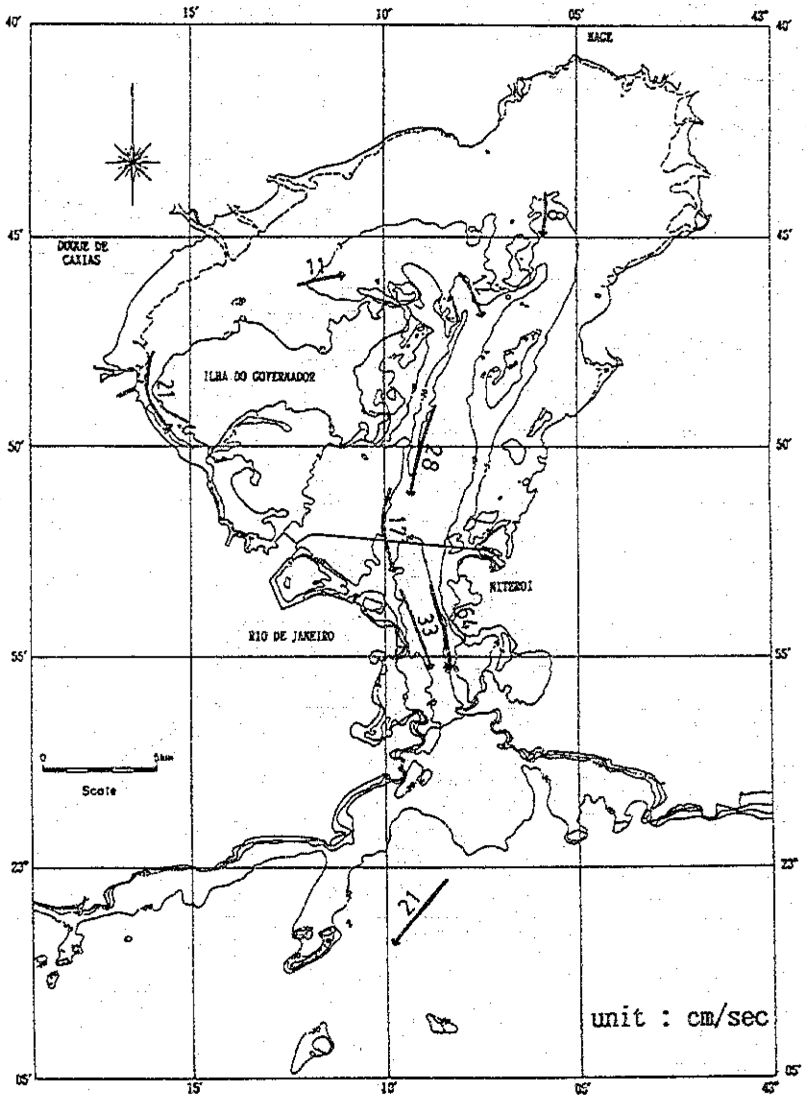
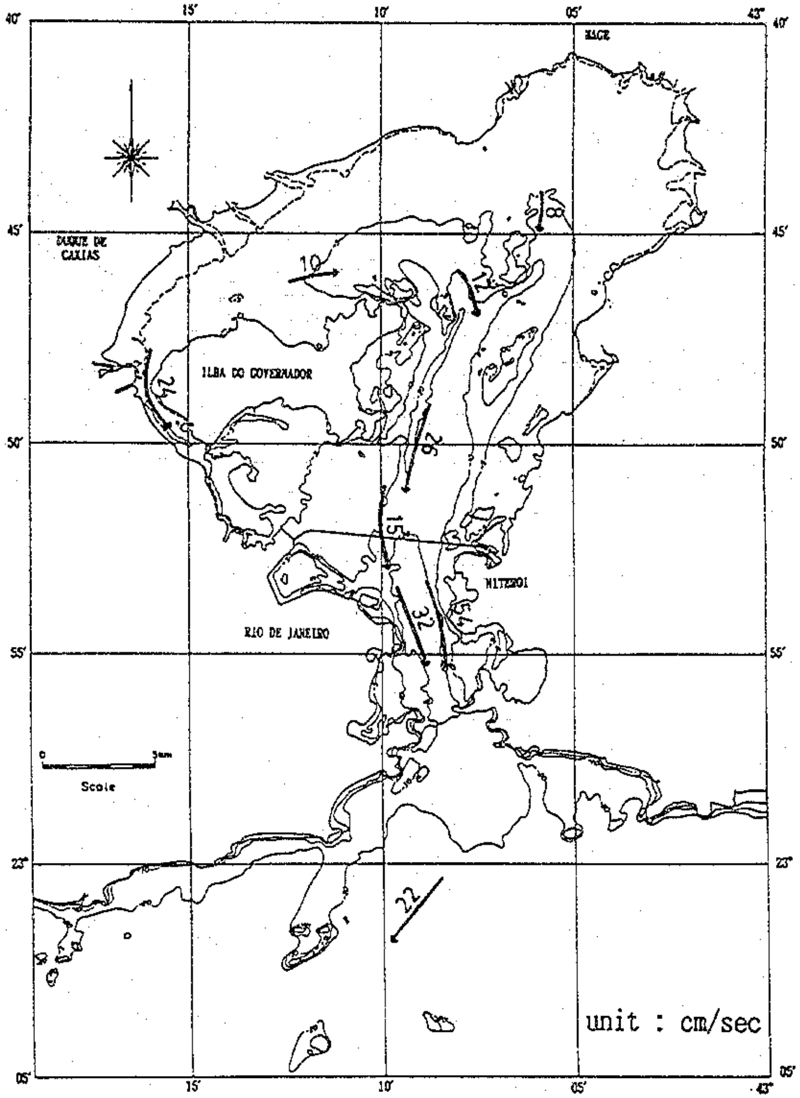


Fig. 4.4-4(3) Hourly Change of Tidal Current of the Mean Spring Tides

T = 6 (Low Water)



T = 7 (1 hour after L.W.)

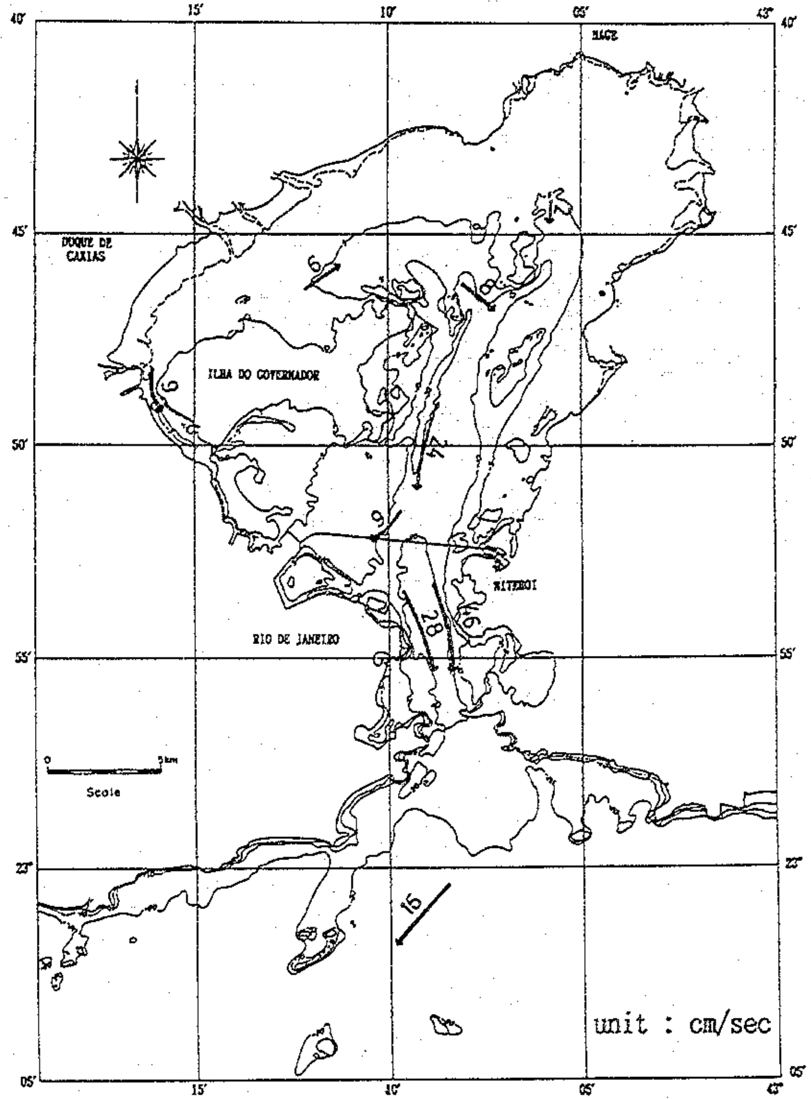
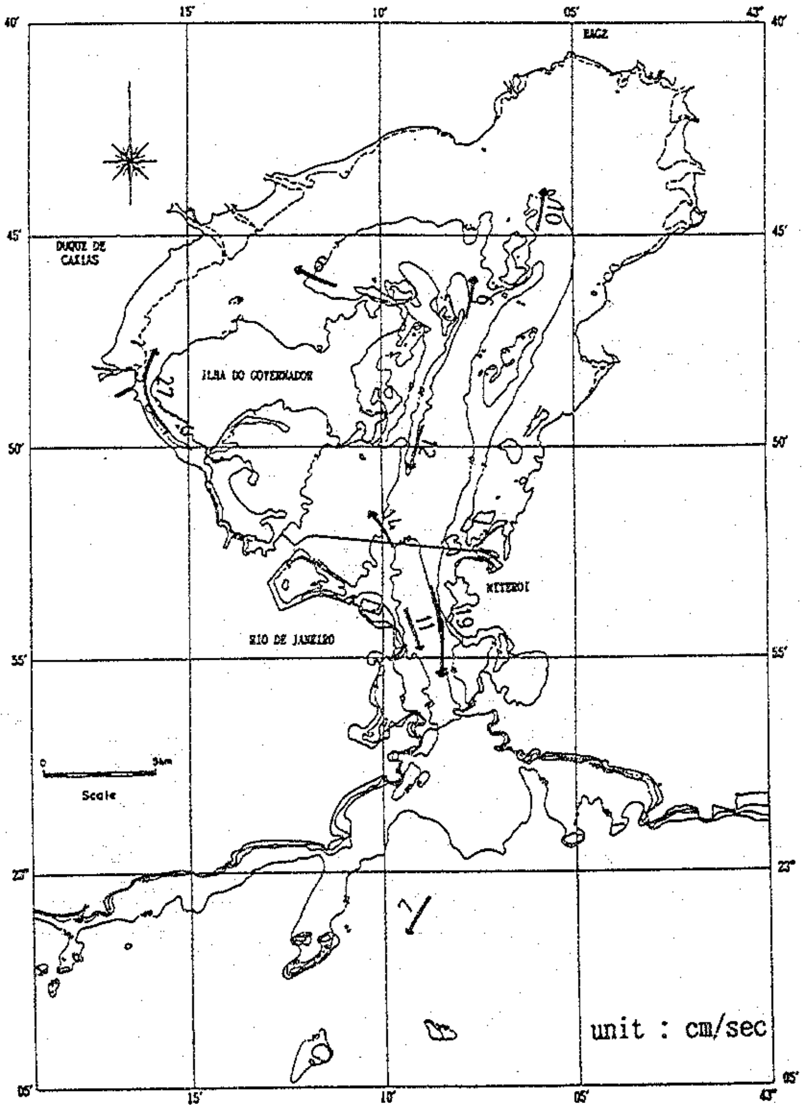


Fig. 4.4-4(4) Hourly-Change of Tidal Current of the Mean Spring Tides

T = 8 (2 hours after L.W.)



T = 9 (3 hours after L.W.)

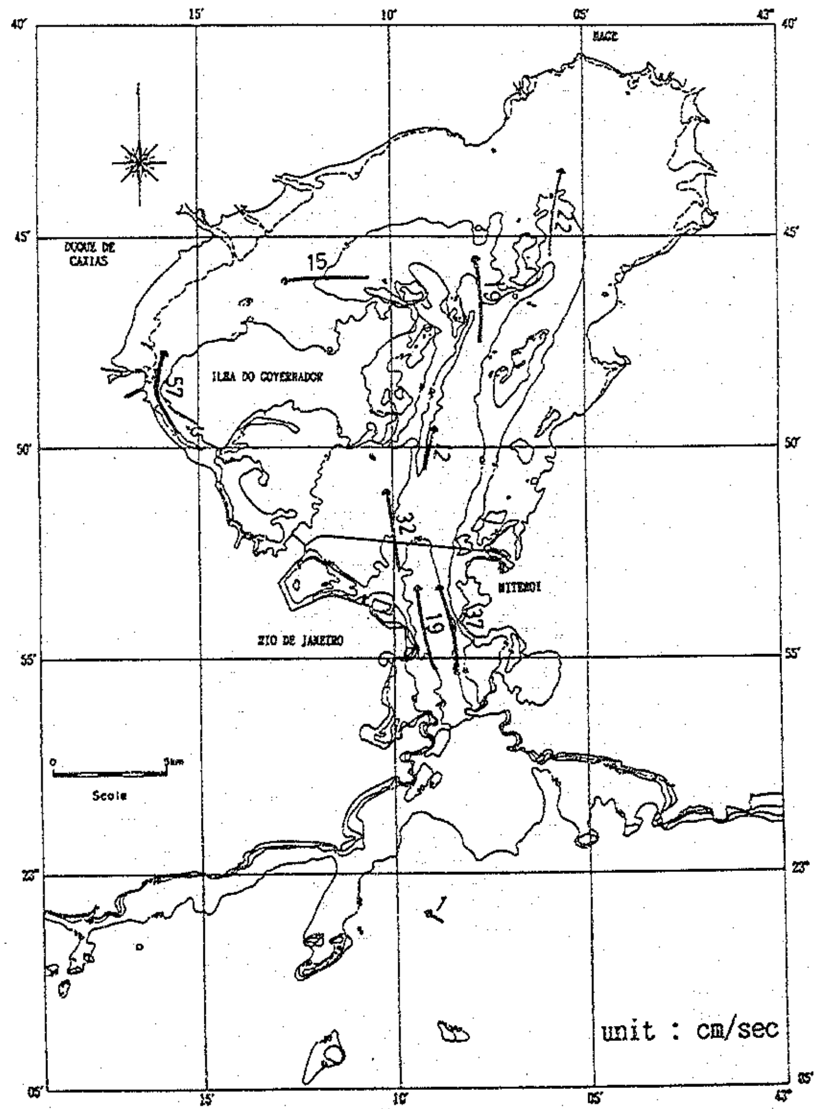
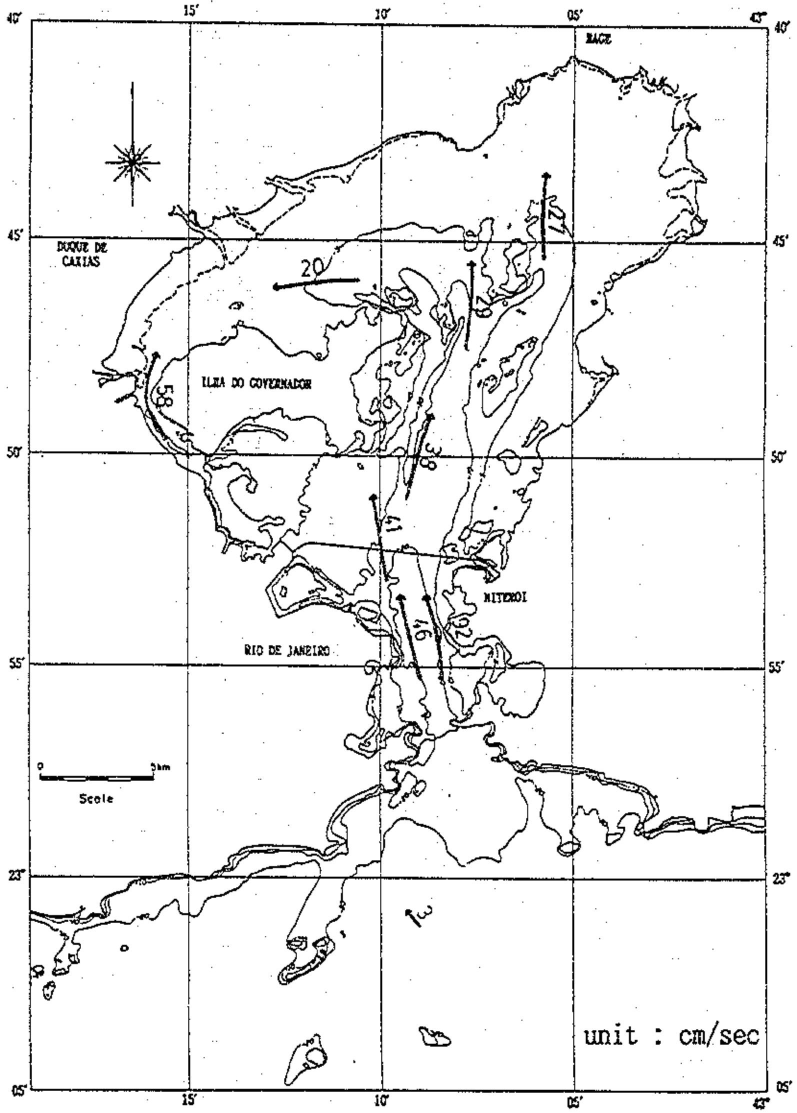


Fig. 4.4-4(5) Hourly Change of Tidal Current of the Mean Spring Tides

T = 10 (2 hours before H.W.)



T = 11 (1 hour before H.W.)

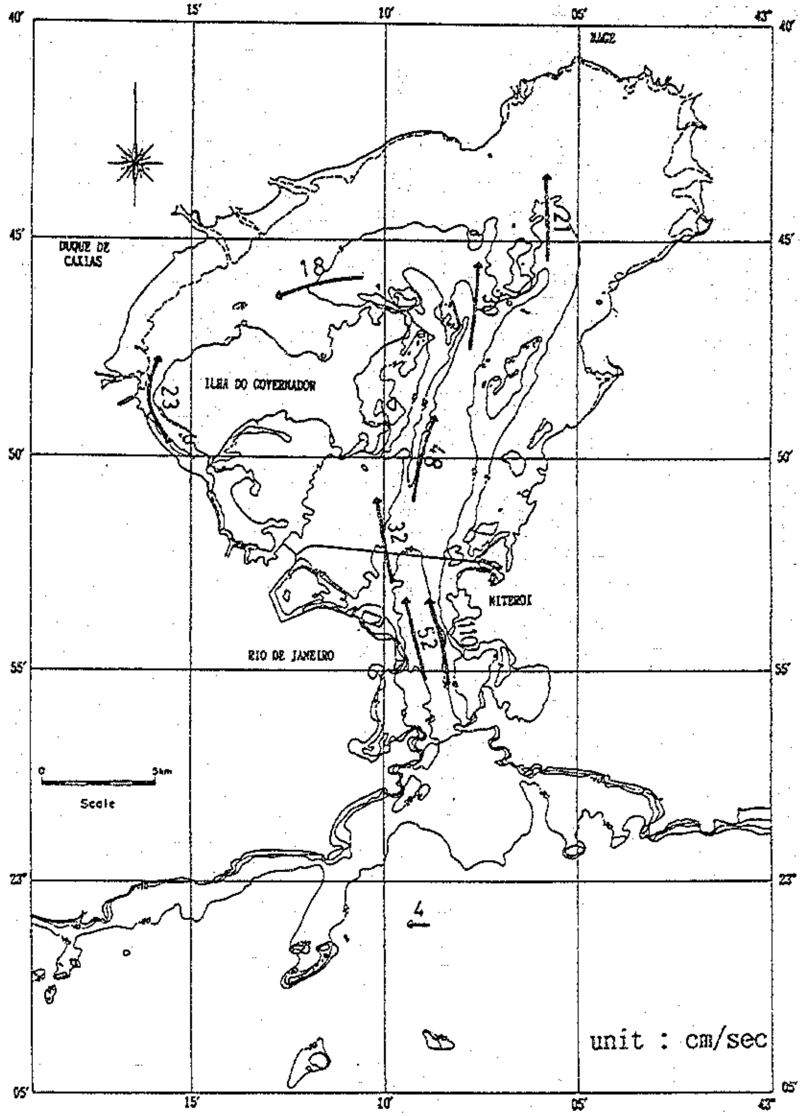


Fig. 4.4-4(6) Hourly Change of Tidal Current of the Mean Spring Tides

4.4.6 Influence of Topography and River-Flow upon Currents

The currents in the Bay are controlled not only by the topography of the coastline and islands but also by the submarine topography as shown in **Fig. 4.4-5**, which gives an outline of the tidal currents in Guanabara Bay with tidal ellipses.

The principal directions of tidal currents, which are expressed by the major axis of an ellipse at each point, follow an abyss in the center of the Bay used as a navigational route.

The tidal currents decrease in speed, which is expressed by the length of the major axis, in proportion to the distance from the mouth of the Bay except in the channel area.

The currents are also affected by river flows especially in the inner part of the enclosed sea area. The relationship between tidal currents and salinity is shown in **Fig. 4.4-6**, which are the results of tidal current observations taken at St. H and St. J in the channel behind Ilha do Governador from March 23 to March 26, 1993.

The curve of salinity variation corresponds with the tidal current curve at both stations. It shows that salinity values of ebb currents are lower than those of flood currents due to fresh water from the rivers.

Comparing the salinity at St. H with that at St. J, the value at St. H was found to be about 2 to 4 lower than that at St. J. This means that the area around St. H is more strongly influenced by river waters than the area around St. J, reflecting its distance from the river-mouth.

On the other hand, the influence of precipitation upon currents in the Bay is considerably large, though it is difficult to say quantitatively. No precipitation was observed before or during the observation period in June 1992, while some precipitation, around 5 mm/day, was observed on four consecutive days before the October to November observation period.

The effect of this precipitation is evident when we compare the faster current speeds for the October-November period with those for June.

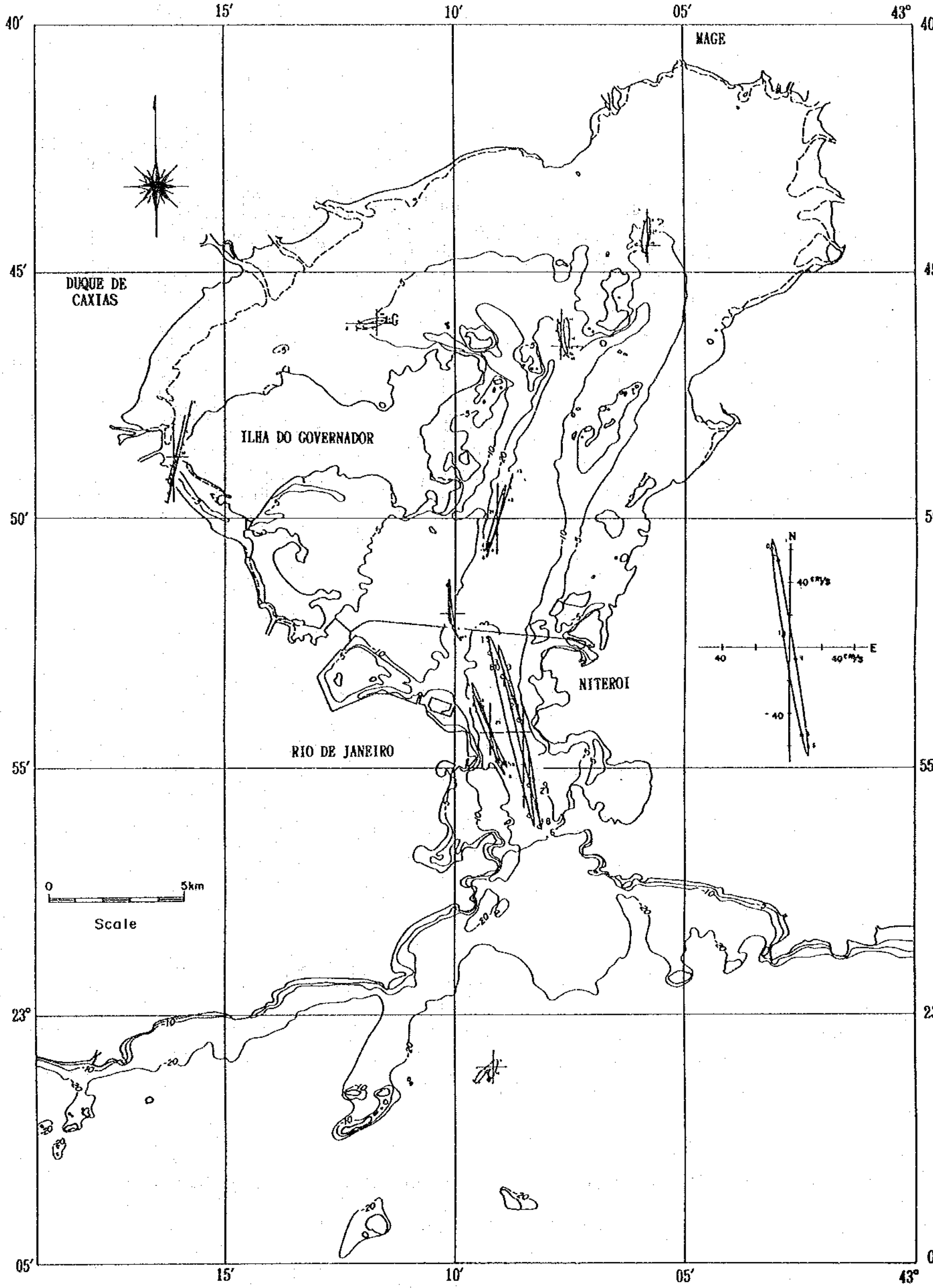
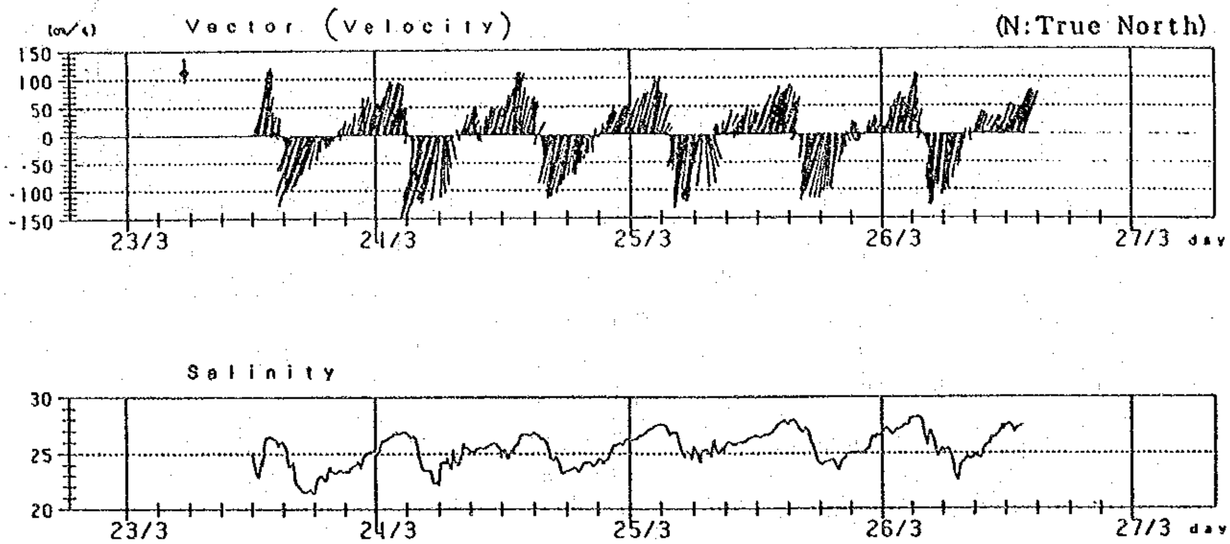


Fig. 4.4- 5 Relation between Tidal Ellipses and the Submarine Topography

St. H



St. J

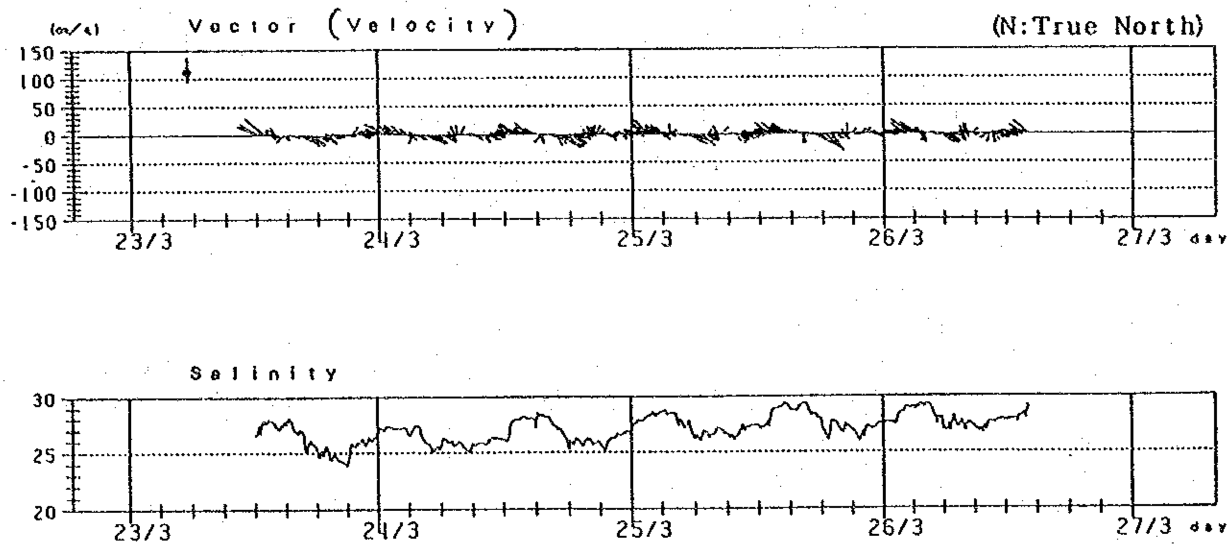


Fig.4.4-6 Relationship between Tidal Currents and Salinity

4.5 Water Mass Structure

The physical environmental factors: temperature, salinity and electric conductivity were measured during the survey period on the occasions of the preliminary surveys 1 and 2, the simultaneous surveys 1, 2 and 3, and the measurements taken near the mouth of the bay (details are described in Chapter 5 and the Supporting Report IV).

Density in situ, expressed by sigma-t, was calculated from the obtained temperature and salinity values at the same stations.

Dissolved oxygen and transparency were also measured at the same time.

4.5.1 Salinity Distribution

(1) Horizontal Distribution

Salinity at the surface varied largely in both seasons, decreasing toward the inner Bay area.

In the dry season, as shown in **Fig. 4.5-1**, there was the tendency for lower salinity to be found on the west side of the inner Bay; around 26 ‰, while in the wet season lower salinity values were obtained on the northeast side of the Bay; around 10 ‰.

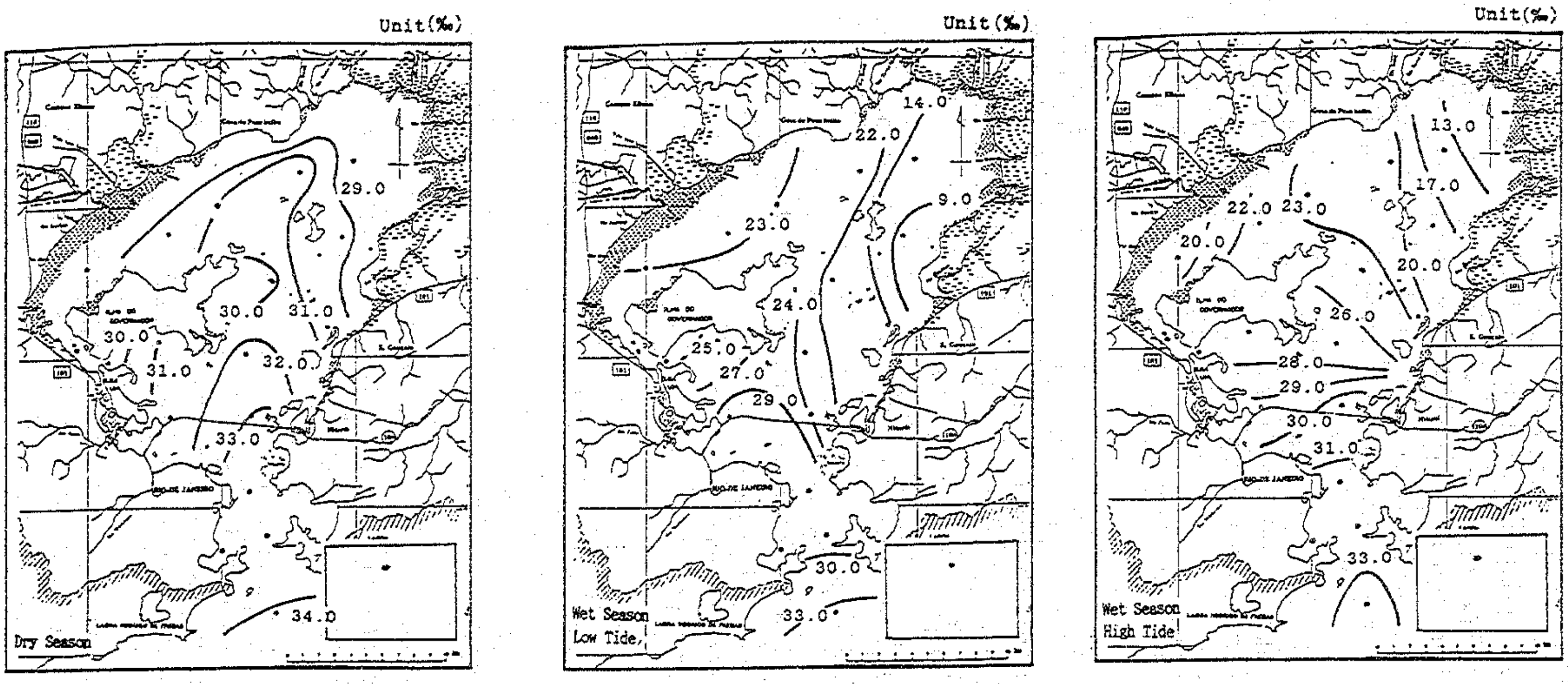
Reflecting river discharge, salinity levels at low tide were generally lower than those at high tide for both seasons, although the differences found were not large.

(2) Vertical Distribution

Salinity always increased downward. The gradient was greater in the central part of the Bay, while it was slight near the mouth, reflecting offshore water salinity (**Fig. 4.5-2**).

Fig. 4.5-3 shows the salinity distribution in vertical sections as seen form the south and the east. Salinity at Stns. 3 and 5 near the narrow entrance of the Bay, was always vertically homogeneous, which was due to the mixing of water flowing into the Bay.

Fig. 4.5-3 shows clearly that during the wet season, even near the mouth of the Bay, around Stns. 5 and 6, inflow of fresh water more greatly affects the salinity distribution than the water coming from outside of the Bay.



Dry Season

Wet Season

Fig.4.5-1 Distribution of Salinity in the Surface Layer

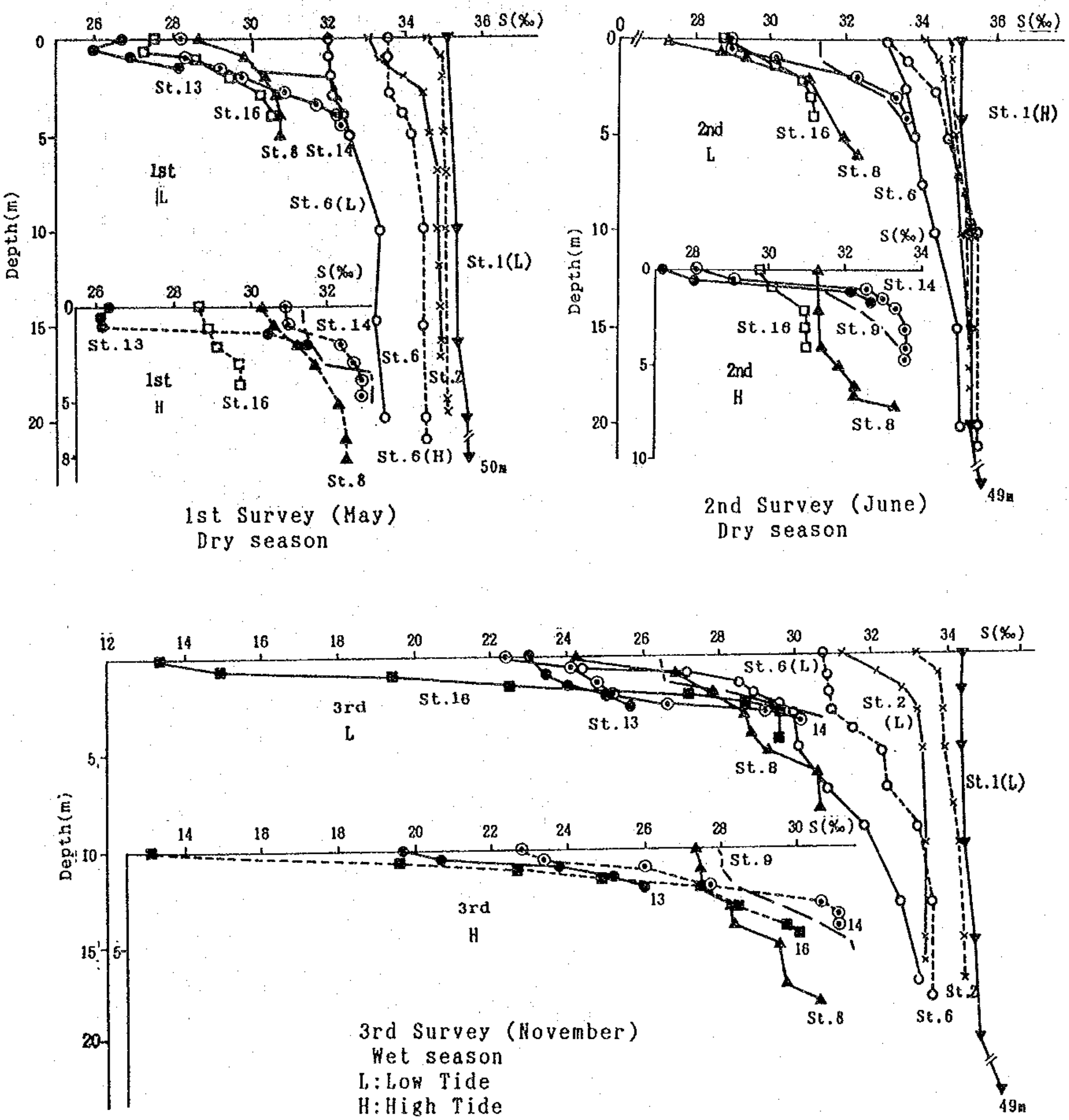
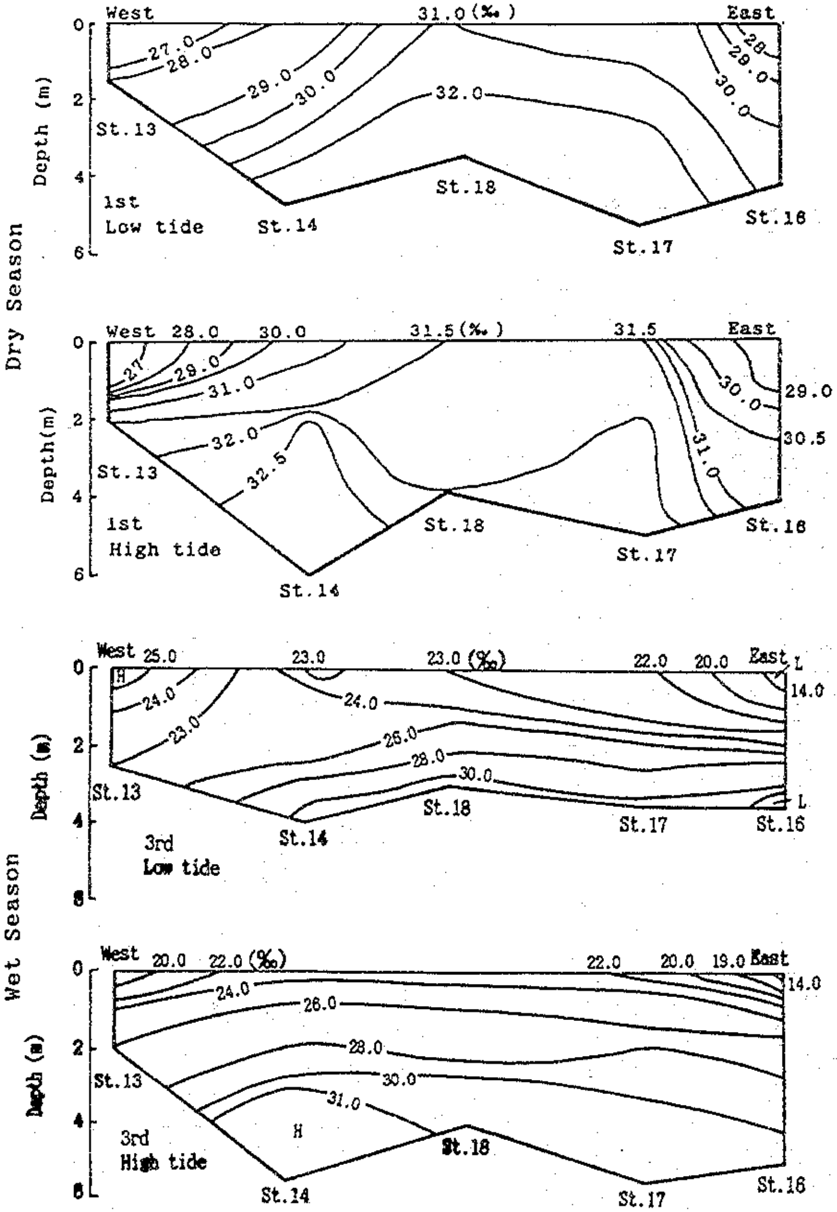
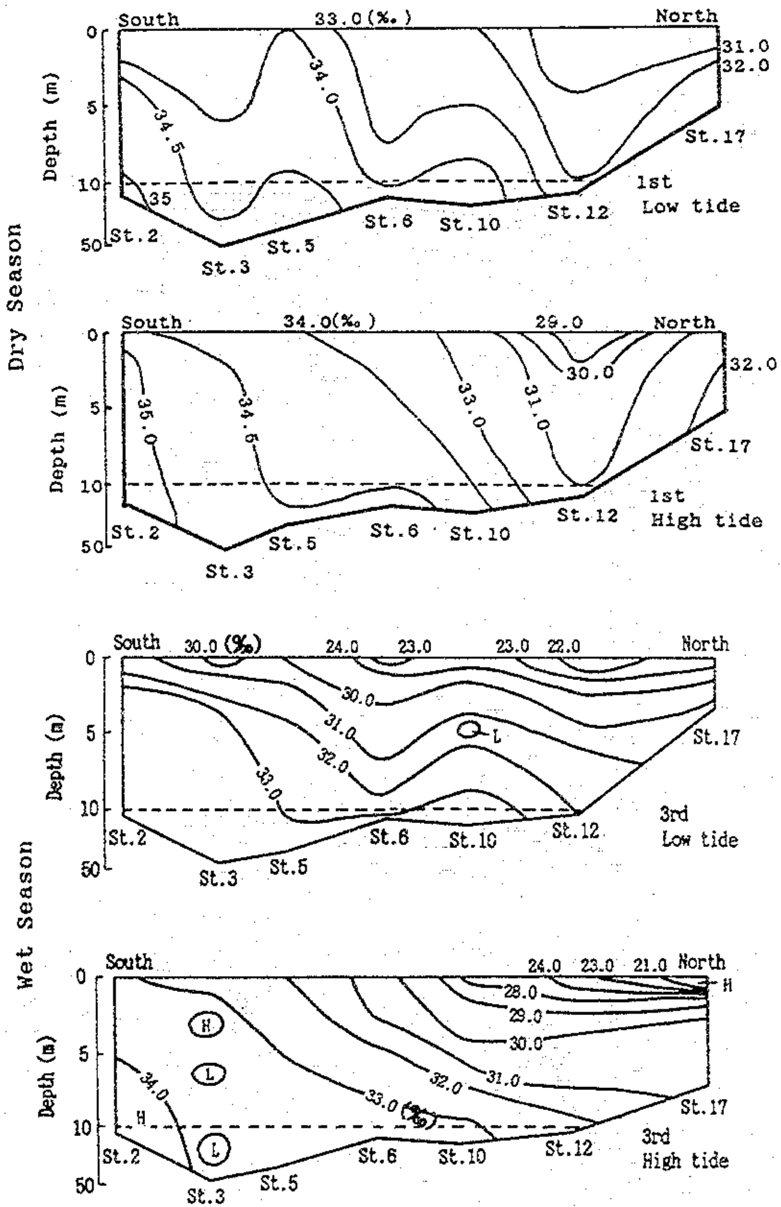


Fig.4.5-2 Vertical Distribution of Salinity



Sections as seen from the South



Sections as seen from the East

Fig.4.5-3 Vertical Sections of the Salinity Distributions across the Bay

4.5.2 Water Temperature Distribution

(1) Horizontal Distribution

Water temperature at the surface increased from the mouth of the Bay toward the inner part of the Bay in both the dry and the wet seasons, although its ranges in both seasons were not wide.(**Fig. 4.5-4**).

The temperature at the surface at low tide was significantly higher than at high tide in dry season, but they were almost the same in wet season reflecting the air temperature.

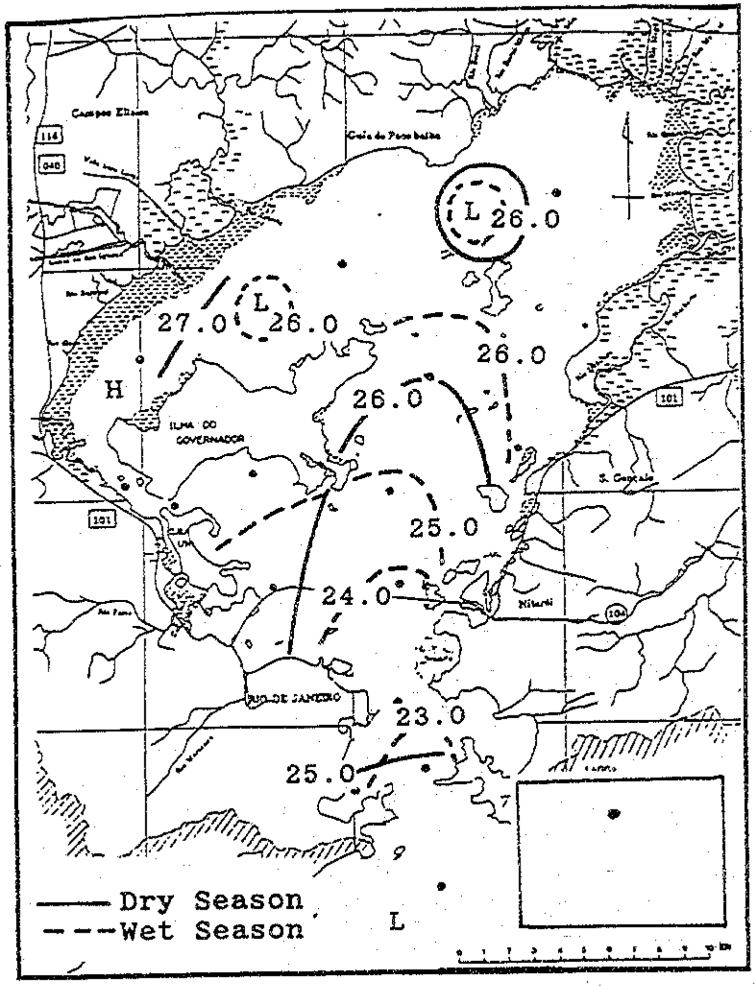
The mean water temperatures obtained in the dry season were also significantly higher than that in the wet season. As with the salinity distributions, in the wet season, the effect of river discharge is great on the surface temperature distribution.

(2) Vertical Distribution

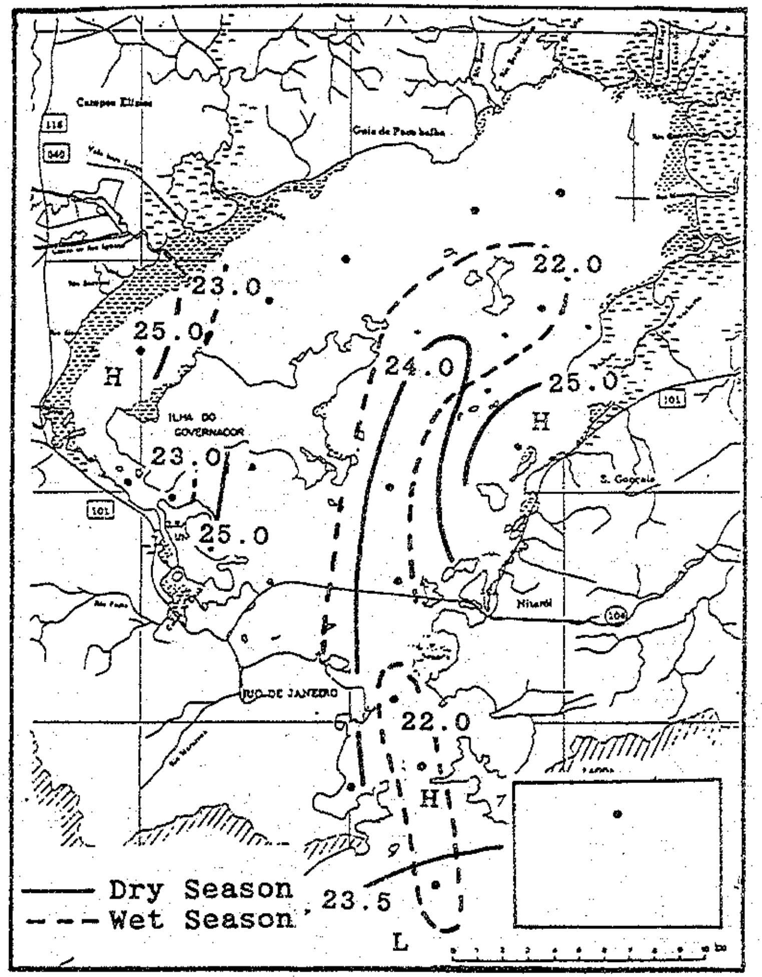
Water temperature decreases with the depth at all stations. The gradient in the inner Bay is greater than the outer Bay, in particular the gradient was greater in the upper 3 meters in the inner Bay area.

In the wet season a steeper gradient than in the dry season was observed (**Fig. 4.5-5**).

The temperature distribution on the bottom showed the effects of water penetrating from outside the Bay is stronger on the bottom than on the surface. It also showed that the water is coming from outside in the deeper layers and going out in the upper layers, this is especially clear in the wet season (**Fig. 4.5-6**; St. 2 to St. 17 section).



Distribution of Temperature in the Surface Layer



Distribution of Temperature at the Bottom

Fig.4.5-4 Horizontal Temperature Distribution

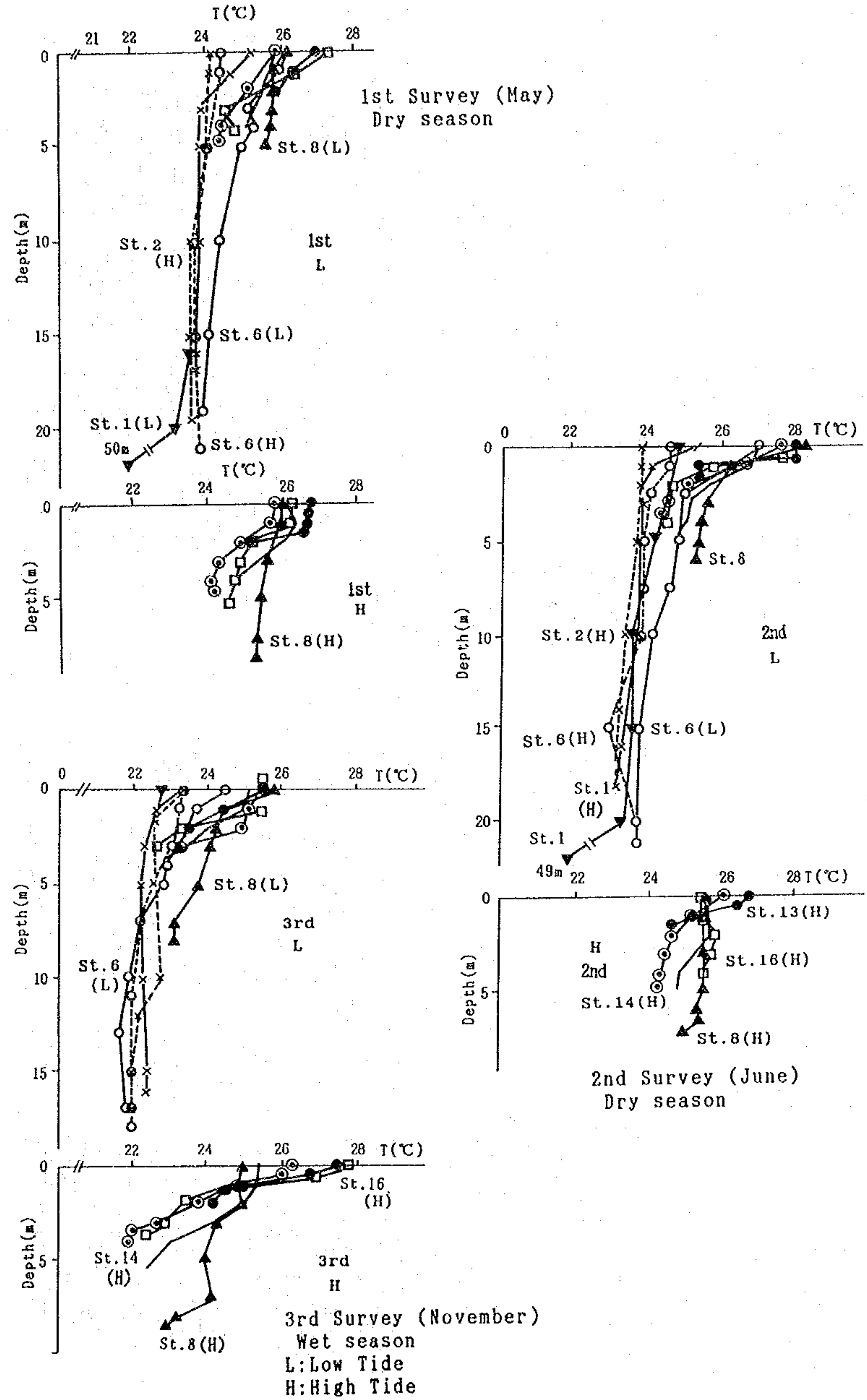
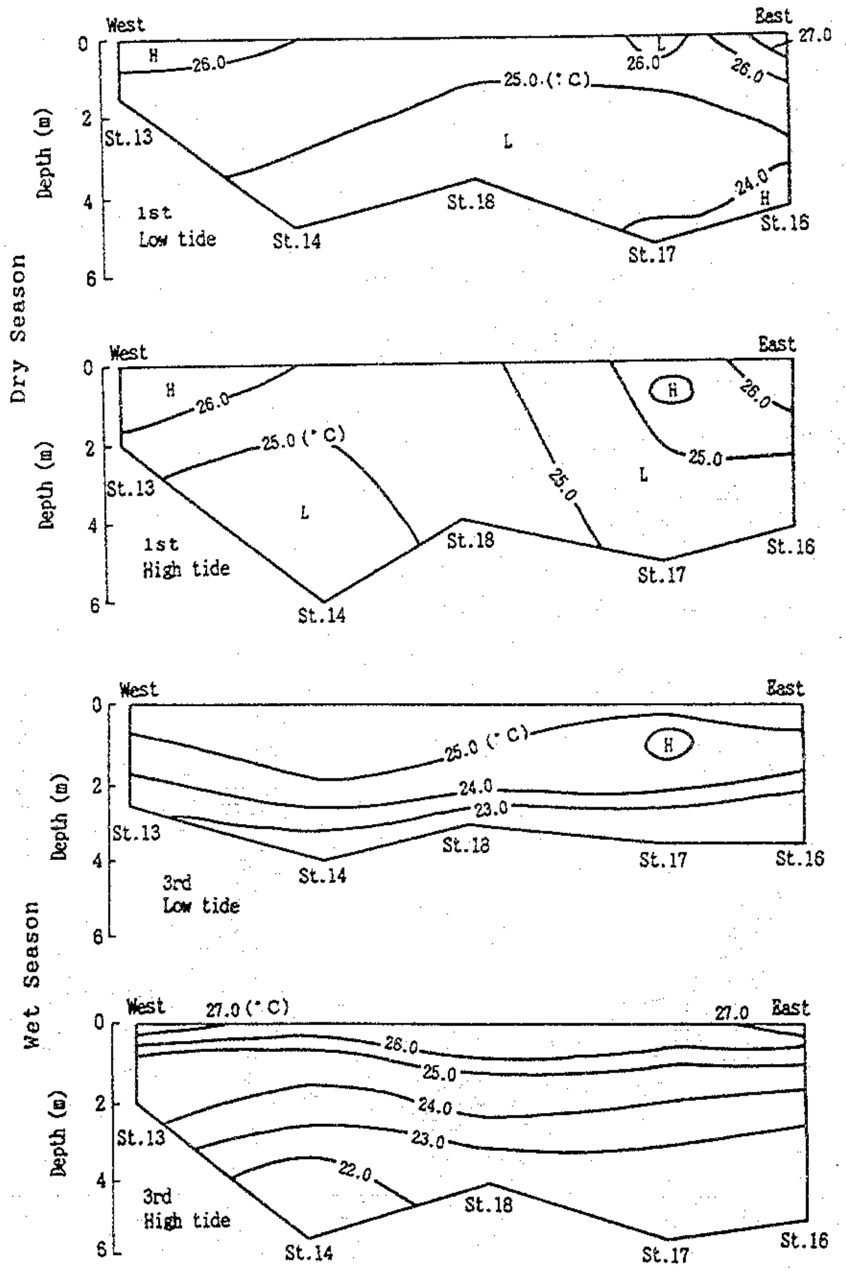
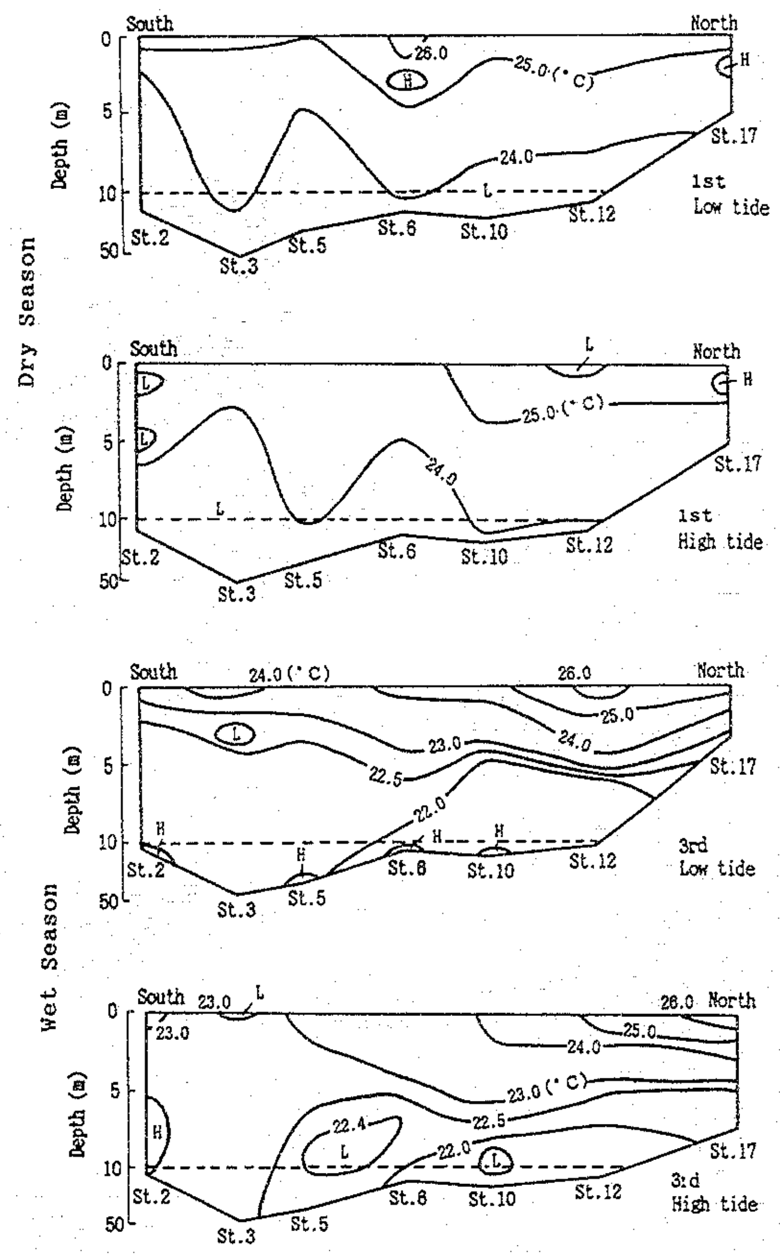


Fig.4.5-5 Vertical Distribution of Temperature



Sections as seen from the South



Sections as seen from the East

Fig.4.5-6 Vertical Sections of the Temperature Distributions across the Bay

4.5.3 T-S Relation

Both water temperature (T) and salinity (S) values change depending on the seasons and the area in the Bay. The T-S relationship, therefore, varies throughout the year and from one area to another. The T-S relation curve against the depth with sigma-t, the latter is explained in 4.5.4, illustrates some of the physical characteristics of the water in the Bay.

T-S relation for the low tide of the spring tides in the dry season (May 1991) showed both relatively higher temperatures and salinities within a smaller range than that for the neap tides (June) at the same stations (**Fig. 4.5-7**).

The graph clearly demonstrates that in the wet season lower temperatures were obtained at all stations and the range of the salinity expanded considerably toward the lower end, especially at Stns. 11 and 16.

Strong stratifications develop in all cases in both seasons, except at stations near the mouth (Stns. 2 and 6) and outside the Bay.

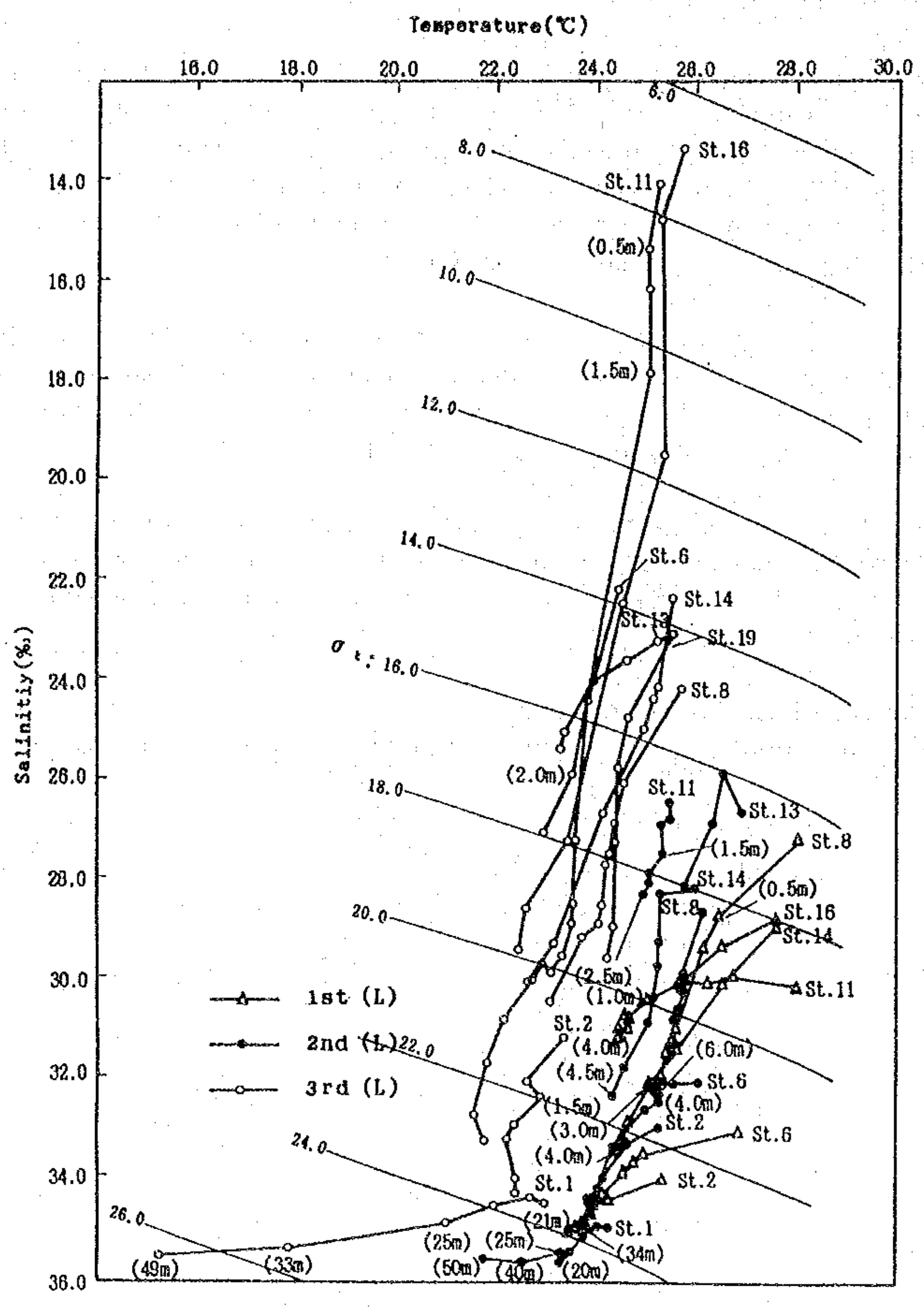


Fig.4.5-7 T-S Relationship obtained from Simultaneous Surveys

4.5.4 Density (Sigma-t) Distribution and Stratification

Density in situ is indicated by sigma-t, which is defined as (density-1)/1000. Sigma-t was calculated using the salinity and temperature values measured in simultaneous surveys at each station; horizontal and vertical profiles of sigma-t are shown in **Fig. 4.5-8**.

Generally sigma-t increased downwards and the degree of increase per unit depth gradually developed from the mouth toward the inner Bay, mostly depending on salinity distribution.

Sigma-t in the upper layers was lower in the wet season than in the dry season, particularly in the inner Bay, mainly due to low salinity.

It seems that stratification develops on the northwestern side in the inner bay in the dry season. In the wet season, more stable stratification develops not only in the inner Bay area but also in the central Bay area (**Fig. 4.5-8**).

In contrast to the inner Bay, a homogeneous vertical distribution of sigma-t takes place near the mouth of the bay including Stns. 5 and 6, even in the wet season (**Fig. 4.5-9**). Formation of stratification around these stations seems to be difficult throughout the year.

Breakdown of the stratification decreases with depth until the water is vertically mixed well was observed in the inner Bay during preliminary survey-2, October 21st (**Fig. 4.5-10**).

The figures indicate that the layers in a well-mixed water state developed downward until 1.5 to 3.0 m. These depths were compared with the depths most of the same stations, obtained in the third simultaneous survey, when no strong winds were recorded, resulting in stratification development.

The relationship between sigma-t and the critical wind velocity that causes the breakdown and the developed state of layers with well-mixed water state is unknown.

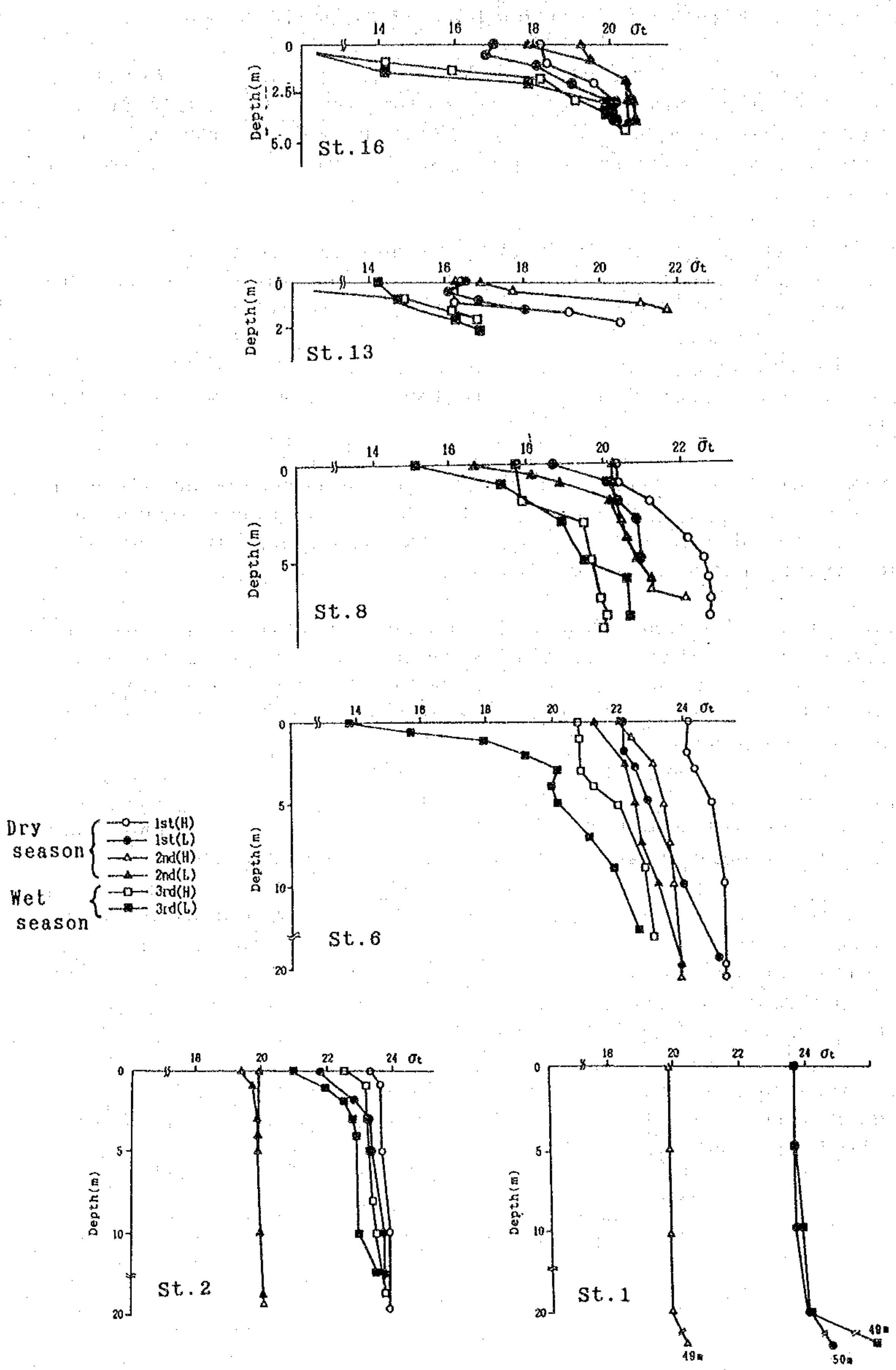


Fig.4.5-8 Vertical Distribution of Sigma-t

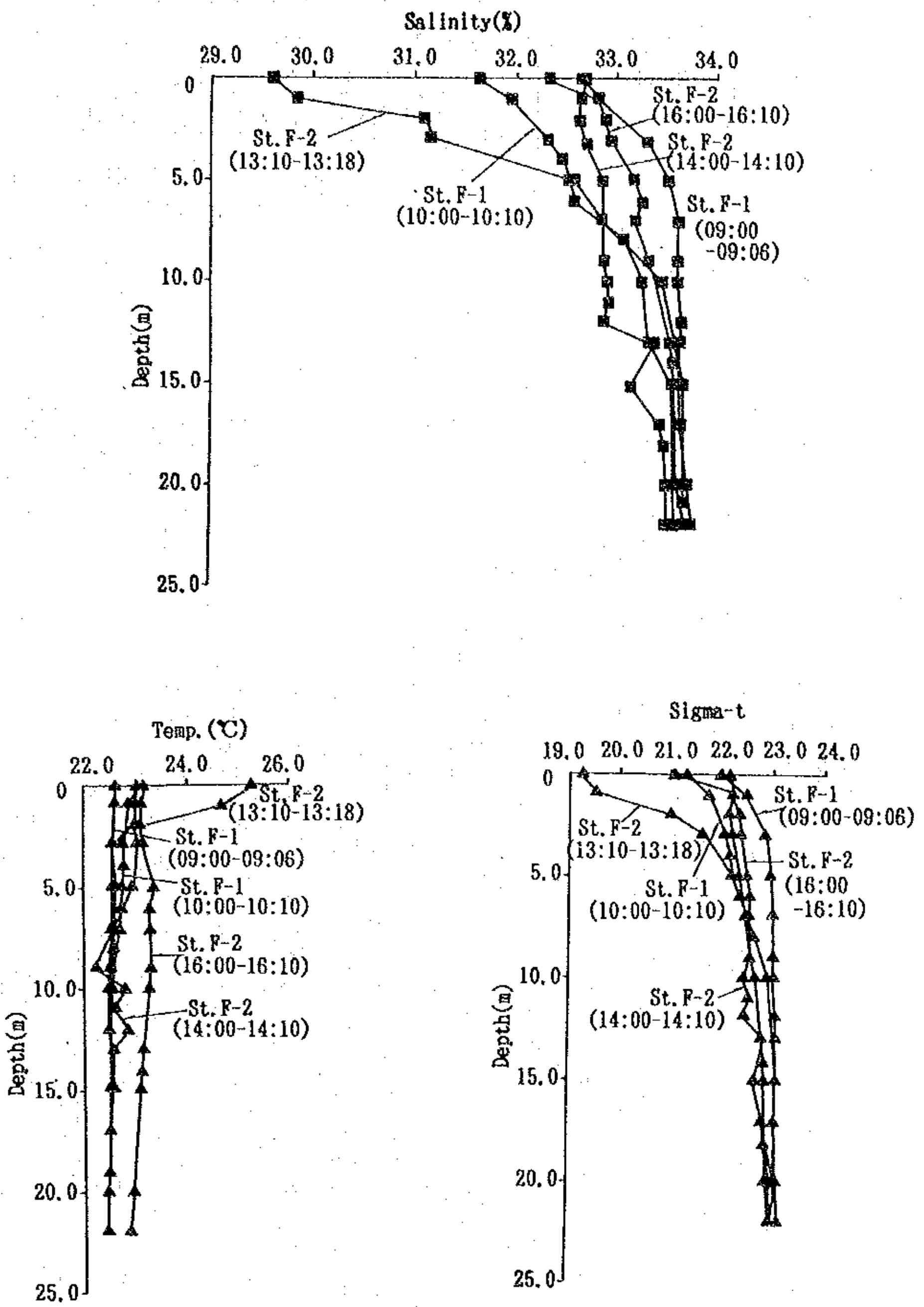
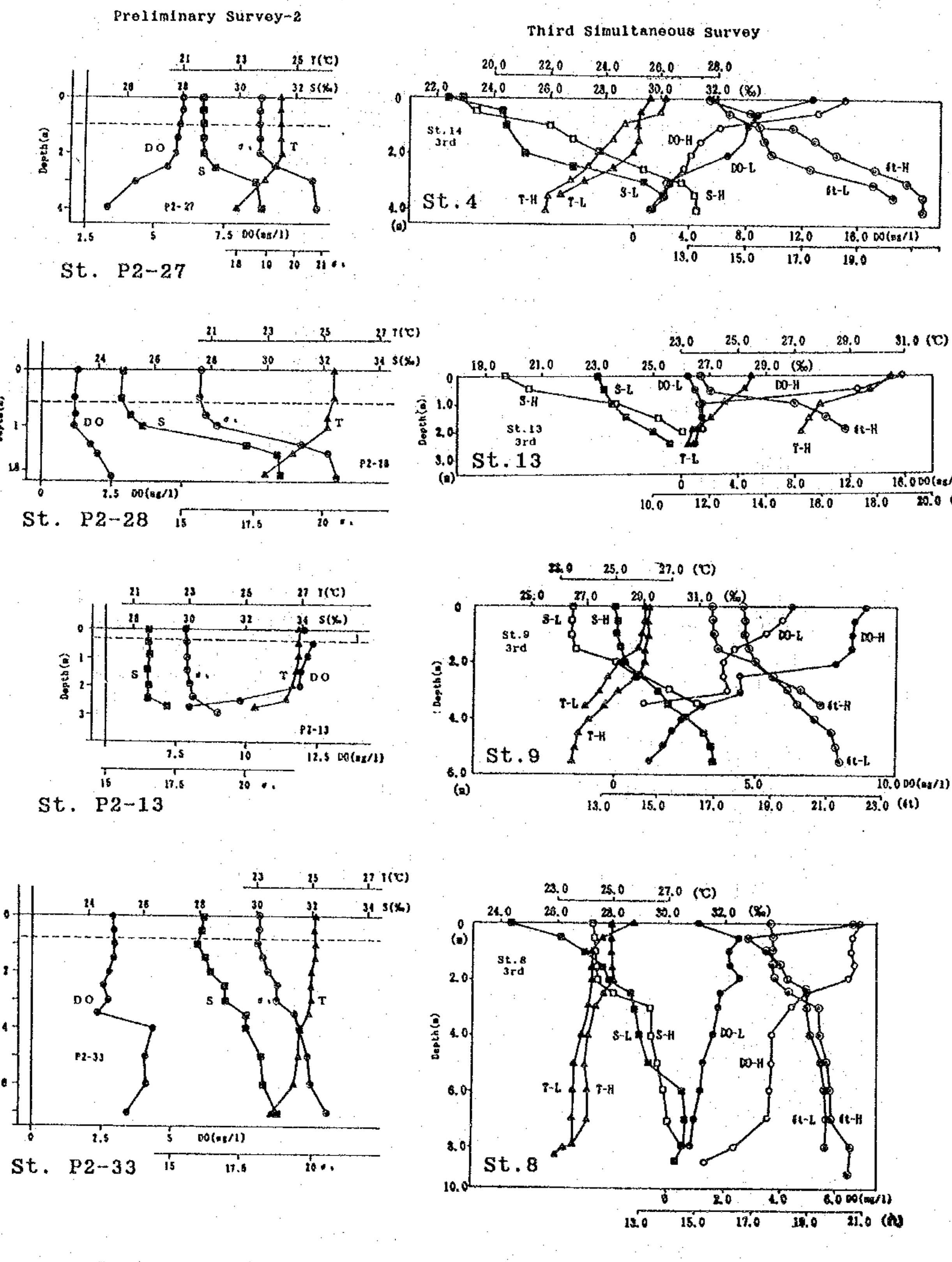


Fig.4.5-9 Physical Characteristics near the Mouth of the Bay (wet season)



T-L: Temp.(Low tide)
S-L: Salinity(Low tide)
DO-L: DO(Low tide)
σ_t-L: σ_t(Low tide)

T-H: Temp.(High tide)(°C)
S-H: Salinity(High tide)(‰)
DO-H: DO(High tide)(mg/l)
σ_t-H: σ_t(High tide)

Fig.4.5-10 Breakdown of Stratification

4.5.5 Distribution of Dissolved Oxygen

(1) Horizontal Distribution

The surface Dissolved Oxygen (DO) concentration and saturation rates ranged widely in all areas of the Bay reflecting complicated biological, chemical and physical reactions (**Fig. 4.5-11**).

The mean surface concentrations in the dry season were higher on the north-western side (Stns. 13, 14 and 18) than other areas in the Bay, and tended to decrease toward the mouth of the bay (**Fig. 4.5-12**).

DO saturation percentage was occasionally higher than 200 %, and unbelievably high values of 306 % and 301 % were recorded at the shallow inner Bay area (St. 14) and in the surface layer near the mouth of the Bay (St. 5) at low tide in June, respectively (**Fig. 4.5-11**).

In the upper layers, particularly in the inner Bay, oxygen was obviously always produced by the high productivity of phytoplankton with sufficient nutrients, strong light intensity and high temperature. Surface DO distribution tending to correspond to the Chl-a distribution and phytoplankton numbers also proves that high DO in the surface layer is the result of active photosynthesis.

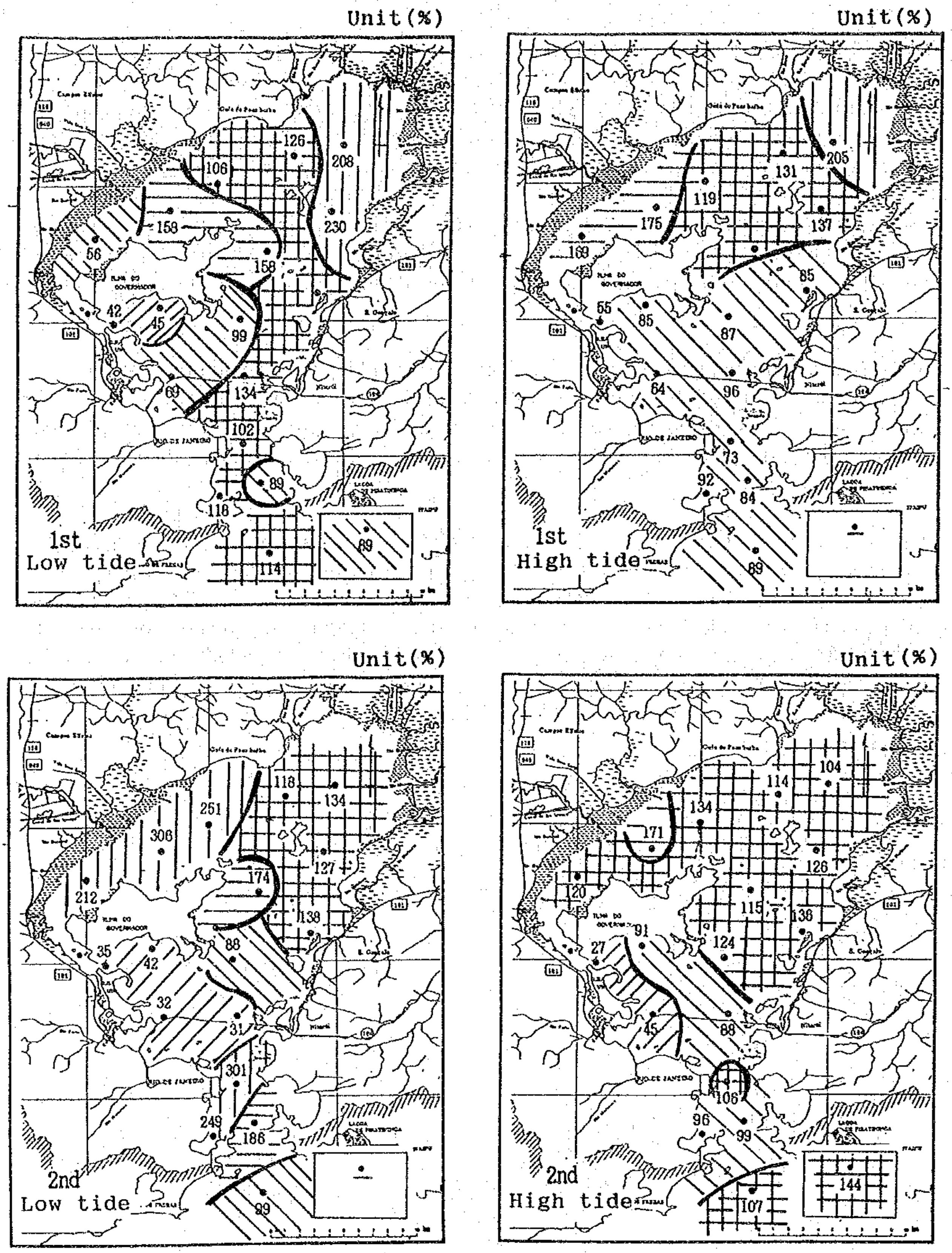


Fig.4.5-11(1) Distribution of Dissolved Oxygen in the Surface Layer in the Dry Season

Legend

- : 0 - 50
- : 51 - 100
- : 101 - 150
- : 151 - 200
- : 200 ≤

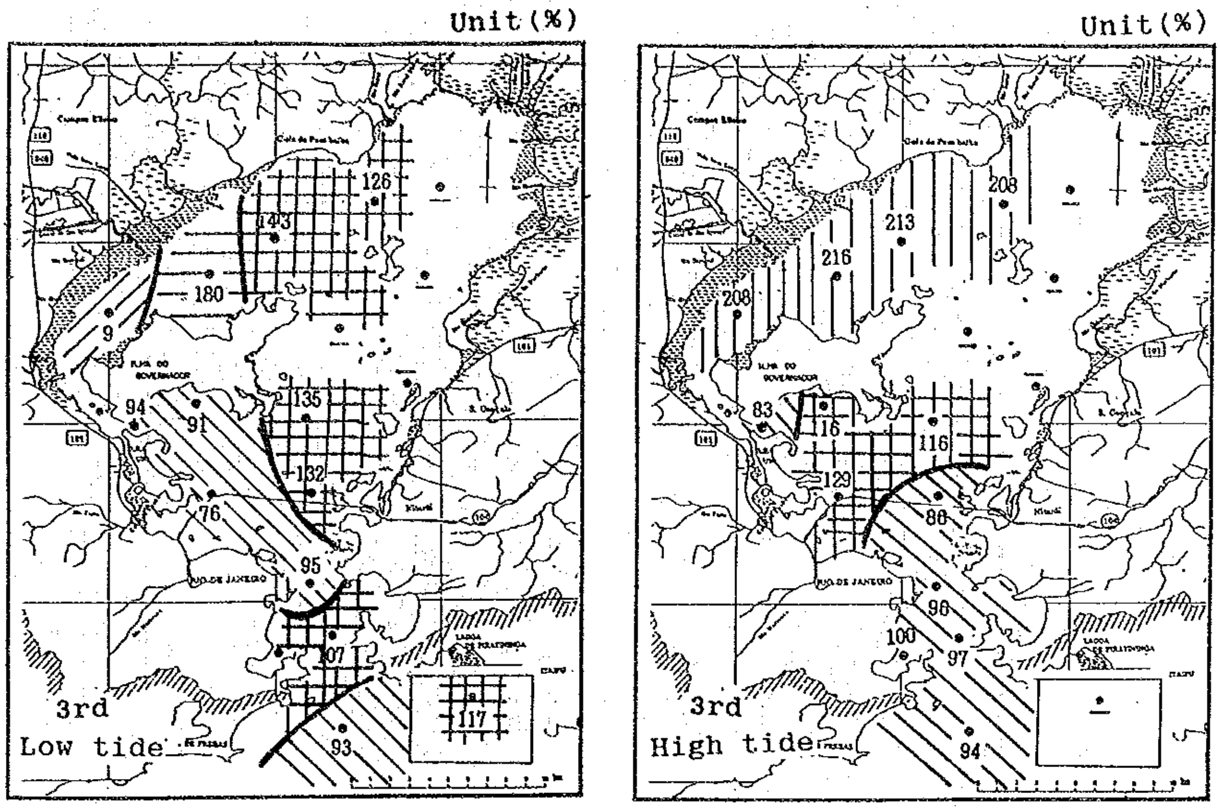


Fig.4.5-11(2) Distribution of Dissolved Oxygen in the Surface Layer in the Wet Season

Legend

: 00 - 50
: 51 - 100
: 101 - 150
: 151 - 200
: 200 ≤

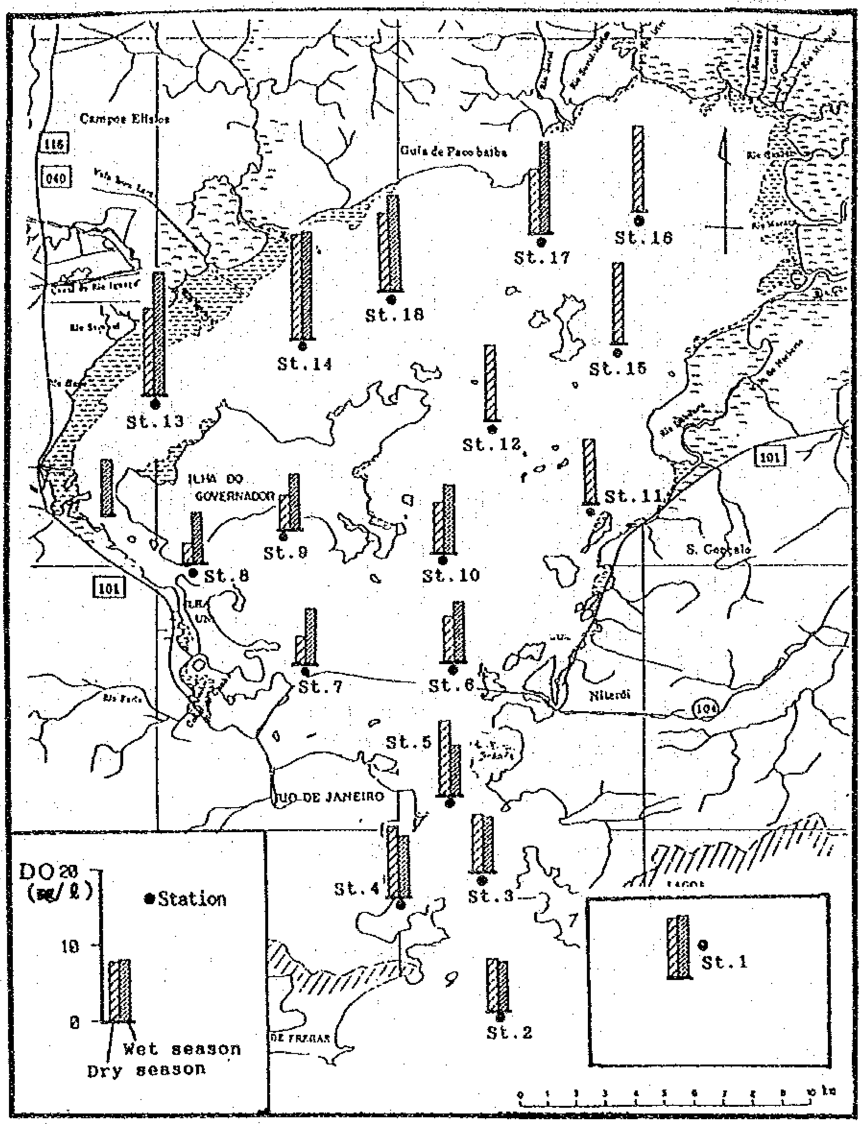


Fig.4.5-12 Distribution of Mean Dissolved Oxygen in the Surface Layer

(2) Vertical Distribution

In contrast to the high values found in the surface layers in the inner Bay area, DO sharply decreased in the deeper layers (**Fig. 4.5-13**). DO, particularly near the bottom, was sometimes remarkably low ; 0 mg/l near St. 16, on the northeastern side in April, 1992 (preliminary survey-1), lower than 0.5 mg/l at many stations on the western side of the inner Bay in April and May, 1992.

The DO discontinuous depths were generally found around three meters deep, usually a little above the depth where sigma-t greatly increased. It is obvious that phytoplankton resides and condenses above this depth producing large quantities of oxygen.

DO values near the bottom increased from the inner bay area toward the outer area. The difference in DO values between the surface and the bottom was significantly greater in the inner Bay than the outer part of the Bay (**Figs. 4.5-13, 14 and 15**).

DO at the bottom is consumed by sediments due mainly to decomposition of organic materials in the sediment and oxidation of reduced materials.

Organic materials also consume oxygen by decomposition in the deeper layers. On the other hand, DO is supplied from the upper layers by the mixing of water or its turnover.

DO distribution near the mouth of the Bay in the St. 6 area was vertically very homogeneous, as was found with the salinity and temperature distributions at Stns. 5 and 6 in particular (**Fig. 4.5-9**). This also proves that water in the area mixes well or that turnover of water occurs in these areas.

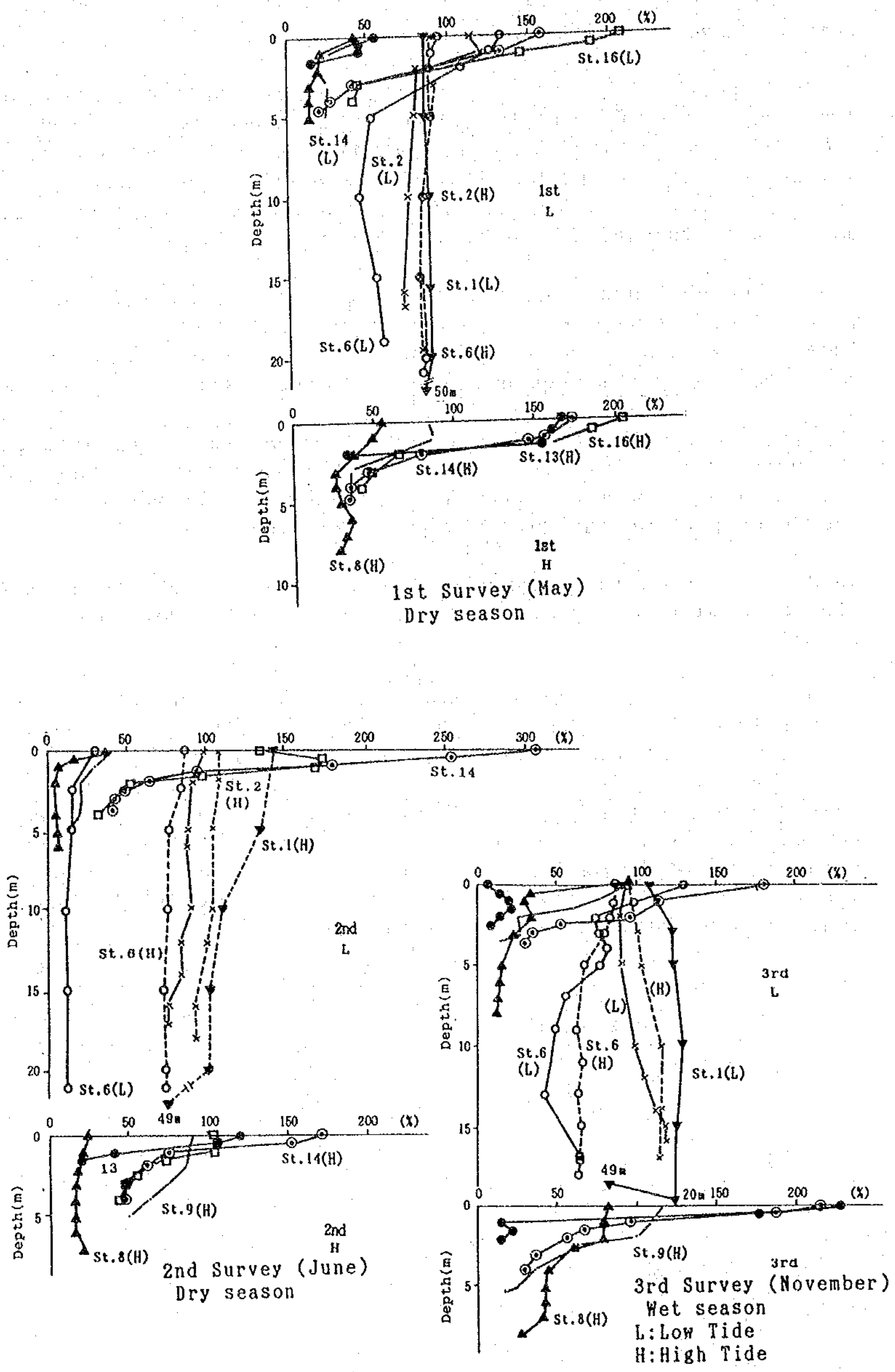


Fig.4.5-13 Vertical Distribution of Dissolved Oxygen

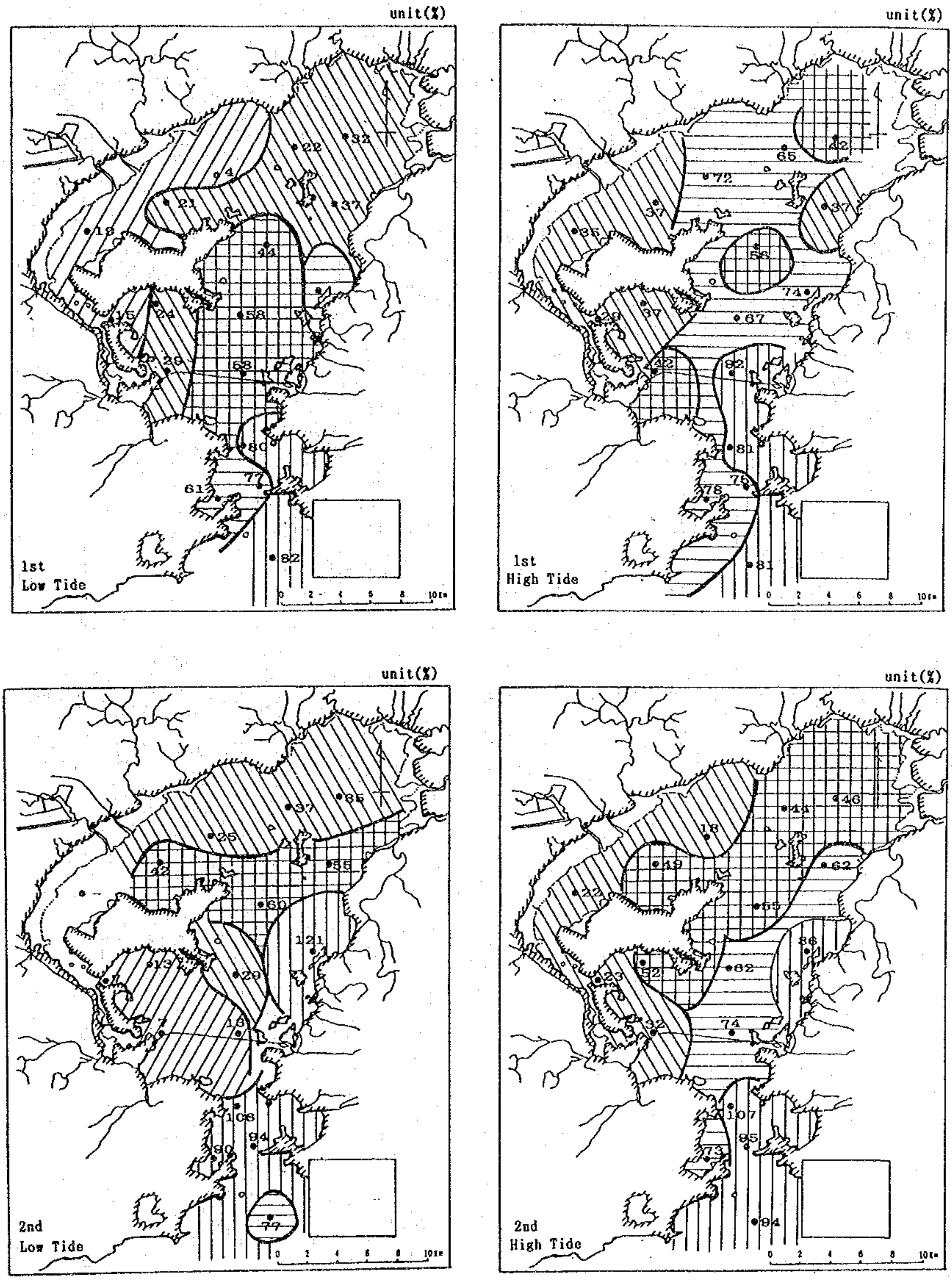
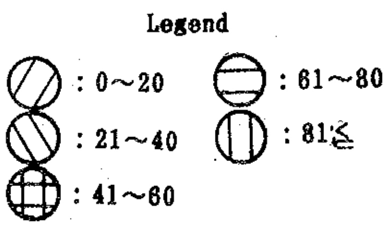


Fig.4.5-14(1) Distribution of Dissolved Oxygen at the Bottom (Dry Season)



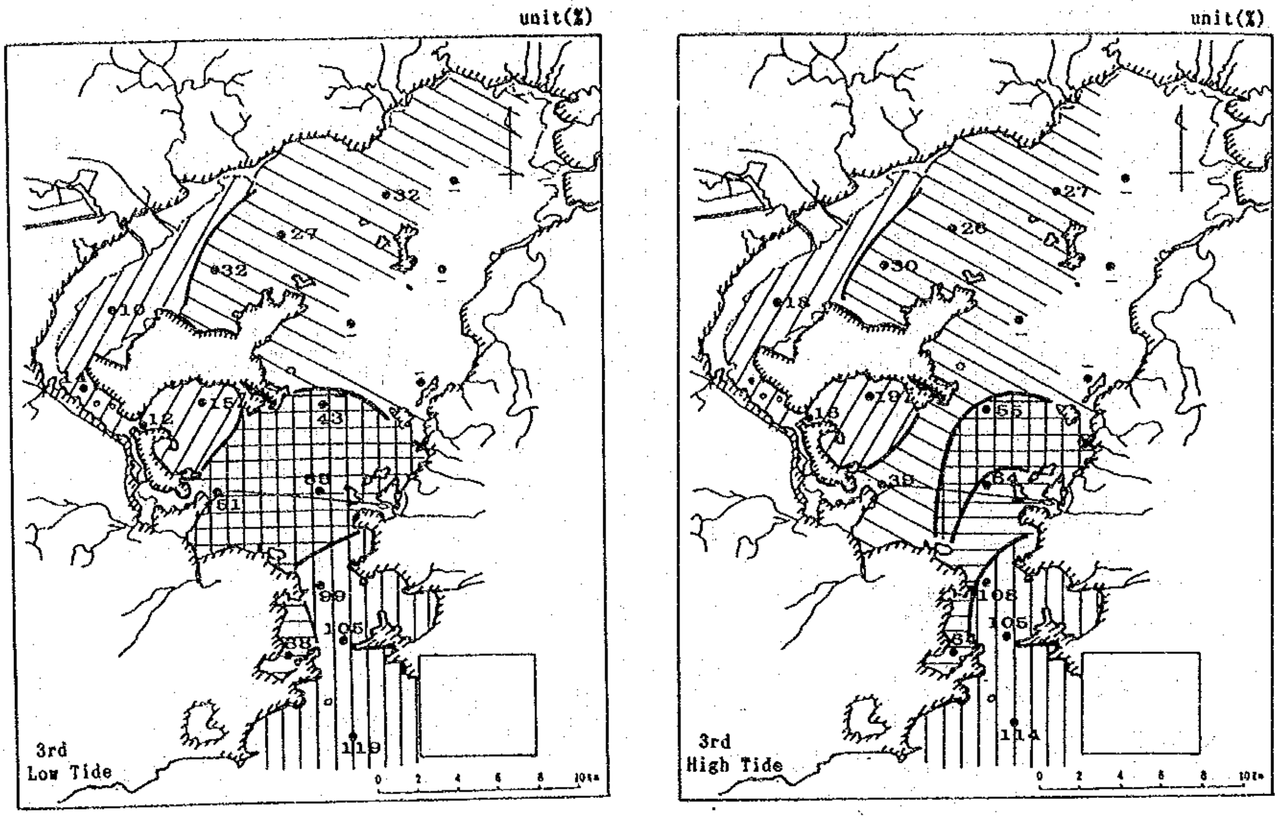
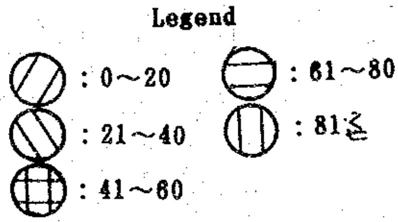
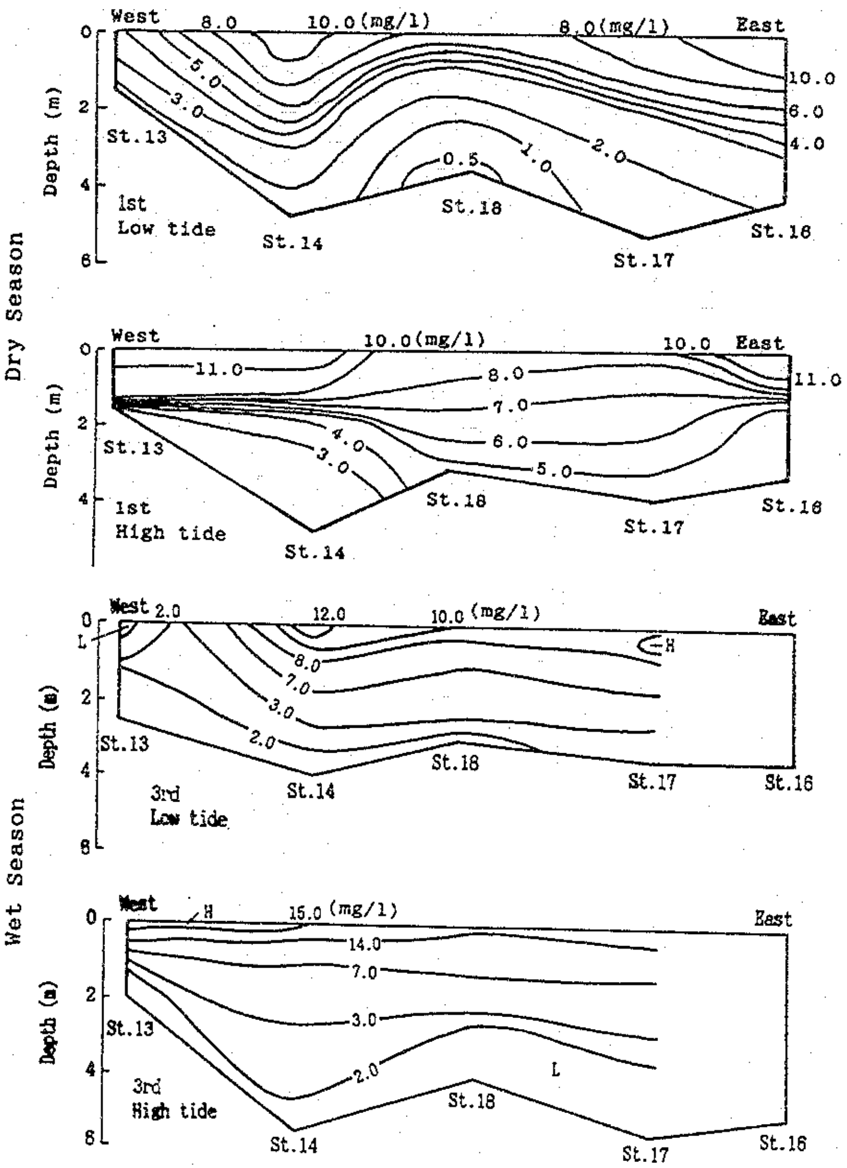
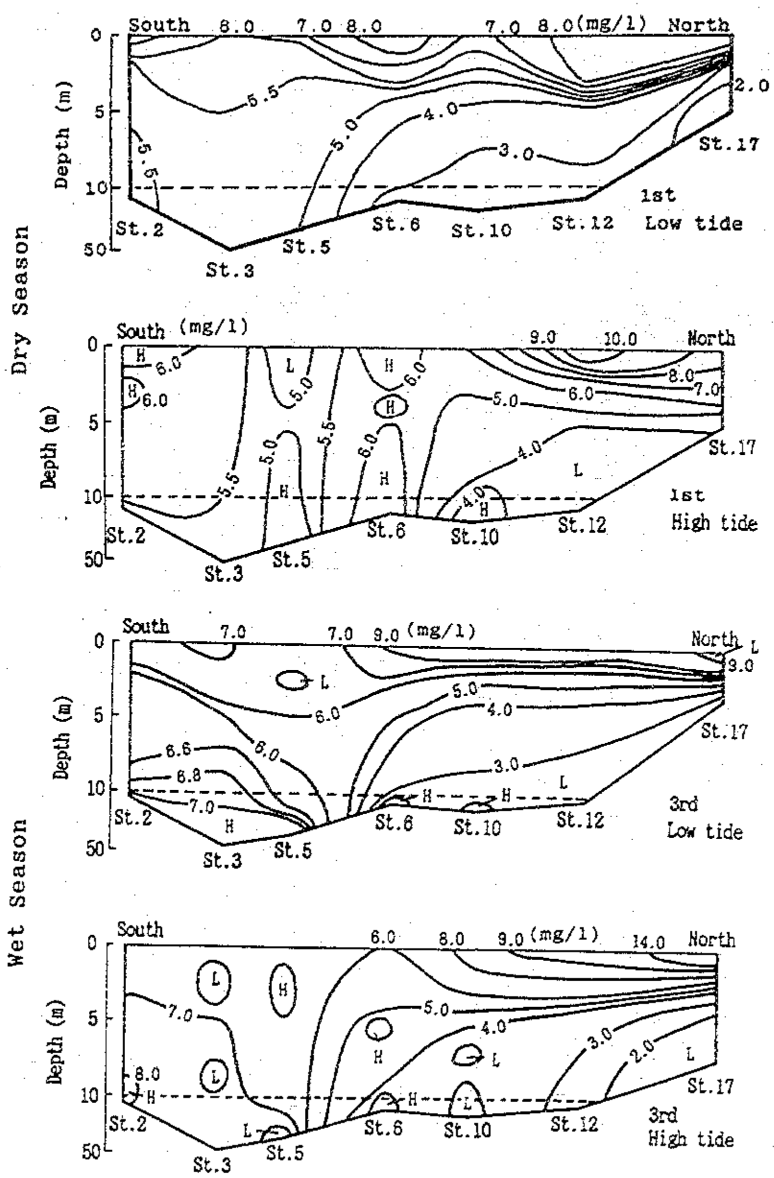


Fig.4.5-14(2) Distribution of Dissolved Oxygen at the Bottom (Wet Season)





Sections as seen from the South



Sections as seen from the East

Fig.4.5-15 Vertical Sections of the Dissolved Oxygen Distributions across the Bay

4.6 Exchange of Bay Waters

4.6.1 Water Volume and River Flow

The water volume of the Bay and the amount of river-flow from the whole basin of the Guanabara Bay were estimated at the values shown in **Table 4.6-1**.

Now, if we supposed that the exchange of bay waters is caused only by the river flows, it will take more than 90 days at least to exchange the bay waters.

As the strong tidal currents, however, are seen at the bay mouth, the bay waters will be exchanged faster than the number of days calculated simply in **Table 4.6-1**.

Table 4.6-1 Relationship between Water Volume of the bay and the Amount of River-Flow

Item	Water Volume/River-Flow	V / Q
Water Volume of the Bay (V)	2.20×10^9 m^3	
Amount of River-Flow (Q)		
Mean Value of Dry Season	1.54×10^7 m^3/day	143 days
Mean Value of Rainy Season	2.44×10^7 m^3/day	90 days

4.6.2 Analysis by a Marker and Cell Method

The movement of markers such as buoys with no weight was calculated by using the result of the tidal current simulation (hydrodynamic model).

Fig. 4.6-1 shows the distribution of markers flowed into the bay, which changes every second by an advection, from the Meriti, Iguacu and Guapimirim rivers.

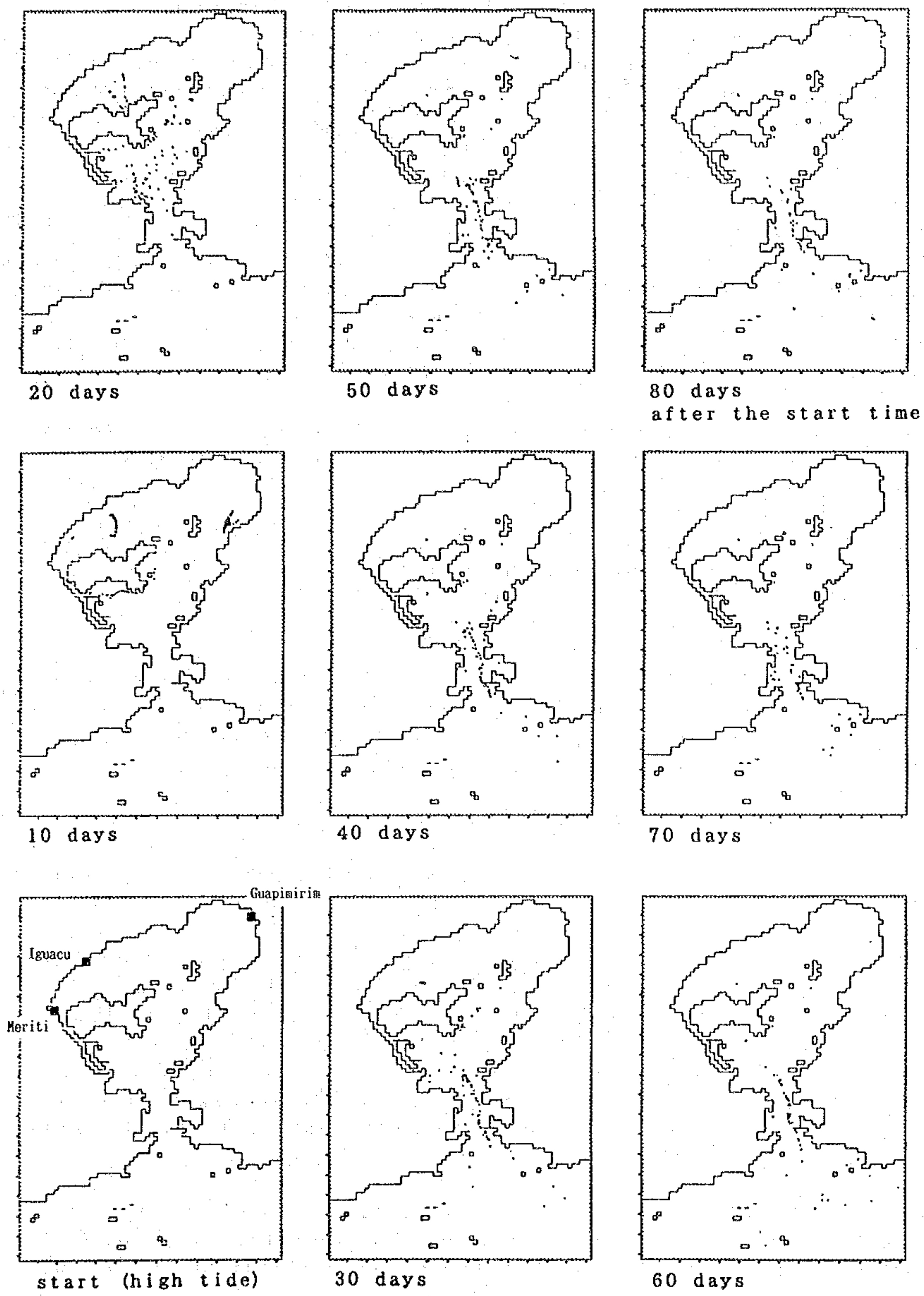


Fig.4.6-1 Distribution of Markers from the Meriti, the Iguacu and the Guapimirim rivers (Rainy Season)

It is observed that the markers flow toward the bay-mouth with the passage of time and it takes about 30 days for the some part of buoys to flow out from the bay-mouth into the outer ocean. After 80 days inflowed from the rivers, however, the buoys still remain in the bay.

4.6.3 Analysis by a Diffusion Simulation Model

We divided the bay into four (4) blocks and release conservative matters instantaneously into some block. Then the concentration change with time (a relative concentration to the initial one: C/C_o) is calculated by a diffusion simulation model under the assumption of a perfect mixture in the bay.

Fig. 4.6-2 shows the result of the calculation and the number of days becoming one tenth (1/10) of the initial concentration (C_o) for each block is as follows;

Block 1 : 30 tidals (about 15 days)
Block 2 : 70 tidals (about 35 days)
Block 3 : 10 tidals (about 5 days)
Block 4 : 80 tidals (about 40 days)

This means that the western part (Block 3) has the best water exchange (retention time is shortest) and the west side of the inner part (Block 1) is in the second place. In contrast it, the eastern part (Blocks 2 and 4) shows a bad exchange (retention time is long).

Regarding with the exchange of water between the blocks, a good water exchange is seen between Block 1 and Block 2, and between Block 3 and Block 4.

Moreover, in case of releasing in Block 4 near the bay-mouth, it is seen that the concentration of Block 4 is higher than that of other blocks in the first stage, then the concentration of Block 3 in the west side of Block 4 soon becomes higher than that of Block 4 temporarily, and after one week the concentration of Blocks 1 and 2 situated in the inner part becomes higher than that of the releasing Block 4. This means that the inner part is strongly affected by the water quality in the bay-mouth area.

Seeing the concentration change with time in case of releasing conservative matters instantaneoulsy in the wholw bay area, it takes more than 60 days to become one tenth (1/10) of the initial concentrations.