(1) In case of releasing in Block 1

C/C₀ axis: C/C_0

(2) In case of releasing in Block 2

(3) In case of releasing in Block 3

(4) In case of releasing in Block 4

Block : —1 ···2 ···3 ··4

Tidal   (60 days)

(5) In case of releasing in the Whole Bay Area

Block : —1 ···2 ···3 ··4

Tidal   (60 days)

(6) Block Division of the Guanabara Bay

Fig.4.6-2   Concentration Change of Conservative Matters by Water Exchange in the Bay

CHAPTER 5

WATER AND SEDIMENT

POLLUTION

CHAPTER 5

WATER AND SEDIMENT POLLUTION

In order to know the present state of the water quality and bottom sediments in the Bay, physical and chemical studies were carried out all over Guanabara Bay in the dry and wet seasons.

Experiments on primary productivity, release rate of sediments, settling speed of particles and oxygen consumption rate were also carried out to determine the material cycle in the Bay.

These data provide a basis for the analyses of pollution mechanism of the Bay and setting up of a simulation model (see Chapter 10).

5.1 Method of Survey and Analysis

5.1.1 On Site Observation and Sampling

(1) Preliminary Survey

Prior to the first and the third simultaneous surveys, preliminary surveys were done to obtain the horizontal and vertical distributions of the basic physical water quality.(See Supporting Report IV, Chapter 1).

(2) Simultaneous Survey

The main survey for the water quality carried out simultaneously, three times during the dry and wet seasons.

The survey and the sampling time at each station was set as close as possible to the high and low tide levels.

Dry season
    First simultaneous survey:
        At low (morning) and high (afternoon) tides for the spring tides of May 18th, 1992
    Second simultaneous survey:
        At high (morning) and low (afternoon) tides for the neap tides of June 8th, 1992

Wet season
    Third simultaneous survey:
        At low (morning) and high (afternoon) tides for the
        spring tides of November 10th, 1992

18 stations were established for the first and the second surveys, and also for the third survey at high tide. These stations covered the whole Bay area, and one station of these stations was set 10 km from as a reference for non-polluted water or background water (**Fig. 5.1-1**).

All stations were set up using as a reference of previous results obtained in preliminary surveys 1 and 2. One more station (St. 19) located between the southwestern side of Ilha do Governador and the main land was added at low tide for the third survey.

The locations, the sampling depths and the parameters analyzed in the first survey are shown in **Table 5.1-1**. The sampling depths were decided according to water depth.

Basically the same locations, depths and parameters were employed in the second and third surveys.

(3)   Survey in Small Bays and Coastal Areas

Surveys were conducted in two small bays (Botafogo and Jurujuba) and at two coastal stations (Centro de Ilha do Engenho and Rio Porto), and their results were added to those of the water quality in the Bay previously obtained only in open areas by the simultaneous and preliminary surveys (**Fig. 5.1-2**).

All areas were assumed to be seriously polluted mainly because of their locations.

Survey and the measurement methods and parameters used were similar to those in the simultaneous surveys.
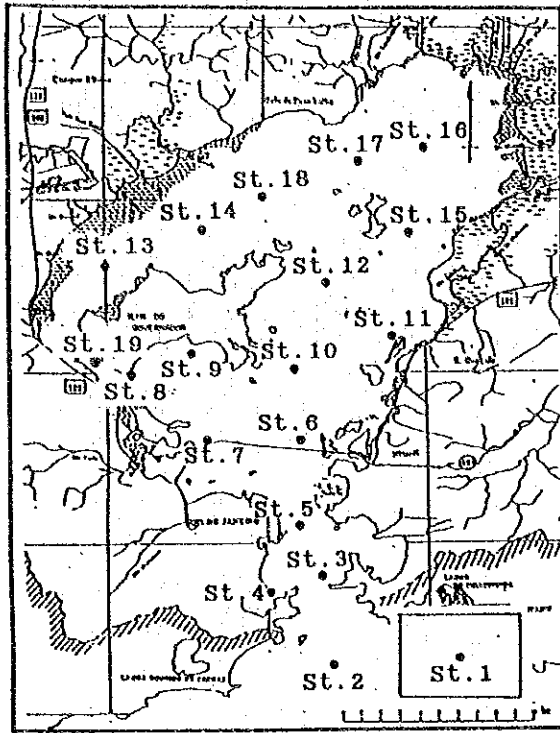
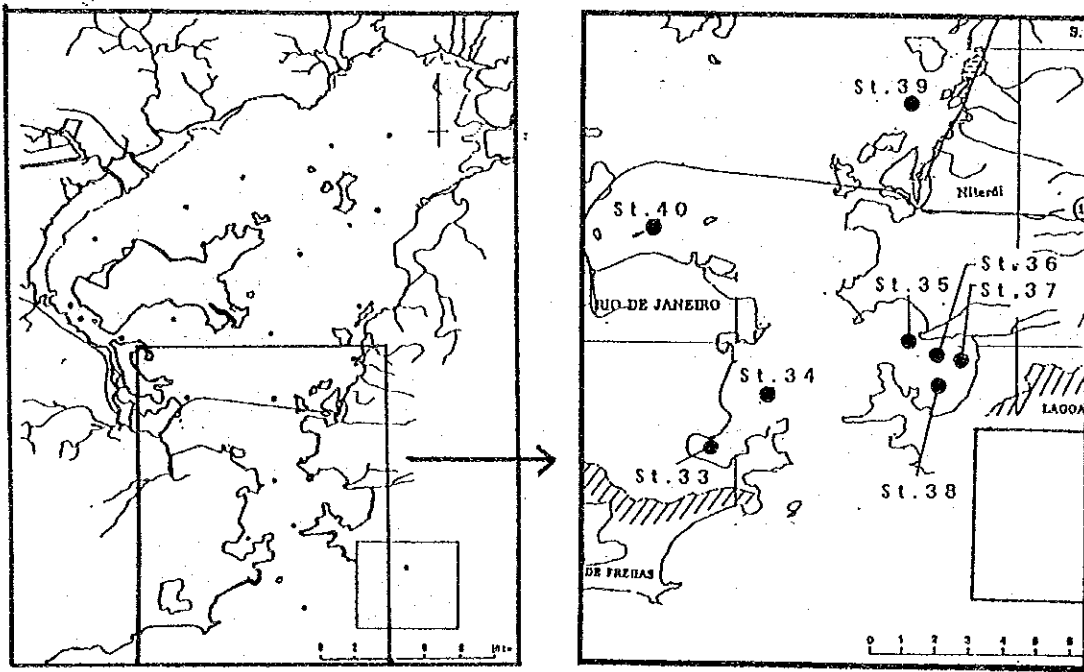Fig. 5.1- 1   Sampling Stations for Simultaneous Survey

Fig. 5.1- 2   Sampling Stations in Small Bays and Coastal Areas

Table 5.1-1 Location, Sampling Depth and Analytical Parameters of the First Simultaneous Survey

Spring Tides - Low Tide (morning)

Item St.	Location South	West	Water Depth(m)	COD(Mn) DCOD(Mn)	BOD T-KN D-KN	SS, NH4-N, NO2-N NO3-N, TP, PO4-P Coli-forms	Phenols, CN	n. Hex. Extract	Metals, Toxic Substance	Chl-a, Phyto-plankton
1	23°04'44.7'	43°04'59.6'	51.0	0, 5, 25, B	--	0, 5, 25, B	--	0	0, B	0, 5
2	22°58'27.8'	43°08'02.4'	17.3	--	--	0, 5, B	--	0	0, B	0, 5
3	22°55'48.3'	43°08'40.0'	50.0	0, 5, B	0, B	0, 5, B	0, B	0	0, B	0, 5
4	22°56'25.5'	43°10'02.0'	12.5	0, 3, 7, B	--	0, 3, 7, B	--	0	0, B	0, 3
5	22°54'15.6'	43°09'03.3'	38.5	--	--	0, 5, 10, B	--	0	0, B	0, 5
6	22°51'52.0'	43°11'31.0'	20.0	0, 5, 10, B	0, B	0, 5, 10, B	0, B	0	0, B	0, 5
7	22°51'59.1'	43°11'57.8'	6.0	--	--	0, 3, B	--	0	0, B	0, 3
8	22°50'10.0'	43°14'11.8'	6.0	0, 2, B	0, B	0, 2, B	0, B	0	0, B	0, 2
9	22°49'33.8'	43°12'28.4'	5.0	0, B	0, B	0, B	0, B	0	0, B	0, B
10	22°50'01.0'	43°09'10.4'	24.0	--	--	0, 5, B	--	0	0, B	0, 5
11	22°49'01.0'	43°06'13.4'	2.4	0, B	0, B	0, B	0, B	0	0, B	0, B
12	22°47'49.1'	43°07'56.1'	15.4	0, 5, B	--	0, 5, B	--	0	0, B	0, 5
13	22°47'00.0'	43°15'00.0'	1.5	0, B	0, B	0, B	0, B	0	0, B	0, B
14	22°46.00.0'	43°12'00.0'	4.7	0, 3, B	0, B	0, 3, B	0, B	0	0, B	0, 3, B
15	22°46'09.1'	43°05'29.2'	7.5	0, 3, B	--	0, 3, B	--	0	0, B	0, 3
16	22°47'13.3'	43°05'41.9'	4.3	0, B	0, B	0, B	0, B	0	0, B	0, B
17	22°44.00.0'	43°07'00.0'	5.2	0, B	0, B	0, B	0, B	0	0, B	0, B
18	22°44'00.0'	43°10'00.0'	3.5	0, B	0, B	0, B	0, B	0	0, B	0, B

Spring Tides - High Tide (afternoon)

Item St.	Water Depth(m)	COD(Mn) DCOD(Mn)	BOD T-KN D-KN	SS, NH4-N, NO2-N NO3-N, TP, PO4-P Coli-forms	Phenols, CN	n. Hex. Extract	Metals, Toxic Substance	Chl-a
1	-	-	--	--	--	-	-	0, 5
2	20.0	0, 5, B	--	0, 5, B	-	--	--	0, 5
3	50.0	0, 5, B	--	0, 5, B	-	--	--	0, 5
4	7.5	0, 3, 7, B	--	0, 3, 7, B	-	--	--	0, 3
5	34.0	0, 5, 10, B	--	0, 5, 10, B	--	--	--	0, 5
6	22.0	0, 5, 10, B	--	0, 5, 10, B	-	--	--	0, 5
7	6.5	0, 3, B	--	0, 3, B	-	--	--	0, 3
8	8.5	0, 2, B	--	0, 2, B	-	--	--	0, 2
9	5.0	0, B	--	0, B	-	--	--	0, B
10	26.0	0, 5, B	--	0, 5, B	-	--	--	0, 5
11	5.0	0, B	--	0, B	-	--	--	0, B
12	17.5	0, 5, B	--	0, 5, B	--	--	--	0, 5
13	2.0	0, B	--	0, B	-	--	--	0, B
14	6.0	0, 3, B	--	0, 3, B	-	--	--	0, 3, B
15	10.0	0, 3, B	--	0, 3, B	--	--	--	0, 3
16	4.3	0, B	--	0, B	-	--	--	0, B
17	5.0	0, B	--	0, B	-	--	--	0, B
18	4.0	0, B	--	0, B	-	--	--	0, B

5.1.2 Treatment and Analysis of the Samples

(1) Treatment of Sampled Water

The collected seawater was treated with chemicals and was stored in the ice-boxes to prevent decomposition at low temperatures.

After the survey, they were immediately transferred to the refrigerators in the laboratory at 4° C until they were analyzed.

(2) Analytical Method

Microbiological analysis was immediately commenced after the samples arrived at the laboratory.

Water was sampled to determine biochemical oxygen demand (BOD) at several representative stations assumed to be seriously polluted. Results were used as parameters for the determination of material balance and for simulation. Although the number of BOD data was not enough, it was expected to compensate for the lack of data by correlating BOD with chemical oxygen demand (COD(Mn)).

COD(Mn) was analyzed using the $KMnO_4$-alkaline method which was recommended by FAO for sea water; "FAO Fisheries Technical Paper No. 137, 1975 - Manual of Method in Aquatic Environment Research." However, the method is known only to oxidize some part of the organic materials and usually the values were lower than that measured by $KMnO_4$-acidic.

Kjeldal-nitrogen analysis was carried out on the stations with gravely polluted conditions some as for BOD analysis.

The dissolved form was defined for the filtrate through a 0.45 μm pore-size filter paper, usually Millipore-filter paper.

Chlorophyll-a (Chl-a) was analyzed using the modified "Strickland and Parsons": Chl-a was extracted into 90 % acetone after pigment particles were filtered through 0.45 μm filter paper, then its absorption spectrophotometry was measured.

The analytical method for the rest of the parameters was taken from the "Standard Methods for the Examination for Water and Wastewater" of U.S.A.

Cyanide (CN), normal-Hexan extract (n-Hexan extract), polychlori-
nates Biphenyl (PCB's) and DDT were not analyzed in the third
surrey, because values were not detected in the first and second
surveys.

Total organic carbon (TOC) is the most effective parameter used
when the material cycle was considered. Unfortunately, however,
the TOC analyzer did not function well enough throughout the
period to obtain the data needed.

5.2 Water Quality Conditions of the Main Water Body

5.2.1 Transparency

The transparency, obtained from the Secchi-disk reading depth,
was very low throughout the survey period over the whole area of
the Bay (Fig. 5.2-1).

In the inner Bay area it was always lower than 1.0 m in the dry
season and 0.5 m in the wet season, reflecting the distribution
of high Chl-a concentrations.

————— Dry Season
— — — Wet Season
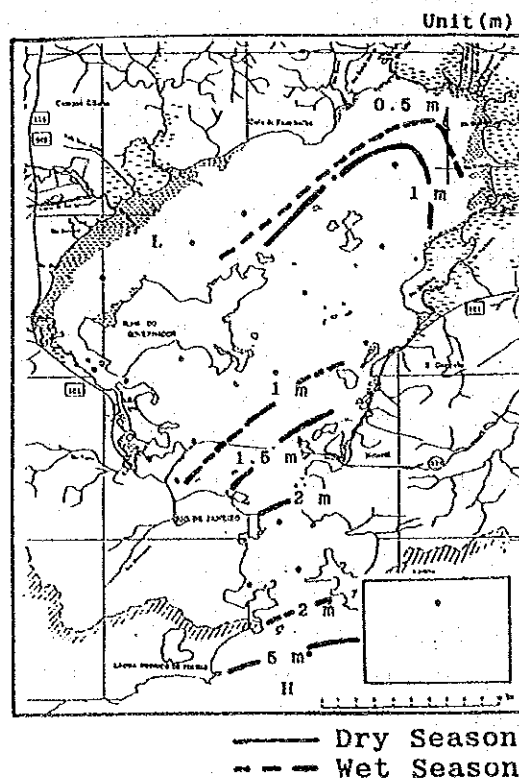
Fig. 5.2- 1   Transparency in the Bay

5.2.2 Chlorophyll-a (Chl-a)

Chl-a was randomly distributed in the space and in the sampling time; however higher values were obtained on the northwestern and western sides, (**Fig. 5.2-2**). This tendency was also found in the distribution of phytoplankton numbers in the Bay.

Although Chl-a does not necessarily express directly amount of phytoplankton biomass resulting from plankton production, a good correlation is usually found between the amount of phytoplankton and the Chl-a concentration.

Higher Chl-a concentrations were more often obtained in the wet than dry season in the central and inner parts of the Bay. Near the mouth area and even in Botafogo, however, Chl-a was higher in the dry than in the wet season (**Fig. 5.2-3**).

Dry Season (upper)
Wet Season (lower)
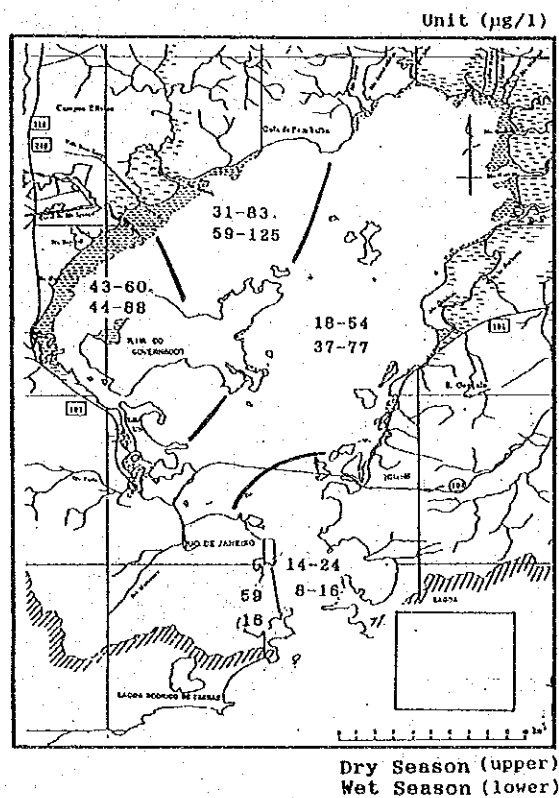
Fig. 5.2- 2   Range of Mean Chl-a Values in the Surface Layer
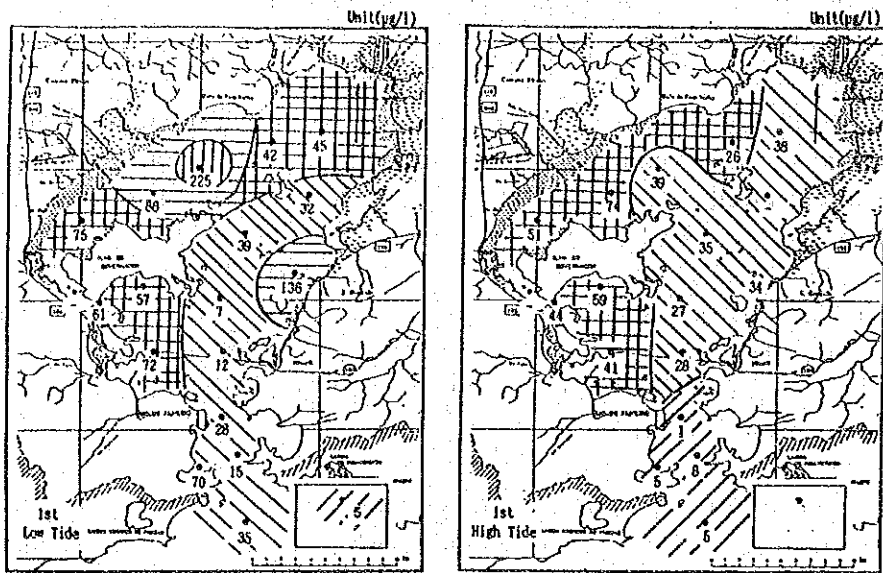
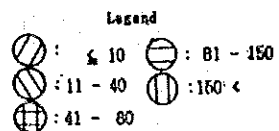(First Survey)
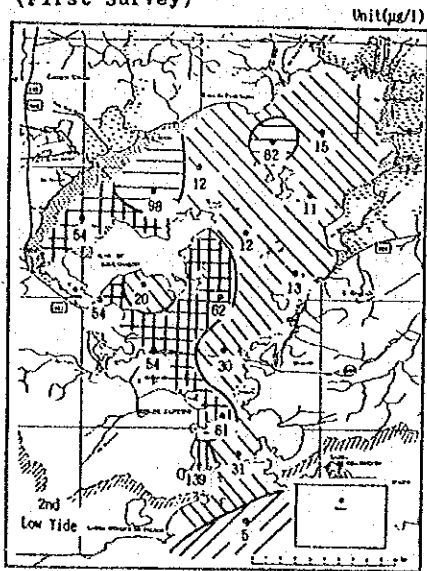
(Second Survey)
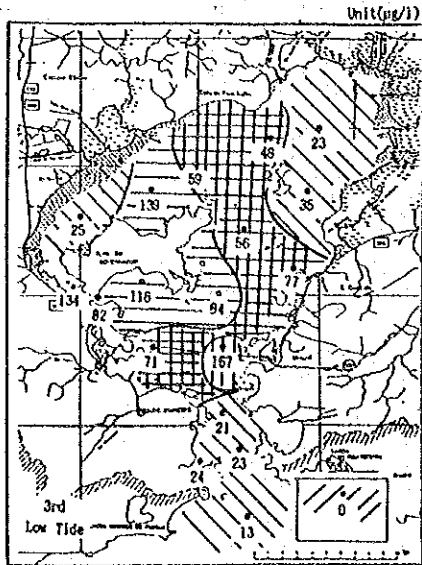
(Third Survey)

Fig. 5.2-3   Distribution of Chl-a in the Surface Layer

5.2.3 Chemical Oxygen Demand (COD(Mn))

The surface COD(Mn) values and their distribution patterns showed significant differences in the dry and the wet seasons, higher values were obtained in the northwest in the dry season, and on the north and northeast in the wet season.(Fig. 5.2-4). Especially at the stations on the northeastern side in the wet season, COD(Mn) was a lot higher (6.8 - 8.8 mg/l) than in the dry season (1.8 - 3.4 mg/l).

These high values found only in the surface layer and in the wet season were thought to be brought about by the discharge of the big rivers (Rio Cacerebu and Rio Guapimirim), which resulted in very low salinity at these stations. Also, high phytoplankton production indicated by Chl-a concentrations may result in these high surface values in the wet season.

The COD(Mn) values and the amount of organic materials as well, measured by other methods are supposedly higher than the obtained values through these surveys. This is because KM_nO_4-alkaline method was used for seawater which is well known to oxidize the organic materials in quite lower levels.
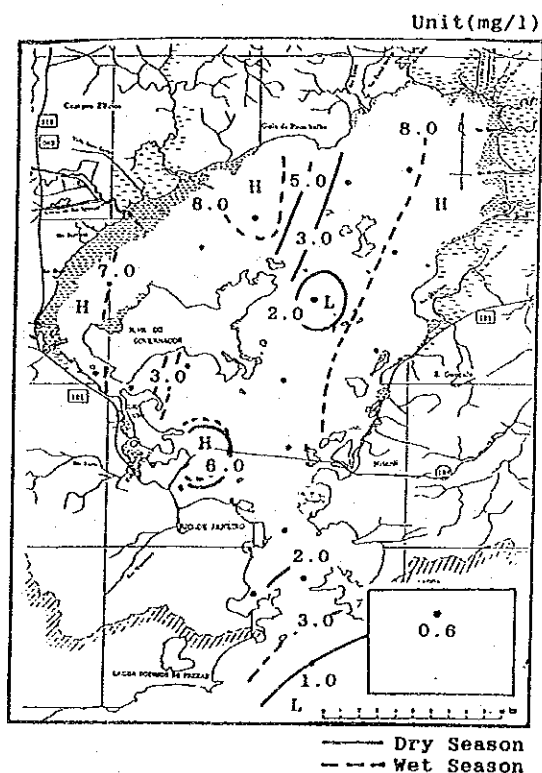

Fig. 5.2- 4   Distribution of COD(Mn)

5.2.4 Biochemical Oxygen Demand (BOD)

For some unexpected reasons, BOD was measured only at the stations seriously polluted. BOD values at other stations were estimated using the correlation with COD(Mn), which gave a high coefficient for the dry season, May, 1992 (r=0.8593), using all data at the surface and at the bottom (COD(Mn)=0.399 BOD + 0.987) (Fig. 5.2-5).

The correlation was lower in the wet season than in the dry season; r=0.5308 (COD(Mn)=0.357 BOD + 2.405). It supposedly resulted from the different and complicated composition of organic materials in the wet season : firstly a large quantity of phytoplankton was observed in the entire Bay and secondly the ratio of materials originating from rivers brought about by large river discharge was high.

BOD measured during the survey period was, however, generally higher than the COD(Mn) values. This could be attributed to the fact that $KMnO_4$-alkaline was used in the COD analysis.

Wet Season

Dry Season

Fig. 5.2- 6   Distribution of BOD in the Surface Layer

Fig. 5.2- 5   Correlation between
COD(Mn) and BOD

5.2.5 Nitrogen

(1) Total Nitrogen (TN)

Very high TN concentrations were observed in the surface layers
of the Bay; concentrations increased from the outer part toward
the inner Bay area, it was particularly high on the western side
on all occasions, although the results were missing at several
stations in the central Bay. These high TN value were produced
by the high ammonium nitrogen (NH_4-N) or total organic nitrogen
(TON)(Fig. 5.2-7).

TN decreased with the depth in all stations, and as in the sur-
face distribution lower values in the outer area and higher TN on
the northwestern side were found.

The surface TN showed very high correlation with the surface TP
(r=0.9217, TN=5.2 TP + 0.39) (Fig. 5.2-8) obtained from the both
seasons.

Nevertheless, correlation between the surface TN and the surface
TP may change seasonally and even regionally, and it is well
supposed that behavior of each nitrogen and phosphorus form (TON,
DIN, TOP and DIP) is different reflecting phytoplankton produc-
tion mechanism.

(2) Total Organic Nitrogen (TON)

TON in the surface layers varied according to the station and the
sampling time (0.28 - 3.91 mg/l), but the range of variation was
relatively small compared to other nitrogen forms. It generally
decreased with depth reflecting phytoplankton occurring in the
upper layer and the minimum value in the deeper layers was 0.22
mg/l.

TON was usually the main constituent of TN having a ratio to TN
of 35 to 99 % with a mean of 77 %, however a very high concentra-
tion of HN_4-N would result in the high TN. The mean ratio in each
tide of each month was high irrespective of the month or season.

Particulate organic nitrogen (PON) may be mainly composed of
planktonic-N, hence the high TON reflected the larger amount of
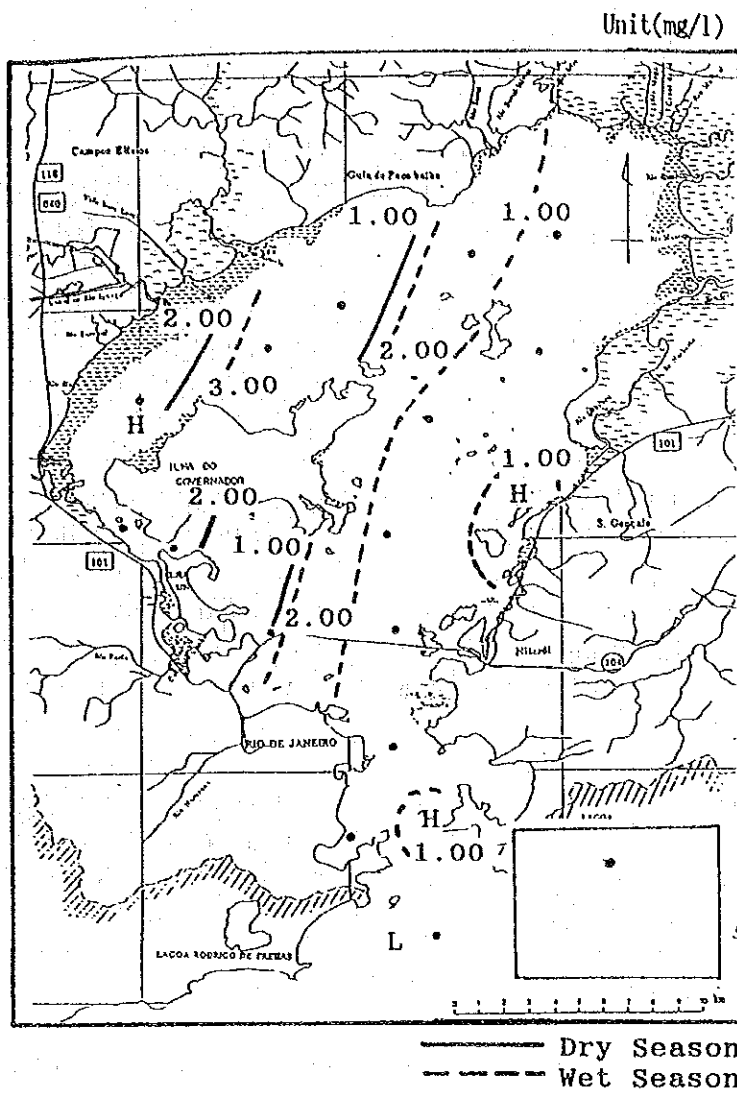phytoplankton, although a direct correlation was not obtained
between Chl-a and PON.

Unit(mg/l)

—————— Dry Season
— — — — Wet Season

Fig. 5.2- 7   Distribution of Total Nitrogen in the Surface Layer

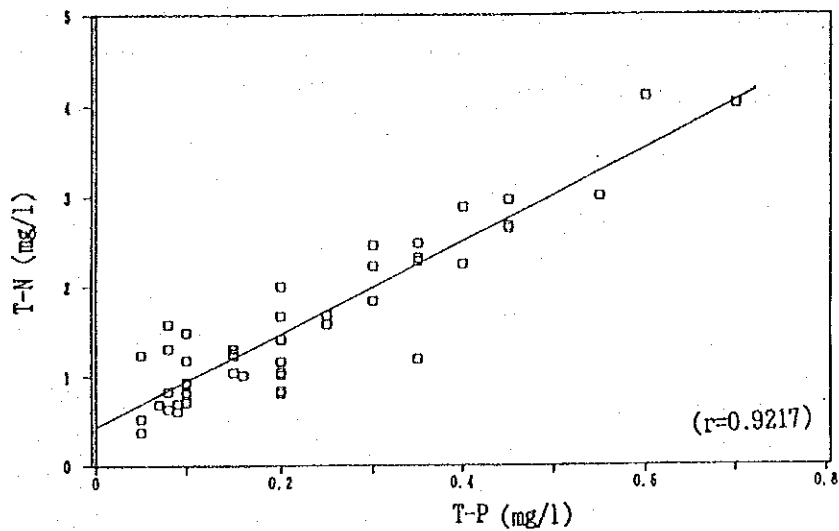(r=0.9217)

T-N (mg/l)

T-P (mg/l)

Fig. 5.2- 8   Correlation between TN and TP in the Surface Layer

(3) Dissolved Inorganic Nitrogen (DIN)

The distributional pattern of dissolved inorganic nitrogen (DIN) was generally similar to TN; high on the western side and low on the northeastern side and outer part of the Bay (Fig. 5.2-9).

However, values covering a wide area from the northeast to the central Bay area, were lower than those near and at the outer part of the Bay, in the wet season. This was attributed to lower NH_4-N.

DIN was higher in the dry season than in the wet season, showing different tendencies from other water quality properties.

Of the DIN, nitrite nitrogen (NO_2-N) values were very low (0.000 - 0.060 mg/l) throughout the survey period, and sometimes it was not detectable in the outer Bay and very low on the northeastern side (Fig. 5.2-10).

Among DIN, nitrate nitrogen (NO_3-N) values were low and similar and NO_2-N values were always negligibly small. The distribution of NH_4-N, therefore, was similar to that of TN and DIN as well, in both seasons; much higher values were observed at Stns. 7, 8, 9, 13 and 19, especially at St. 13 where it was always considerably high from 0.70 to 1.75 mg/l (Fig. 5.2-8).

On the western side, urban type rivers badly polluted by domestic wastewater (Rio Meriti, Rio Iraja and Rio Sarapui), are seriously affecting nitrogen distribution, causing uneven NH_4-N distributions.

It appears that despite NO_3-N being uptaken evenly in all areas of the Bay, wide range of NH_4-N values shows that NH_4-N is selected during phytoplankton production as a nitrogen source when it exists together with NO_3-N in the water.

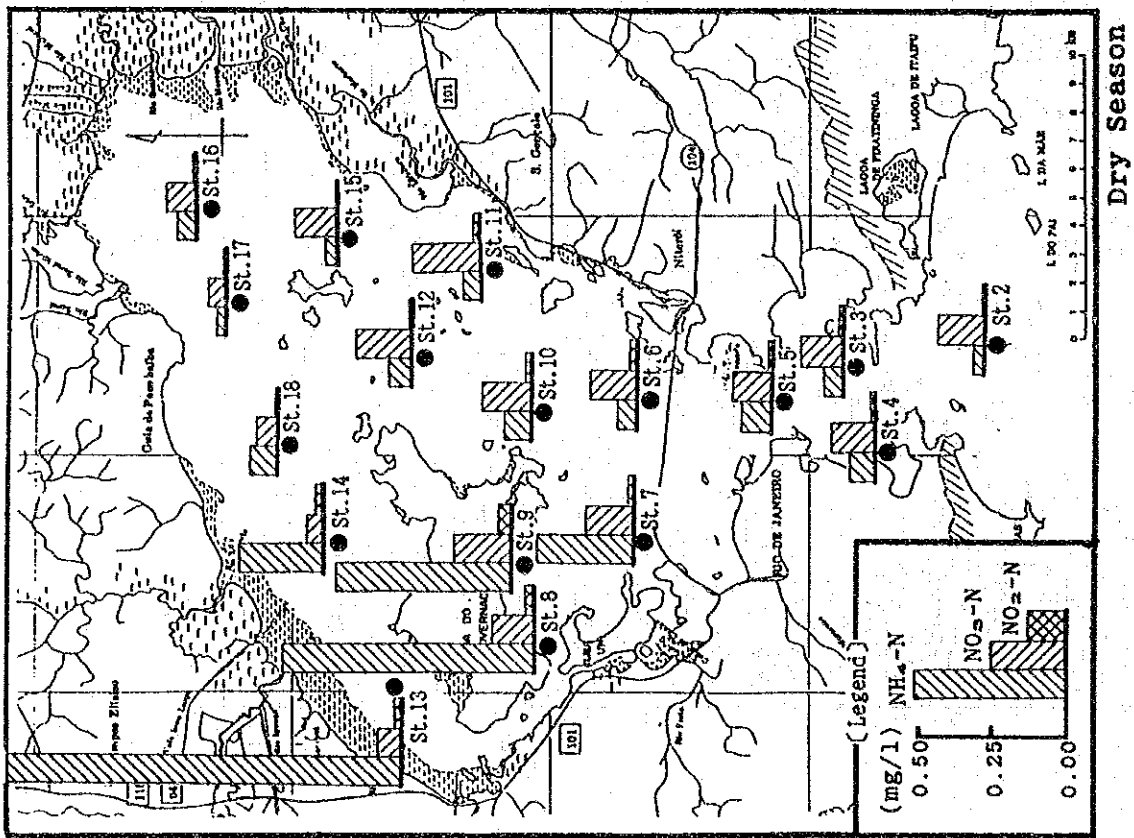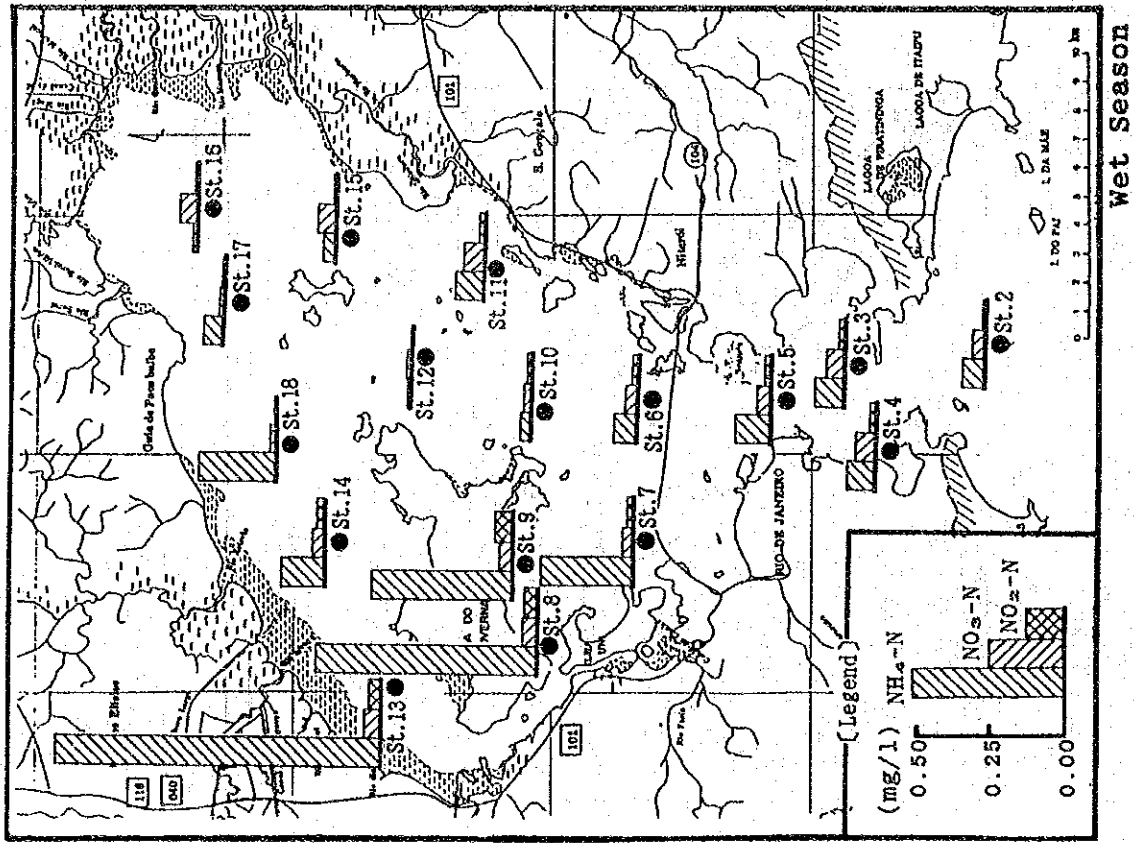Fig. 5.2- 9 Distribution of DIN in the Surface Layer

Fig. 5.2-10　Distribution of each Nitrogen Form in the Surface Layer

5.2.6 Phosphorus

(1) Total Phosphorus (TP)

TP at the surface varied widely (0.02 - 0.60 mg/l) on all occasions showing a tendency to be lower in the outer area and near the mouth, and higher on the eastern side of the Bay, as was observed with the TN distribution. Very high values were obtained at St. 13 (0.25 - 0.55 mg/l) (Fig. 5.2-11).

The values of a wide area, from the northeast to the central Bay area, in both seasons, were only slightly higher than those obtained near the mouth.

TP concentrations are mainly attributed to POP, which is mostly composed of phytoplanktonic phosphorus, except when PO_4-P values are very high. This corresponds well with the fact that TP values are higher in the wet season and that they decrease with depth in all cases.

(2) Total Organic Phosphorus (TOP)

TOP is composed of dissolved (DOP) and particulate organic phosphorus (POP), although POP was not determined directly during survey period but calculated through TOP-DOP.

As mentioned above, POP must be correlated with the amount of phytoplankton. A high degree of correlation was not found between POP and Chl-a (r=0.378), however, every time Chl-a is high, high POP was obtained; in the northwestern and western sides in May, and at many stations in November.

(3) Dissolved Inorganic Phosphorus (DIP or PO_4-P)

DIP or PO_4-P in the surface layer varied widely according to the station, from 0.00 to 0.30 mg/l (Fig. 5.2-12).

At several stations in both the outer and inner Bay areas on the northeastern side, PO_4-P was not detected (0.00 mg/l) in the first survey, particularly at high tide when it was not detected at seven stations.

It is considered that this condition in the outer Bay area, at Stns. 2 and 4, may possibly be caused by the penetration of offshore water which has a low concentration of PO_4-P.

On the other hand, in the inner Bay area, at Stns. 10 and from 14

to 18, the quick uptake of PO_4-P by the condensed phytoplankton population could be the cause. It was thought that stratification usually develops in the inner Bay area, causing phytoplankton to condense and inhabit the upper layers.

In the second survey, PO_4-P was only undetected once (St. 10, high tide), while it was detected on all occasions in the third survey.

The mean values for May and November were significantly lower than those for June, seeming to reflect the higher Chl-a concentrations found in May, especially in November; these low concentrations of PO_4-P is due to the active uptake for photosynthesis.
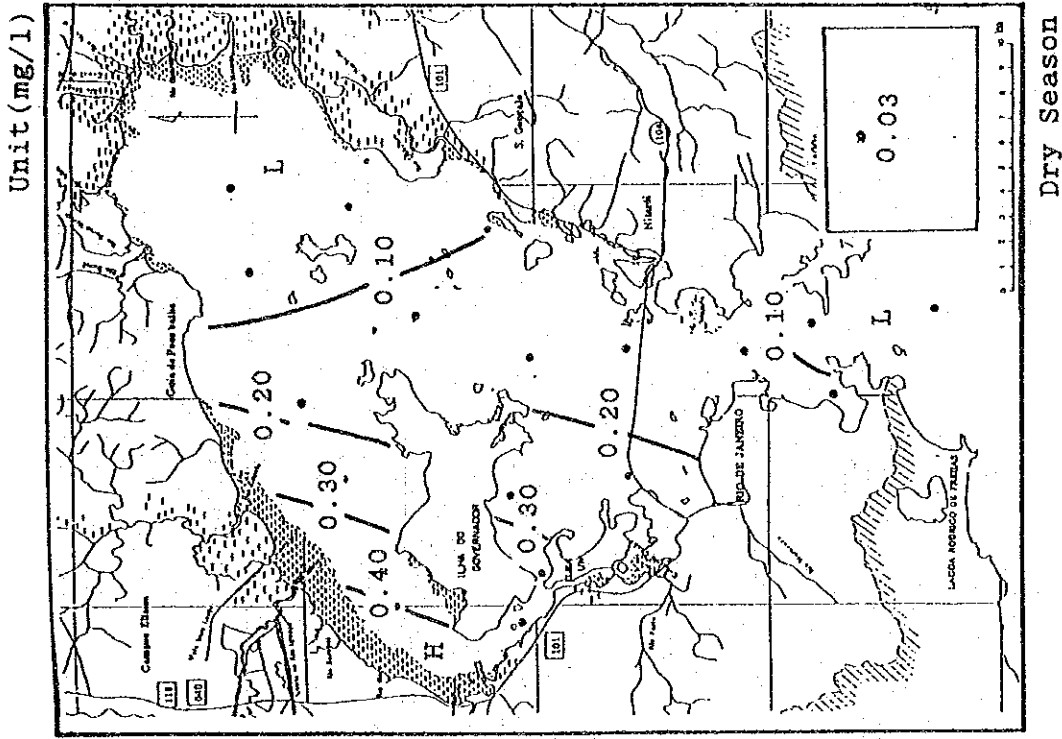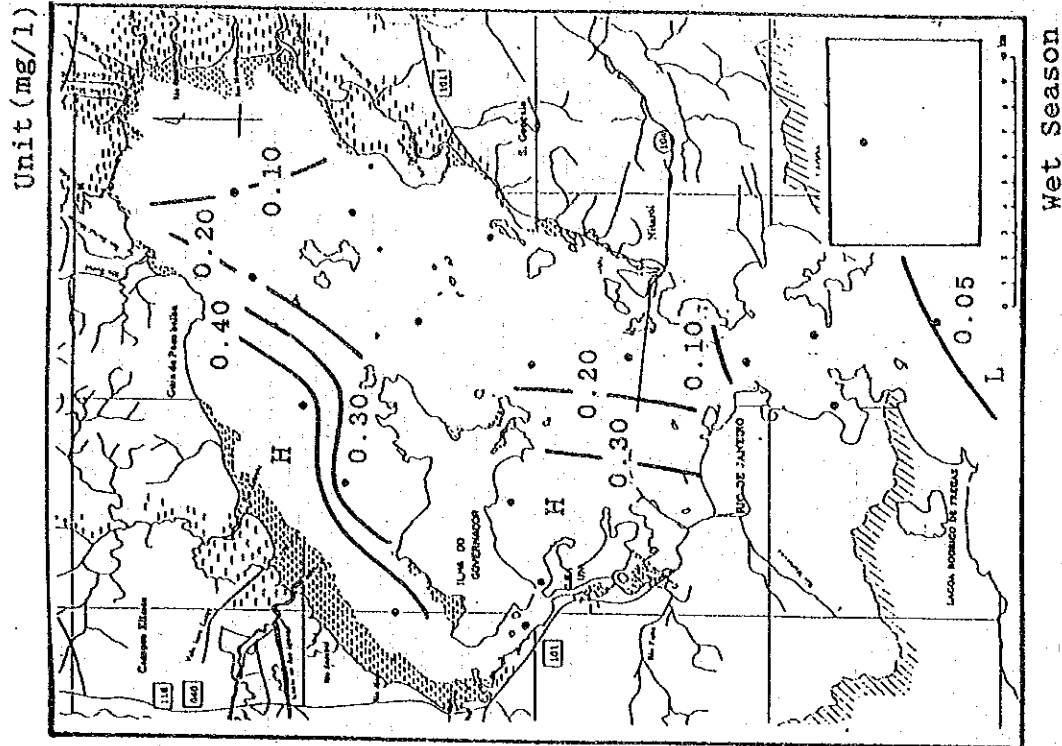
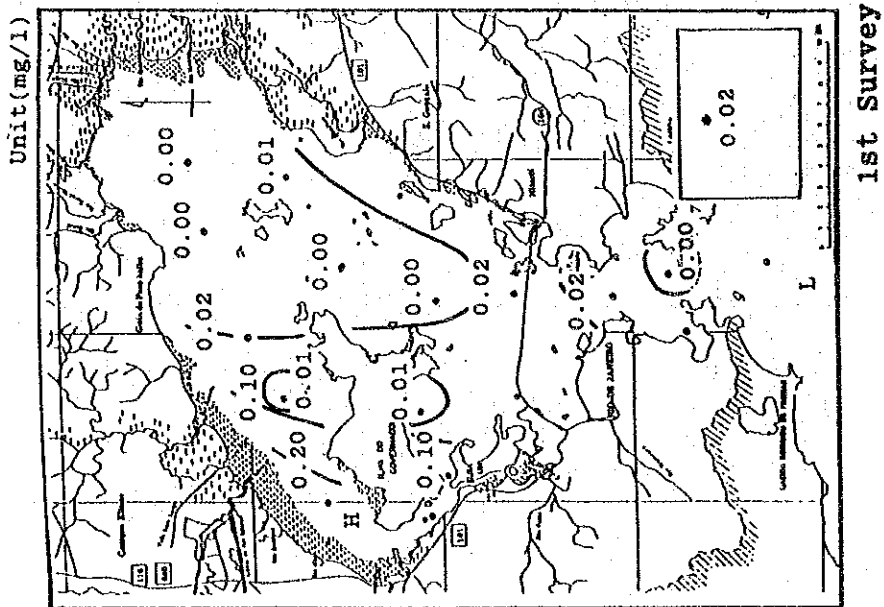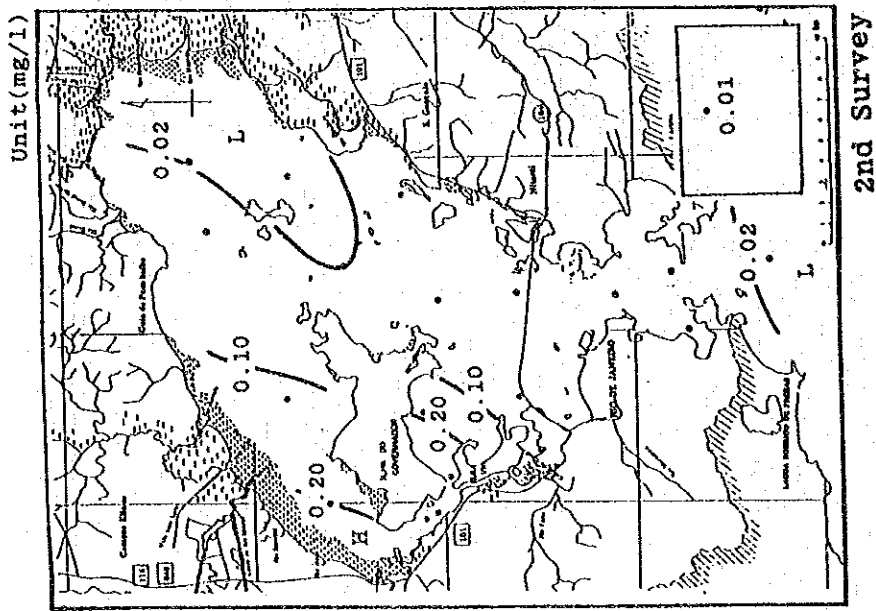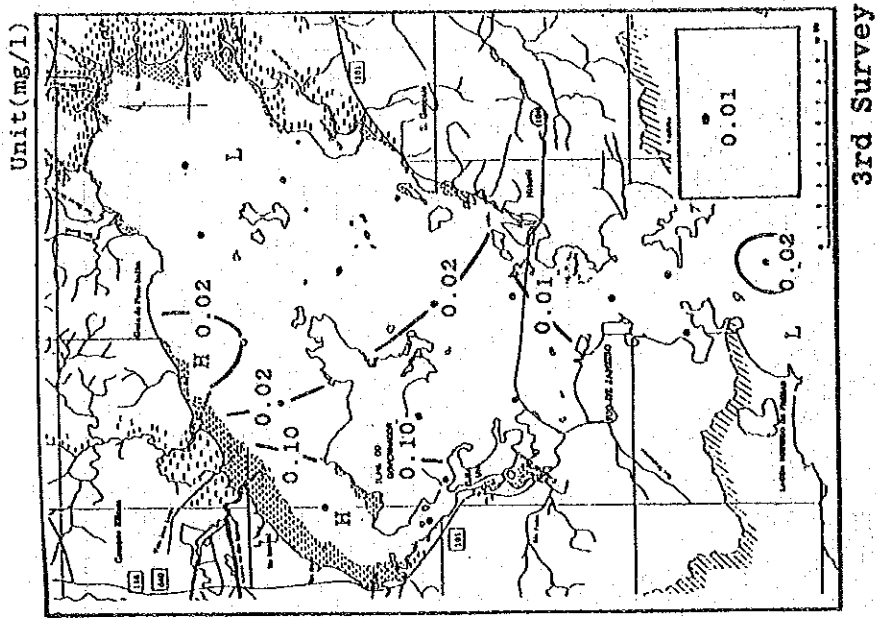Fig. 5.2-11 Distribution of Total Phosphorus in the Surface Layer

Fig. 5.2-12   Distribution of DIP in the Surface Layer

5.2.7 Suspended Solids (SS)

As found on the distribution of other items, SS tended to increase from the outer area toward the inner Bay area in the dry season. Higher SS values were found consequently in the northeastern side and the northwestern side (Fig. 5.2-13).

SS also increased toward the inner Bay in the wet season although only slightly, and higher values were observed in the southern part of Ilha Governador at Stns. 7, 8 and 9.

Contrary to other values, SS values in the dry season were generally higher than in the wet season, except in Stns. 5, 7 and 18.
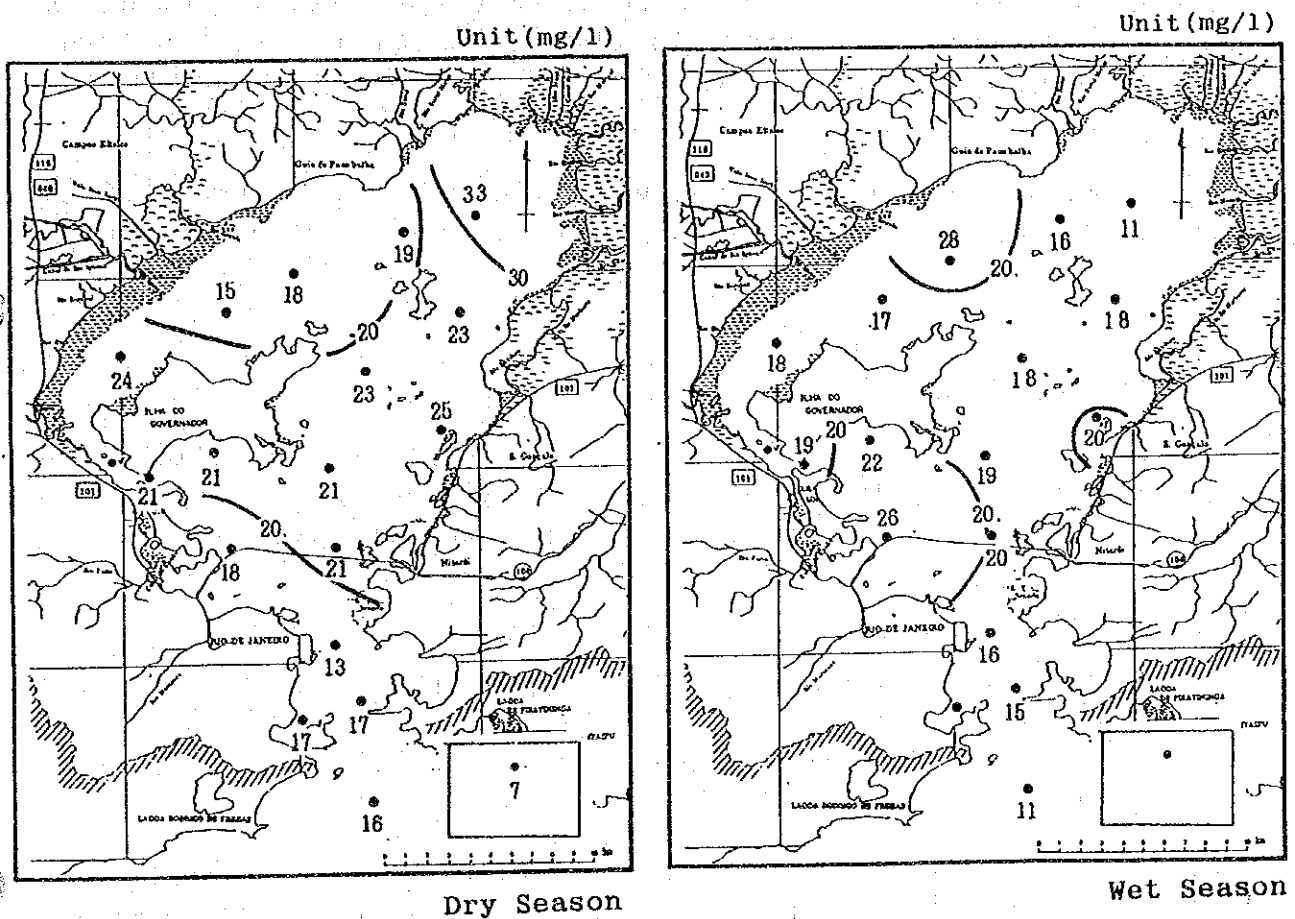
Fig. 5.2-13   Distribution of Suspended Solid in the Surface Layer

5.2.8 Phenols

Low concentrations of phenols at the surface or the bottom were observed (0.002 mg/l) at only 4 stations in May (Stns. 3, 6, 8 and 16). Values lower than the analytical limit (<0.001 mg/l) were obtained at all other stations in June. There seems to be no present problems regarding Phenols at the moment.

5.2.9 Cyanide (CN)

CN was not detected at all the stations.

5.2.10 n-Hexan Extracts

n-Hexan extracts were measured at several stations, twice in the low tide of the spring tides in May and November. It was lower than analytical limit (4 mg/l) at all sampled stations in May (dry season).

In November (wet season), however, higher values from 4 to 16 mg/l were obtained at 7 stations, which were located around the mouth and inner part of the Bay.

5.2.11 Heavy Metals

All heavy metals, except iron (Fe) and nickel (Ni), were measured at all stations in all three surveys, in the surface layers and in the bottom layers, but only once, in the mornings.

(1) Cadmium (Cd)

Cd values were lower than the analytical limit (<1.0 μg/l) at all stations.

(2) Lead (Pb)

In the wet season, Pb values were detected only at the surface of St. 15 (39.0 μg/l), which is lower than the standard permissible concentration for human health (100 μg/l).

On the contrary, however, high concentrations ranging from 5.0 to 49.0 μg/l were detected at many stations in the dry season. Very high values of 185.0 and 170.0 μg/l were recorded at St. 14 (5.0 m) in May and St. 8 (7.0 m) in June, respectively.

High Pb concentrations have been measured in the past in the northwestern side so it was probable that similar results would be obtained in these measurements.

(3) Copper (Cu)

Cu values were detected at many stations but in quite low concentrations of a little higher than the analytical limit of 2.0 μg/l. On some occasions 13.0 to 24.0 μg/l were observed.

(4) Chromium (Cr)

Cr values were not detected (<10 μg/l) at all stations in all occasions.

(5) Total Mercury (T-Hg)

T-Hg was not detected (<0.1 μg/l) on any occasion, except at St. 12 in June: 1.60 μg/l in the surface layer and 0.10 μg/l at the bottom.

The standard permissible contraction for human health is 0.5 μg/l, therefore these values obtained in the Bay water are not high. However, organic-mercury, particularly alkylic-mercury is concentrated in aquatic organisms with high magnification, consequently it maybe dangerous if humans take in this highly concentrated mercury.

(6) Iron (Fe)

This was measured once in November at the low tide of the spring tide.

The values were generally small except for high values observed at several stations: 460 μg/l at St. 4, 550 and 440 μg/l at Stns. 15 and 16.

The concentrations were usually higher in the surface layers than at the bottom.

(7) Nickel (Ni)

Ni was also measured only once at the same sampling occasion as
Fe was measured. All values were lower than the analytical limit
of 5.0 μg/l.

(8) Zinc (Zn)

Although Zn values were observed at many stations during the
three surveys, the concentrations were not higher than the ana-
lytical limit of 10 μg/l in almost all cases except for several
measurements that gave 70, 80 and 130 μg/l. These concentrations
are not harmful at the moment.

5.2.12 Polychlorinated Biphenyl (PCB's)

PCB's were not detected (<0.01 μg/l) at any station, although they
were analyzed for only in the low tide of the May spring tide.

5.2.13 DDT and its Delivatives

All forms of pp'DDT, pp'DDE and pp'DDD were not detected (<0.001
μg/l) at any station, when measured on the same occasion as PCB's
were measured.

5.2.14 Coliforms

The distributions of both of fecal and total coliform groups were higher on the western side than on the eastern and southern sides (Fig. 5.2-14).

Very high numbers were observed at Stns.   7, 8, 9, 13, and 19, and relatively high numbers were found at St. 4. As mentioned in the TN section(5.2.5), domestic wastewater is directly discharged around these areas into the rivers, resulting in these high coliform distributions.

The values were generally higher in the wet season than in the dry season, and higher in low tide than in high tide. Both aspects indicate the significant influence of human activities.

Fig. 5.2-14   Distribution of Fecal Coliforms
in the Surface layer
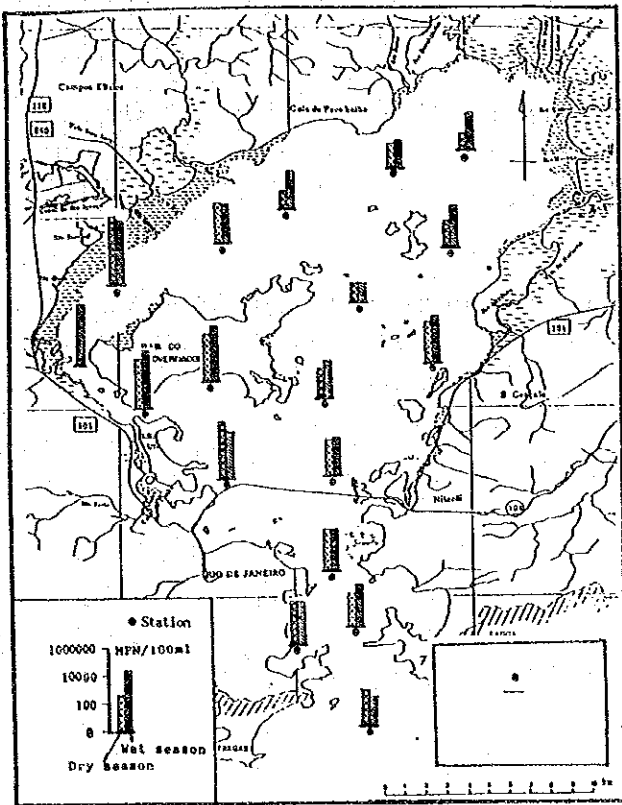
Table 5.2- 1

Mean Number of Fecal Coliforms
in the Surface Layer (MPN/100ml)

St.	1st Survey	3rd Survey
1	*2	*0
2	250	235
3	205	1050
4	800	750
5	1750	2650
6	352	230
7	*1620	9500
8	20500	27000
9	4900	16000
10	47	550
11	1620	2050
12	90	*90
13	105000	9350
14	1555	700
15	25	2535
16	26	440
17	119	165
18	25	475
19	–	*30000

* Measured once

5.3 Water Quality Conditions in Small Bays and Coastal Areas

This survey was carried out on April 1, 1993, the transitional period between the wet and dry seasons. Although it was fine for one week before this survey, low salinity was obtained in the upper layers, just like in the wet season.

Generally water in Jurujuba Bay, except for the outer part of this bay, Centro de Ilha do Eengenho and Rio Porto was of very bad quality. The values of the properties analyzed to determine water quality were similar to those obtained in the inner part of the Guanabara Bay in the wet season, the period when the Bay is most polluted and the area which is most polluted (**Fig. 5.3-1**).

Particularly at St. 37 (in Jurujuba) concentrations of all the water quality parameters were very high; COD(Mn) was 11.0 mg/l in the surface layer and TP was 0.6 mg/l. Chl-a was also extremely high, 132.3 μg/l, causing high DO, 211 % at the surface, and high TN (3.04 mg/l). DO on the bottom was low of 21 % of saturation.

Because of the location, the water around this station is affected by the numerous activities of the large suburb of S. Francisco in Niteroi, and the inflow of the highly polluted river running through it.

Results indicate that the water in the inner part of Botafogo is not seriously polluted yet (St. 33). The outer part of Jurujuba in contrast to the inner part and other areas is also not seriously polluted yet.
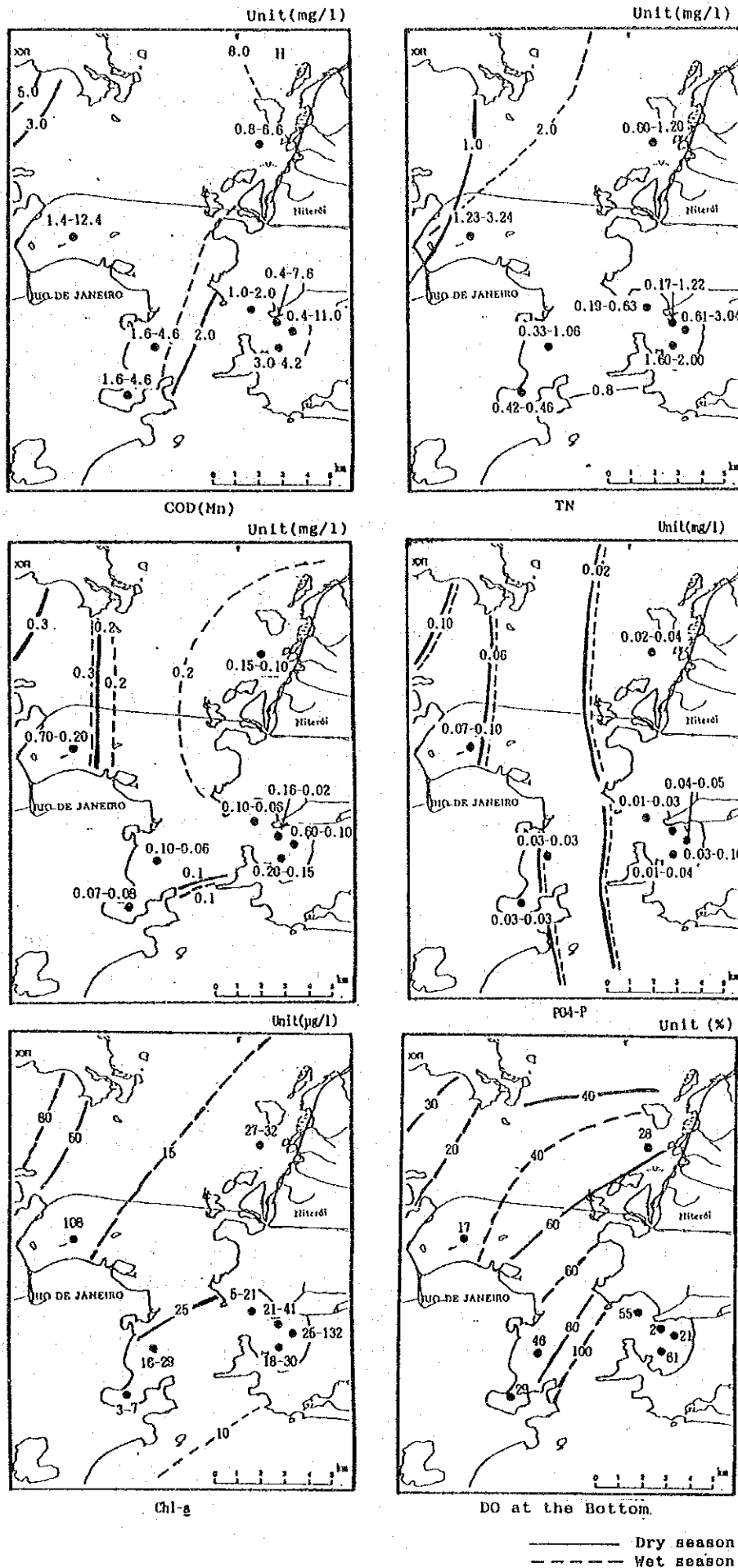
Fig. 5.3- 1   Water Quality Conditions in Small Bays and Coastal Areas

5.4 Sediment Quality

5.4.1 Surface Sediments

To understand the contaminated conditions of the sediments distributed in Guanabara Bay, chemical analysis was carried out on surface samples collected from 15 stations (Fig. 5.4-1).

Sampling was carried out from June 4 - 6 1992. The samples were analyzed using the "Standard Method - For the Examination of Water and Wastewater", 16ed. The concentration and distribution pattern of each parameter are shown in Fig. 5.4-2.

The silt and clay contents of the sampled surface sediments, water content, VS, COD(Cr), KN, TP contents as well, are highly concentrated in the inner Bay, eastern side of Fundao Island and the small bay area of Botafogo, while concentrations tended to decrease on the southern side of Governador Island, the central Bay area and near the Bay mouth.

The areas where the values of the above parameters were high almost coincided with: the mouth areas of rivers with large pollution loads and the areas where the upper layer has high organic and nutrient concentrations and is low in flow velocity. Secondary pollution caused by internal production accelerates sediment contamination in these areas.

On the other hand, the areas (central Bay area and Bay mouth area) where the values were low were those far from the mouths of rivers and were observed to have upper layers with low organic and nutrient concentrations and high flow velocities.

Concentration of organic material and nutrients in the sediment is considered to be strongly controlled by the distance from the river mouth, concentration in the upper layer, and flow velocity and direction in the Bay. However, areas observed to have low values of the above parameters (near the canal at the southern side of Governador Island, and near St. 11 in the eastern Bay area) were identified as areas near the mouths of rivers with large pollution loads, upper layers with low organic content and concentrations and high flow velocity. It was concluded that flow velocity affects the formation a lot more than the other factors mentioned.
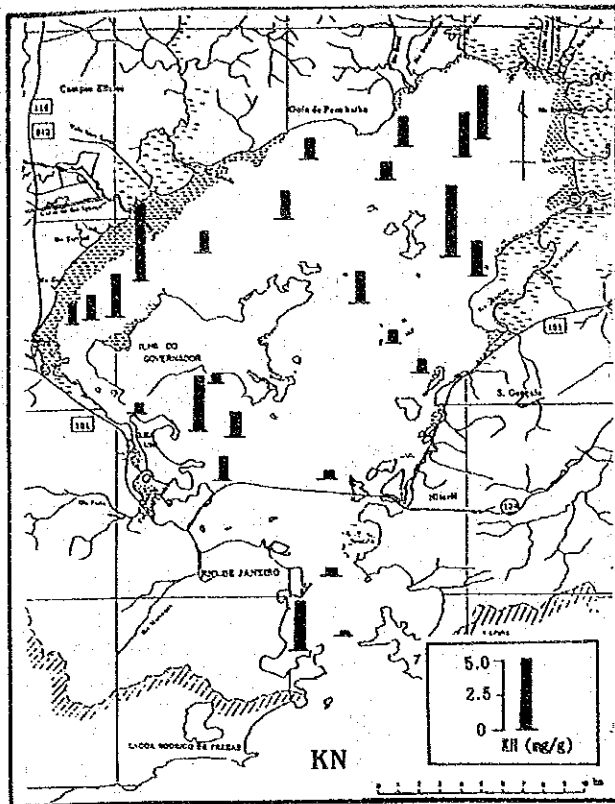
Heavy metal concentrations in surface sediments, with the exception of T-Cd, were observed to be high in the western inner Bay area and on the eastern side of Fundao Island, but inclined to decrease towards the central Bay area and the Bay mouth.

According to the results of a Study on the Source of Pollution in the Guanabara Bay Basin, the inflow from the basins of the Sarapui and Iguacu rivers into the western inner Bay area contained Zn, Cr, Cu and Pb discharged by factories. Further, a river water quality survey conducted by FEEMA from 1980 to 1986 indicated high concentrations of Cr and Hg in the inflow of the Sarapui and Sao Juan de Meriti rivers to the same area. However, the same survey repeated in 1987 - 1989 showed reduced levels of concentrations. The concentrations of these metals were observed to be also low during the River Survey conducted in this study.

Conclusively, heavy metal concentrations detected before 1986 are thought to have accumulated near the river mouth east of Fundao Island and in the western inner Bay area.

Toxic chemicals, DDT its derivatives (op'DDE, pp'DDE and pp'DDD), PCB's and CN were not detected in the Sediment Samples.

Fig. 5.4- 1   Bed Surface and Core Sediment Sampling Stations

Fig. 5.4- 2(1)   Distribution of Characteristics of Bed Sediment
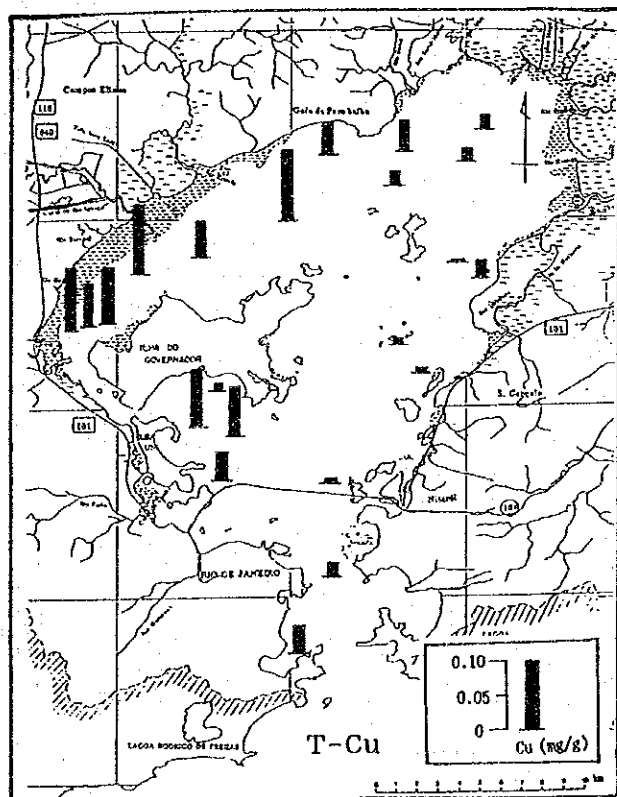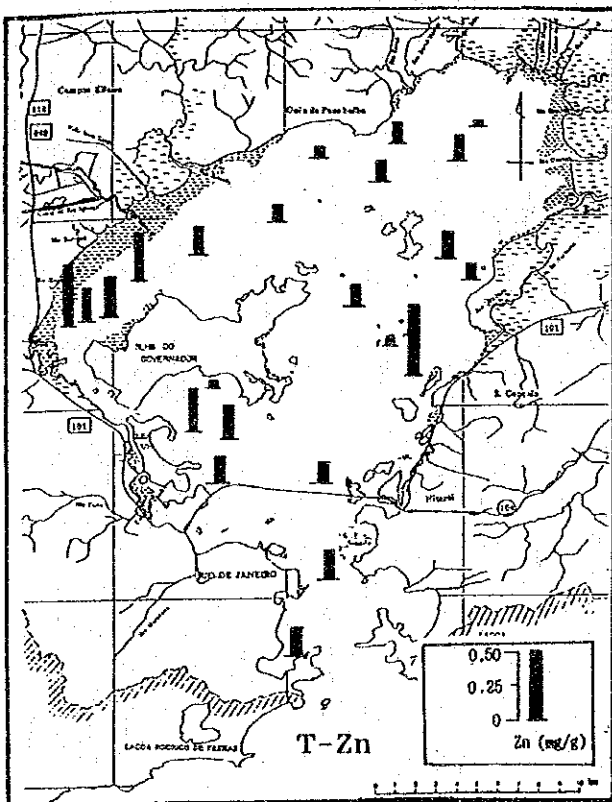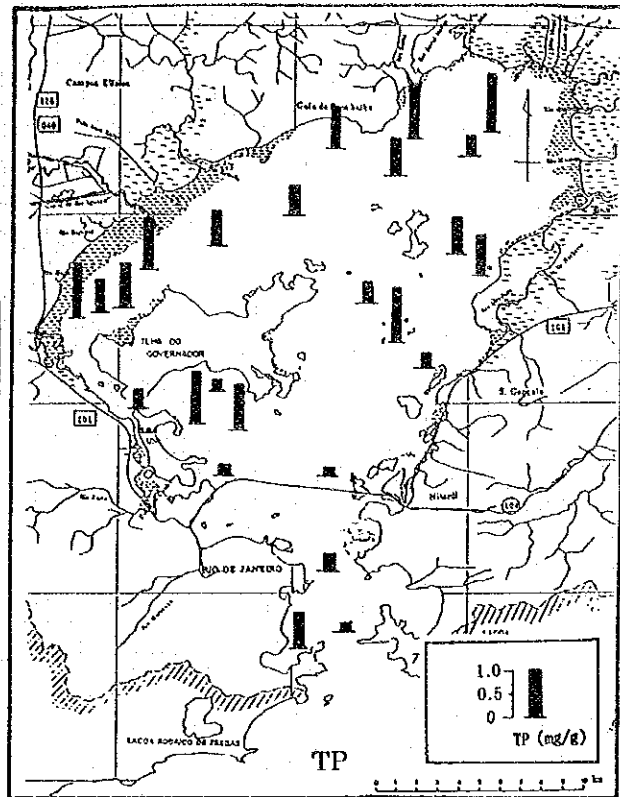
Dry weight basis

Fig. 5.4- 2(2)   Distribution of Characteristics of Bed Sediment
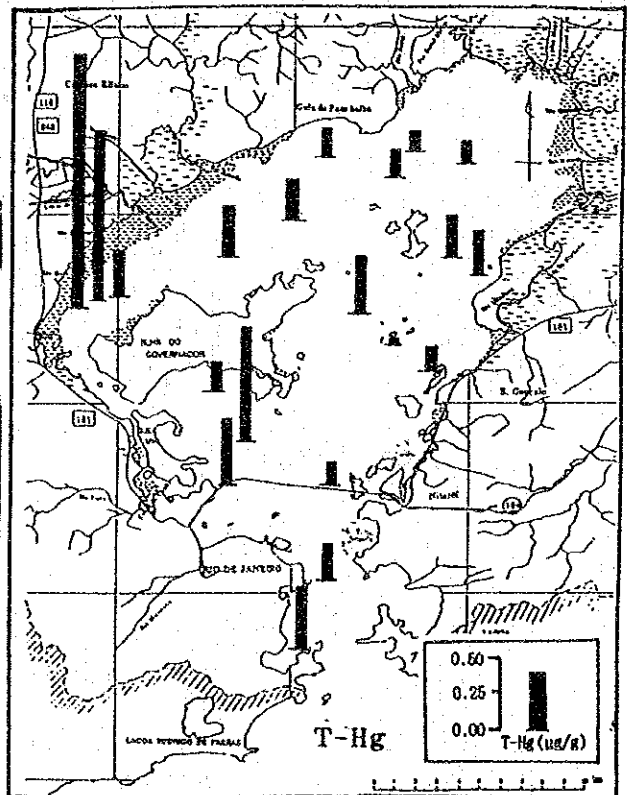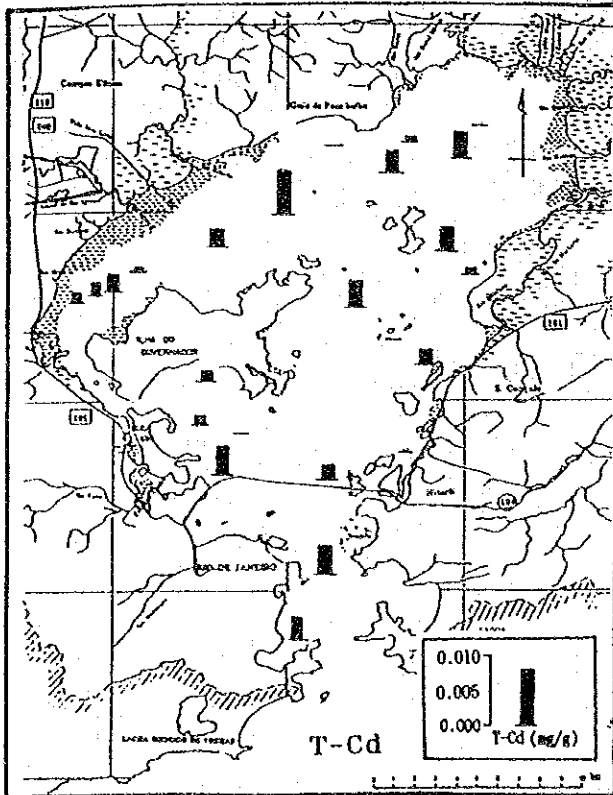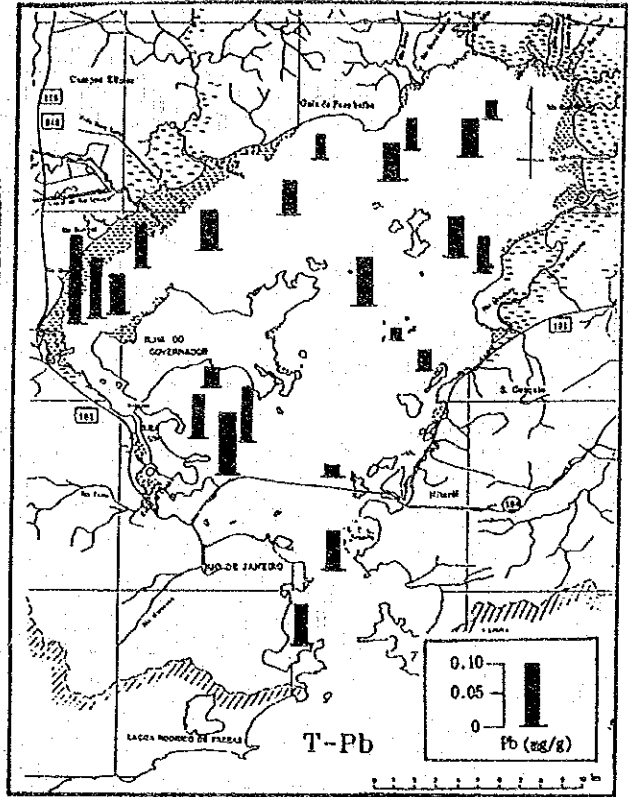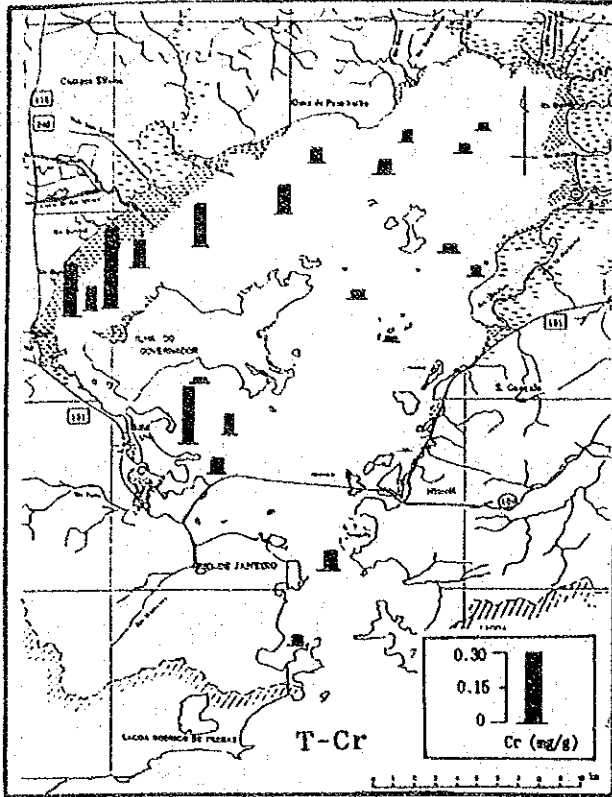
Dry weight basis

Fig. 5.4- 2(3) Distribution of Characteristics of Bed Sediment

5.4.2 Vertical Distribution of Sediment Quality

Core sampling was carried out in October 26, 31, 1992 in 4 stations, illustrated in **Fig. 5.4-1**.

A core sampler with a diameter of 3.8 cm was used and the lengths of the samples taken from each station are shown below:

Station 23	97cm
Station 24	126cm
Station 25	160cm
Station 26	140cm

Analysis was carried out in accordance with standard methods (16 ed.). The distribution of the items analyzed is shown in **Fig. 5.4-3**.

With the exclusion of Station 23, the vertical changes of concentrations of COD(Cr) and TP indicated similar tendencies, which were observed to be higher between 0 and -50 cm than below -50 cm. This is attributed to the fact that the majority of the COD (Cr) and TP flow in particle form; both elements have similar sedimentation behavioral patterns.

Water content and KN concentration at each station decreased with depth similarly mainly due to the compaction of pore water.

The T-Zn, T-Cu, T-Cr, T-Pb, T-Cd and T-Hg concentrations at Station 26, which is located in the western inner Bay area, were considerably higher than at other stations. The change in their vertical distributions are low near the surface layer, higher from 10 to -30 cm, and lower further down. This condition suggests the discharge of heavy metals, mainly prior to 1986 as referred to in 5.4.1. Due to the reduced discharge of heavy metals in recent years, their concentration in the surface layer has decreased.

Sedimentation rate in the inner Bay area was observed to be approximately 7 times faster in layers shallower than -20 to -50cm than in deeper layers.

The areas observed to have high COD(Cr), KN and heavy metal concentrations coincided with areas observed to have fast sedimentation rates, which can be attributed to the voluminous dis-

charge of pollutants when industrial activities were thriving and development in the catchment area was at peak.

According to the results of this study and the previous study carried out by FEEMA, Hg concentrations in the sediments of Guanabara Bay was one fifth the Japanese standard value for sediments in rivers and lakes (25 mg/kg). The measured PCB's concentration was 1/100 the Japanese standard value for sediments (10 mg/kg).

The concentrations of heavy metals and chemical contaminants in fish and shellfish were lower than the standard values established by OMS and The Food and Drug Administration, as shown in studies by the UFRJ, FEEMA and IBAMA.

Consequently, sediment contamination through the food chain is presently not affecting humans.
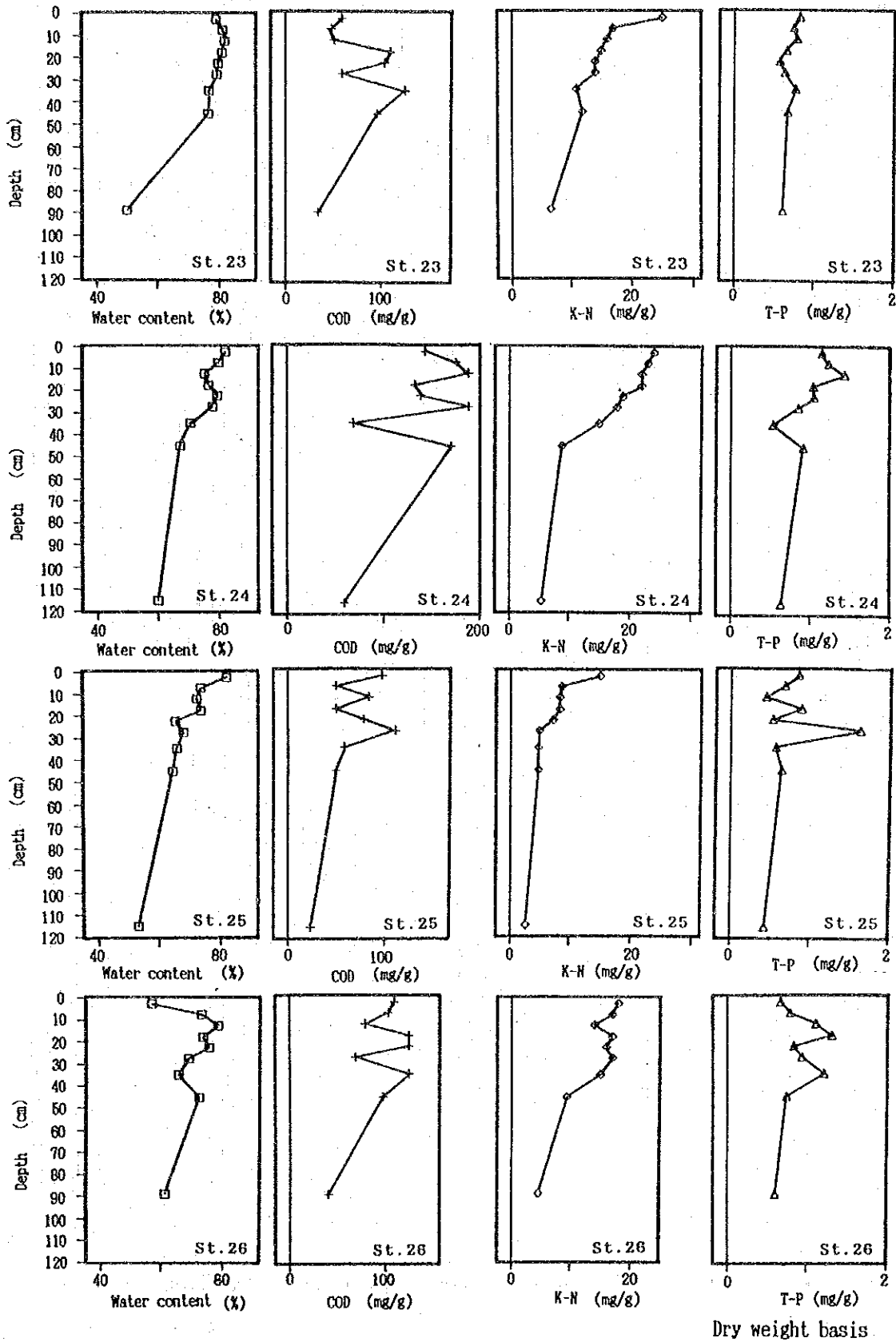
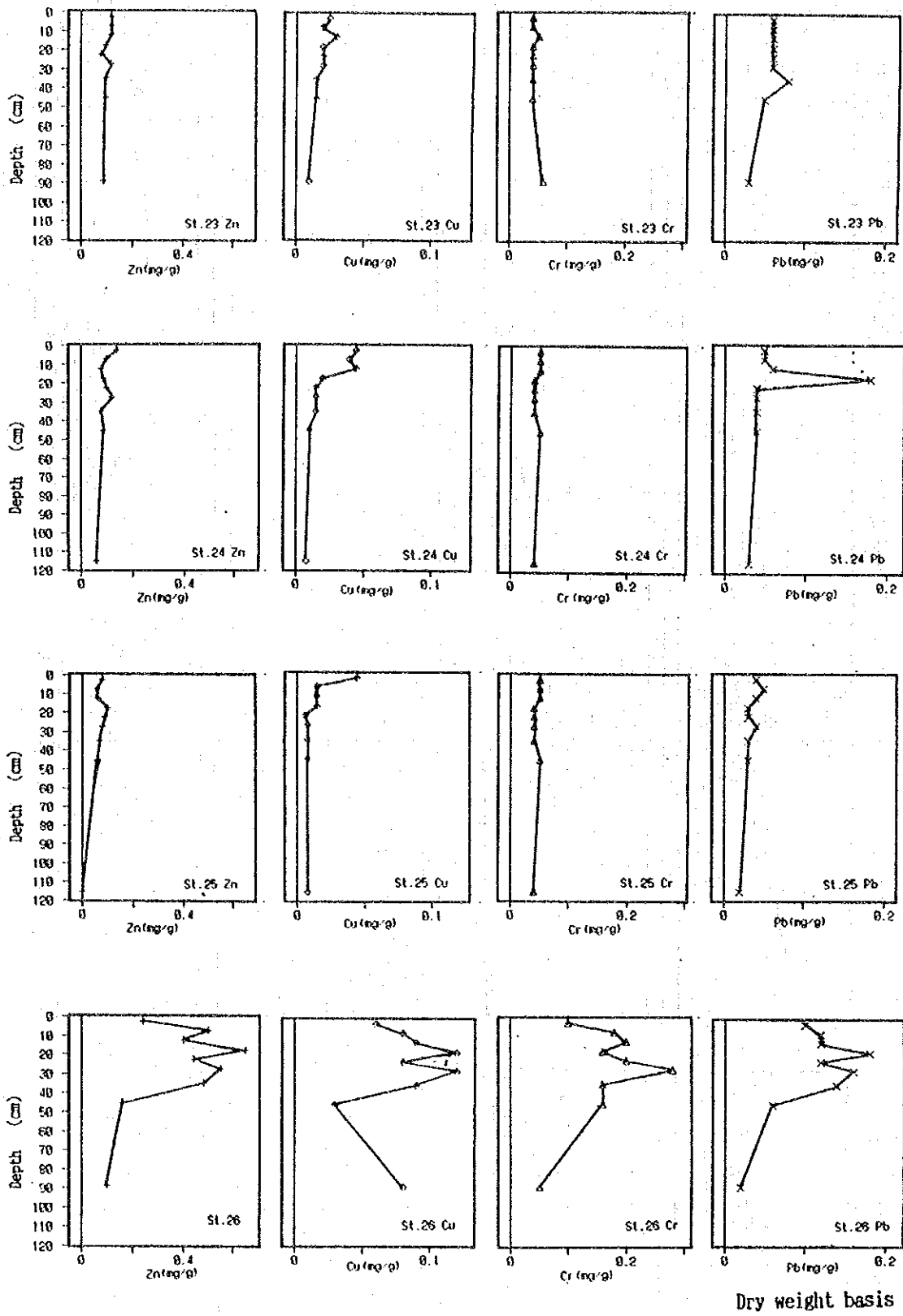Fig. 5.4- 3(1) Vertical Change of Characteristics in the Core Samples

Fig. 5.4- 3(2)· Vertical Change of Characteristics in the Core Samples
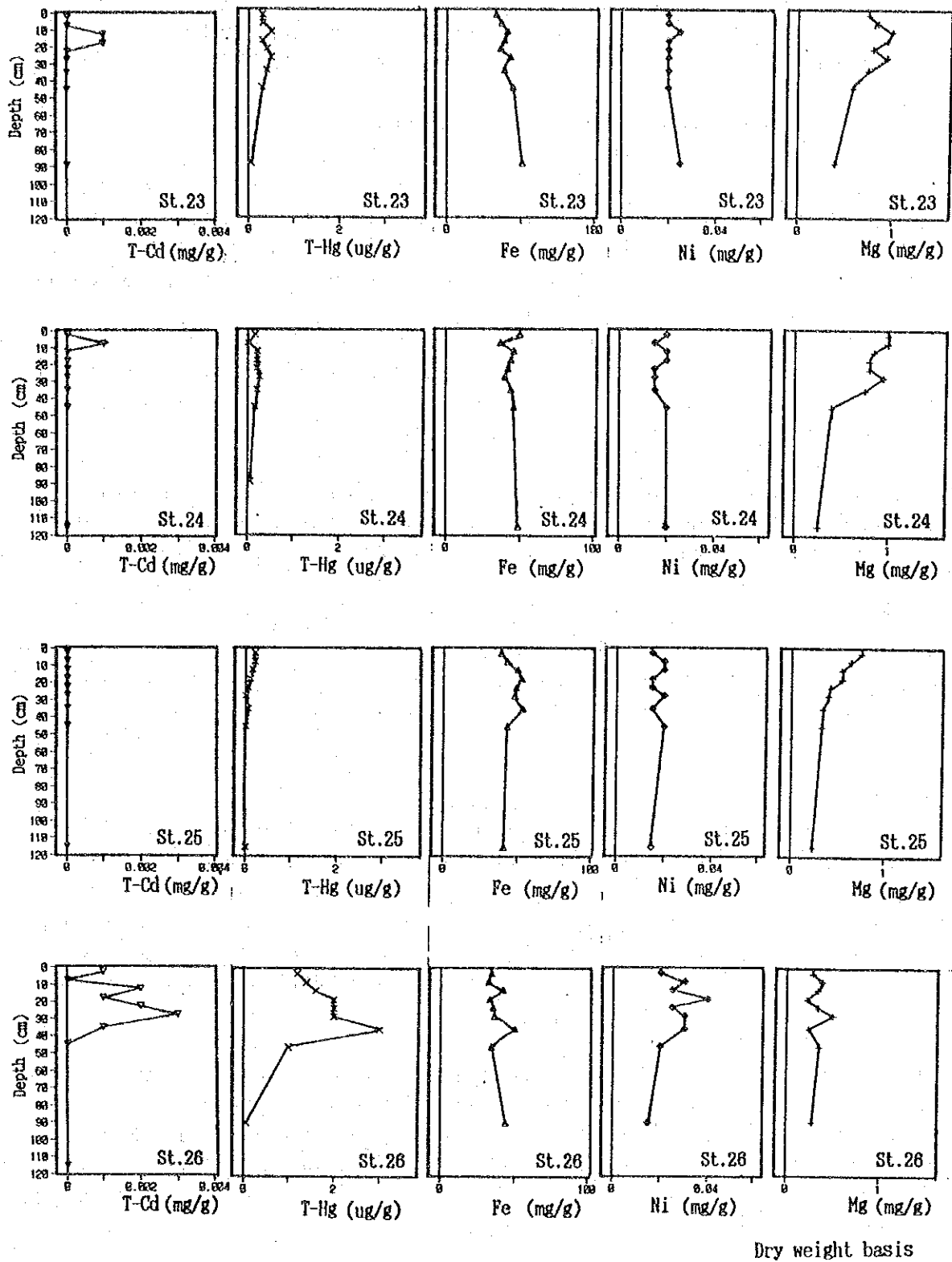
Fig. 5.4- 3(3)   Vertical Change of Characteristics in the Core Samples

5.5 Experiments on Primary Production, Release Rate, Settling Rate and Oxygen Consumption Rate

5.5.1 Primary Productivity Measurement

When the organic pollution mechanism in the Bay is considered, the direct pollution introduced by inflowing organic material through the rivers and the internal production (secondary organic pollution) caused by eutrophication should be taken into account.

The eutrophication has been accelerated dominantly by the changing environmental conditions surrounding the Bay which have increased the flow of nutrients. International production increases with accelerated eutrophication.

Internal production (primary production) was measured as an indicator of eutrophication in the Bay. The results were used to determine the material cycle, the material balance, and the pollution mechanism in the Bay.

The phytoplankton species composition, euryhaline in the inner Bay, and its physiological condition causes different levels of productivity in different areas of the Bay.

(1) Material and Method

Primary productivity measurement were carried out in November, 1992 (Measurement-1, wet season) at 6 stations (St. 27 - St. 32). These stations were selected to represent each sub-area according to degree of water pollution, and in April and May, 1993 (Measurement-2, dry season, St. 50 - St. 55) also at six stations, of which the locations used were slightly different from in the wet season (Fig. 5.5-1).

Clear and dark oxygen bottles were used during the both measurements in-situ; water samples were collected at 0.1 m, at the Secchi-disk reading depth and at the depth where the light intensity was 1 % of the surface for Measurement-1. While for Measurement-2, 0.1 m, and at the depths with 10 % and 1 % light intensity of that at the surface.

Clear and dark oxygen bottles were filled up with water sampled from each depth then hung and left at their original depths for basically 2 hours (Fig. 5.5-2).

Measurement-1 was carried out in the main between 11:00 to 13:00. The incubation time in Measurement-2 was generally between 6:00-9:00, 9:00-11:00 and 11:00-13:00, then produced DO was integrated.

The net primary productivity was calculated by the differences of oxygen concentrations in-situ at the original depths and the concentration at the starting time in the clear bottles after incubation.

The respiration rate measurement method for the dark bottles was the same as for the light bottles.

Net productivity per unit area was calculated by integrating DO production from the surface to the bottom of the euphotic layer, which was, generally, the depth with 1 % surface light intensity.

Productivity per day was then computed for 12 hours.

Measured DO production was converted to carbon using the factor of 0.28 according to the stoichiometric formula for photosynthesis and respiration of phytoplankton.

(2) Results of the Measurement

Both production per unit Chl-a and unit water volume at each station showed a tendency to decrease with depth.

Production per unit Chl-a in Measurement-1 at the Secchi disk depth was from one third to three quarters of that at the surface except at St. 29 where it was only one tenth of the surface value.

Despite very high production per unit Chl-a per hour at St. 50 (Jurujuba) in the surface layer, quite low production was observed in the lower layers. High productivity in the surface layer may be attributed to the high nutrient supply from the polluted rivers and the large amount of direct inflowing loads which were detected on other occasions. On the other hand, this high production of phytoplankton in the surface layer may inhibit production in the lower layers.

Net productivity per unit area a day (total production within the euphotic layer per unit area a day) and net productivity per unit Chl-a in the surface layer at St. 28 were a lot smaller than at other stations in spite of the higher Chl-a, extremely high on some occasions, usually observed around this area. This was mainly because light intensity was very weak during the survey period (300 lux in the surface layer) and the shallow depth (about 3 m) (Fig. 5.5-3 and Table 5.5-1).

Net productivity at each station per unit area a day was slightly different from the productivity per unit Chl-a (Table 5.5-1 and 2, Fig. 5.5-3) due to differences in water quality, photosynthetic potential of phytoplankton population, euphotic depth, etc.

Productivity obtained in Botafogo Bay in 1978 ranged from 0.807 to 3.647 g C/m²/day (in Bull, Mus. nain. Hist. nat., Paris, 4 oser., 1, 1979). It does not seem there is a significant difference between these values and the values obtained by our measurements of 2.868 gC/m²/12h (measurement-1) and 4.650 gC/m²/12h (measurement-2).

Similar respiration rates per unit Chl-a at the three depths were observed at each station in measurement-1, which is the same result as was obtained theoretically.

Respiration rate per unit Chl-a within the euphotic layer ranged from 30 to 80 % of the net productivity (Table 5.5-1). The respiration at night is generally known to be about one third of the net productivity during the daytime. The total respiration per day, therefore, was 60 to 110 % of the productivity per day. These respiration rates seem to be too high to sustain the productivity level.

While, the respiration rate in measurement-2 was obtained only at St. 51 per unit area, due to there being no significant differences in dissolved oxygen levels between the water at starting time and in the dark bottles after incubation.

The computed values were compared to those below from the publication "Marine Phytoplankton", 1974; 8.0 mg C/mg Chl-a/h for tropical areas, 4.95 mg C/mg Chl-a/h for tropical Pacific and 3.0 - 4.0 mg C/mg Chl-a/h for tropical Atlantic under optimum light intensity. For shallow areas 1 gC/m²/day "Marine Biochemistry", 1973.

Fig. 5.5- 2   Scheme for Primary Productivity Measurement

Fig. 5.5- 1   Stations for Primary Productivity Measurement

Table 5.5- 1   Net Productivity and Respiration Rate
                Measurement-1

St.	Productivity	Respiration		Productivity	Respiration	
	(gc/m2/12h)		(%)	(mg C/mg Chl-a/12h)		(%)
St. 27	4.044	2.268	56	163.1	94.2	58
St. 28	1.992	1.044	52	56.0	31.0	53
St. 29	4.104	2.091	51	123.4	95.1	77
St. 30	5.041	2.604	52	121.9	52.2	43
St. 31	8.208	2.223	27	372.2	111.8	30
St. 32	2.868	1.872	65	137.4	110.4	80

Table 5.5- 2   Net Productivity and Respiration Rate
                Measurement-2

St.	Productivity	Respiration	(%)	Productivity (mg C/ mg Chl-a/12h)
	(gc/m2/12h)			
St. 50	4.824	-	-	272.3
St. 51	5.625	2.087	37	191.1
St. 52	4.150	-	-	102.6
St. 53	6.225	-	-	36.2
St. 54	9.408	-	-	125.6
St. 55	4.650	-	-	-
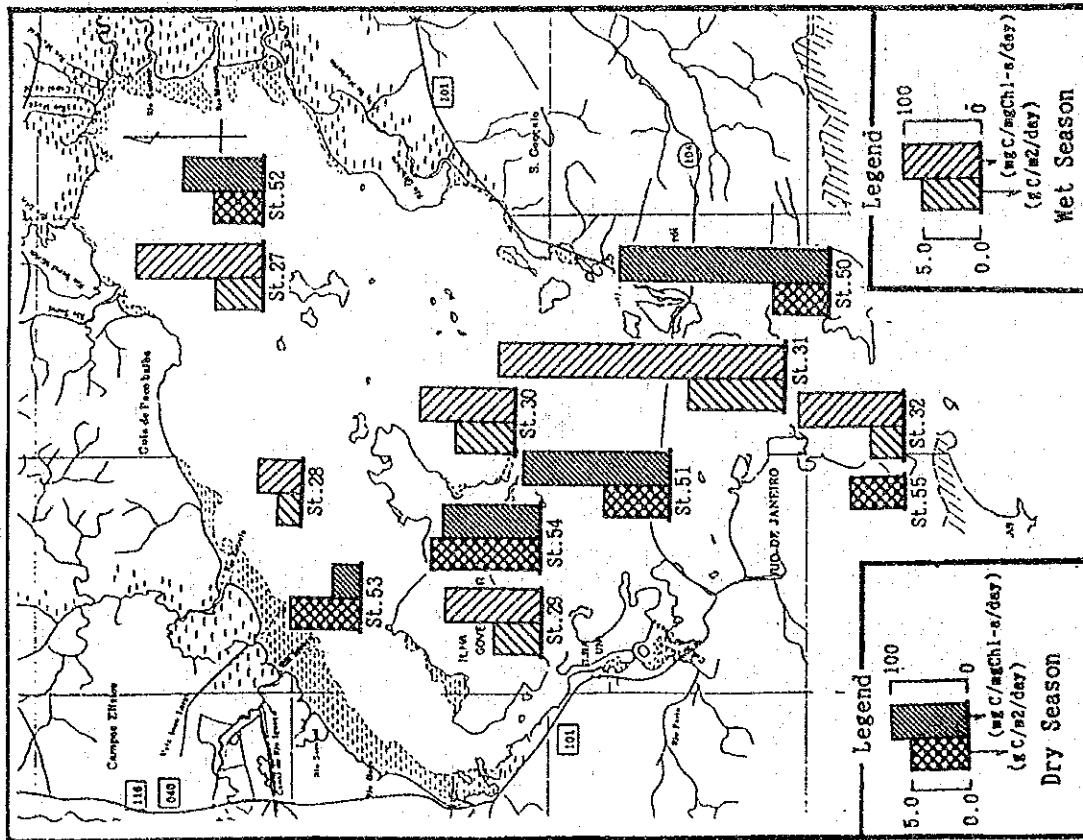
Fig. 5.5- 3   Net Productivity of Measurements 1 and 2

5.5.2 Release Rate from Sediment

Laboratory experiments were carried out, at 3 points in both Phase 2 and 3, to grasp the amount of organic matter, oxygen and phosphorus released from the sediments in Guanabara Bay.

(1) Experimental Apparatus and Theories

Theory and equations to calculate the release rate from sediment in detail are described in the Supporting Report IV. The apparatus used is shown in **Fig. 5.5-4**. It consists of a main reservoir from which water is continuously supplied to three reactors containing sediment samples.

As indicated in **Fig. 5.5-5**, L represents the concentration of water quality parameters present in the reactors and this is determined by multiplying L_A (water quality in the reaction bottle) by Q (flow rate). The base equation from which L is derived is:

$$V \frac{dL}{dt} = L_A Q - LQ + LaV - k_1 LV - k_3 LV$$

where,

L	=	Concentration of organic matter and nutrients in the reactor and outflow
L_A	=	Concentration of organic matter and nutrients in the inflow
La	=	Release Rate
k_1	=	Deoxidation Constant
k_3	=	Settling Constant
V	=	Volume of water in the Reactor
Q	=	Flow Rate

(2) Outline of the Experiment

The samples were collected from the 3 stations shown in Fig. 5.5-6. The experimental apparatus used is specified in Fig. 5.5-4.

The experiments were carried out under aerobic and anaerobic conditions to compensate for the variations in the release mecha-

Fig. 5.5- 4   Experimental Apparatus for Release and O_2 Consumption Test
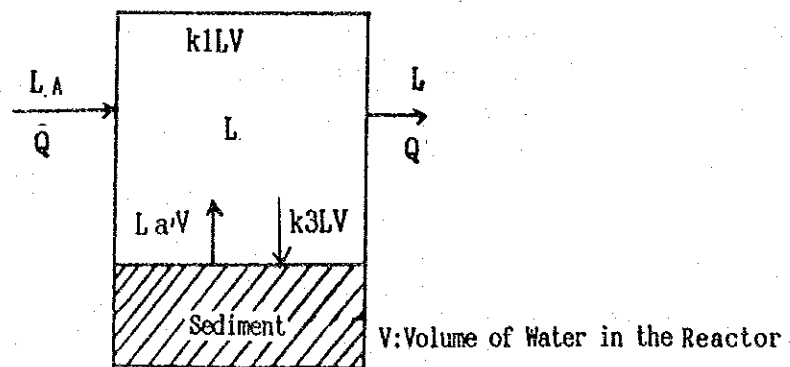
Fig. 5.5- 5   Mass Balance of Water Quality

nism of phosphorus being caused by the different DO concentrations found in the pore water at the sediment surface layer.
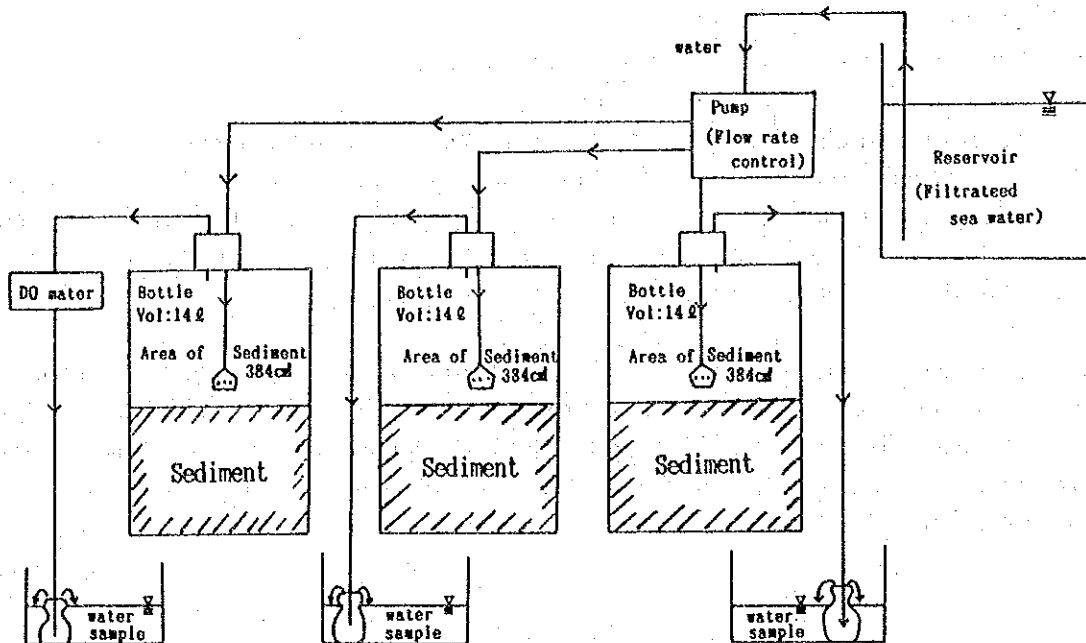
The experiment was carried out over 13 days for Phase 2, and 32 days for Phase 3. For aerobic conditions, the water supplied was aerated in the reservoir to bring it up to the DO saturation level. Under anaerobic conditions, Na_2SO_3 was used in the reservoir to attain DO=0.

NH_4N, TP and PO_4P were analyzed in the inflowing and outflowing water using "Standard Method".(ibid.)

(3) Results

The results obtained from the Phase 2 survey are shown in **Fig. 5.5-7** and **Table 5.5-3**, while those obtained from Phase 3 are shown in **Fig. 5.5-8** and **Table 5.5-3** (see Supporting Report IV in detail).

The release rate of COD(Mn) ranges from 0.111 - 0.223 g/m2/day having a mean value of 0.167 g/m2/day. The amount released in the entire bay area was computed to be 58.8 tons/day.

The release rate of BOD was not measured. But concentrations of BOD highly correlated with COD(Mn) in the upper layer so the concentration ratio of both properties was used to estimate the BOD release rate (0.262 g/m2/day). The amount released in the entire bay area was estimated at 92.2 ton/day.

The mean release rate and amount of NH_4N and PO_4P in the entire Bay area were estimated by using all values measured in the Experiment(see No.1 below).

Probably due to the location of St.22, which is near a river mouth with large loads, this Station has exceptionally high release rates for NH_4N and PO_4P. As the area, where these high release rates were measured, is very small, the release rates at this station were excluded (see No.2, below).

1. When all values measured at all stations were included:
       NH_4N
              Release Rate   : 0.033 g/m^2/day
              Amount Released : 11.6 ton/day

PO_4P

      Release Rate   : 0.018 g/m²/day

      Amount Released : 6.3 ton/day

2. When the value measured in St.22 was excluded:

   NH_4N

      Release Rate   : 0.014 g/m²/day

      Amount Released : 4.9 ton/day

   PO_4P

      Release Rate   : 0.016 g/m²/day

      Amount Released : 5.6 ton/day
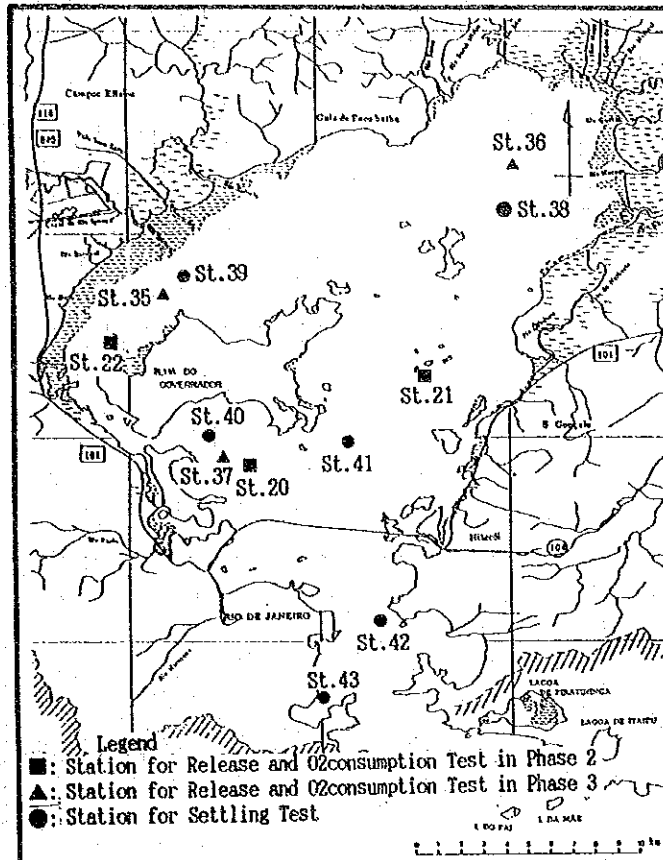
Fig. 5.5- 6   Sampling Stations for Release, O_2 Consumption
and Settling Tests

Table   5.5- 3   Release Rate from Sediment

Condition	Item	Release Rate (g/m2/day)					
		Phase2			Phase3		
		St.20	St.21	St.22	St.35	St.36	St.37
Aerobic	COD(Mn)	–	–	–	–	0.111	0.223
	NH4N	0.053	0.021	0.331	0.014	0.032	0.015
	TP	0.028	0.019	0.056	–	–	–
	PO4P	0.025	0.021	0.056	0.019	0.017	0.013
Anaerobic	NH4N	0.015	0.011	0.158	0.008	0.010	0.005
	TP	0.015	0.005	0.028	–	–	–
	PO4P	0.017	0.006	0.032	0.021	0.023	0.009
Mean	NH4N	0.034	0.016	0.245	0.011	0.021	0.010
	TP	0.022	0.012	0.042	–	–	–
	PO4P	0.021	0.014	0.044	0.020	0.020	0.011
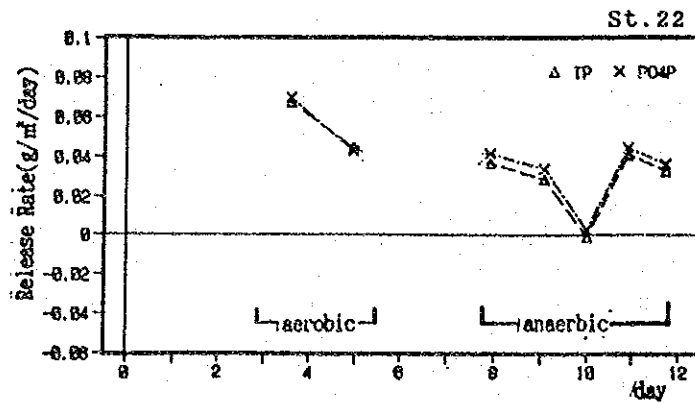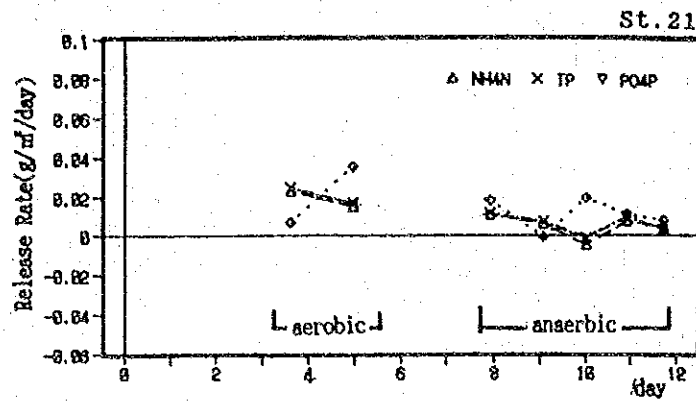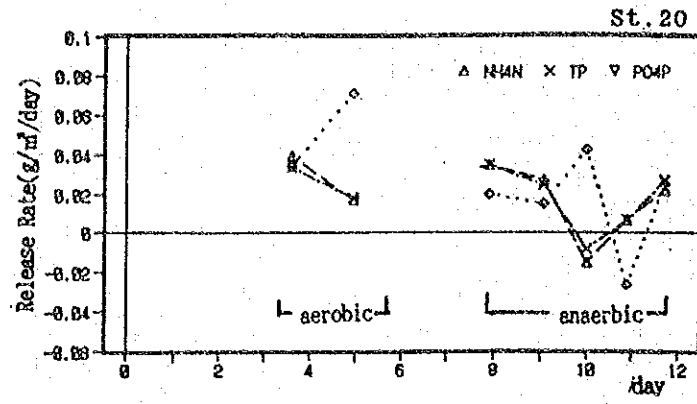
Fig. 5.5- 7　　Change of Release Rate obtained in Phase 2
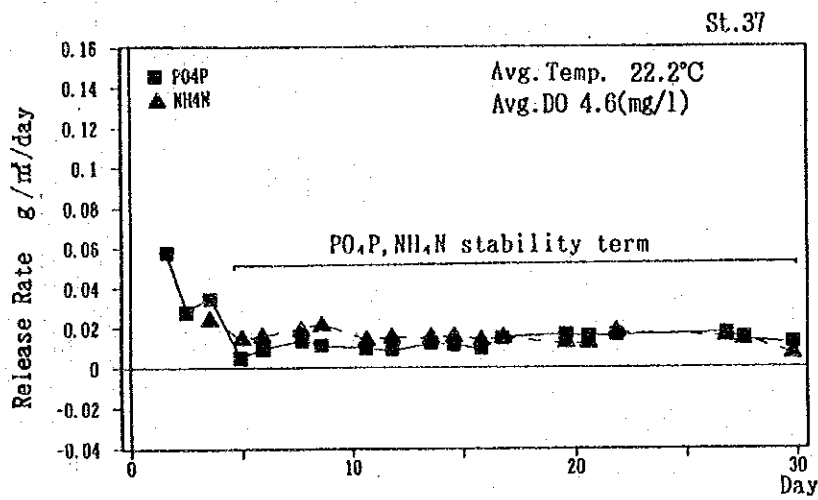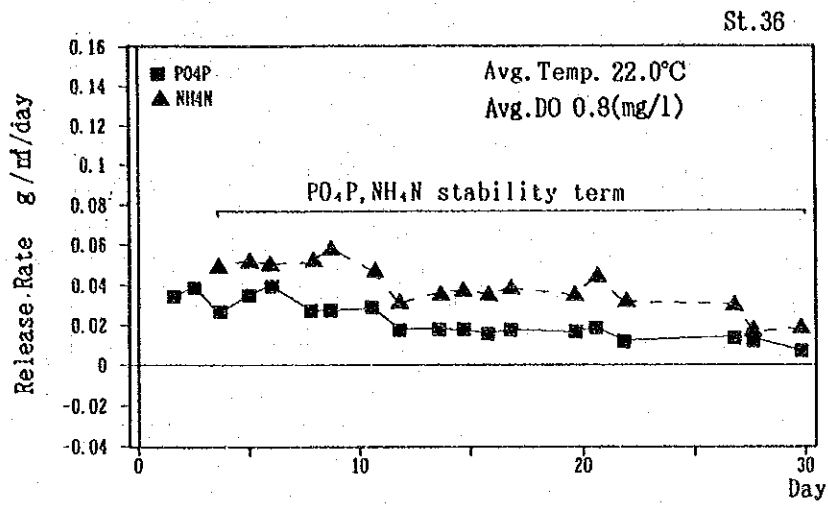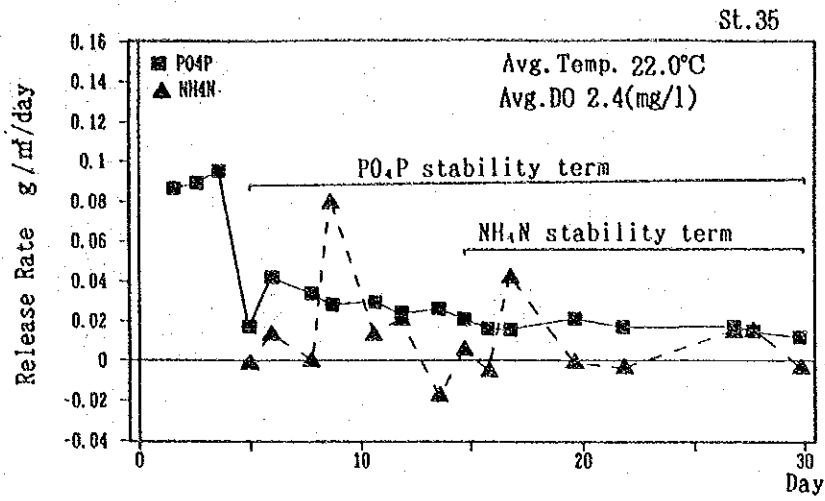
Fig. 5.5- 8(1)　　　Change of Release Rate obtained in Phase 3
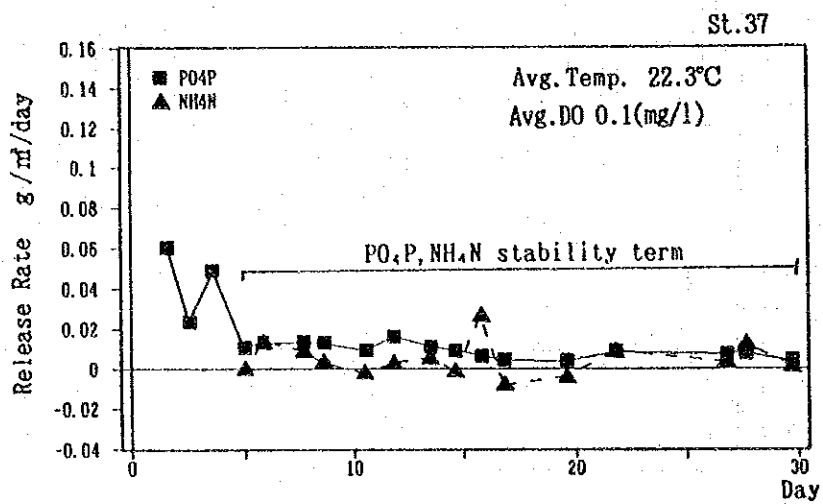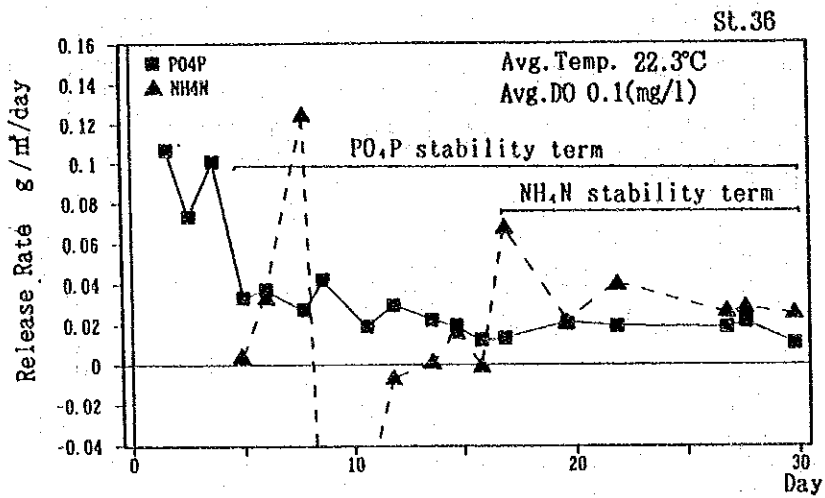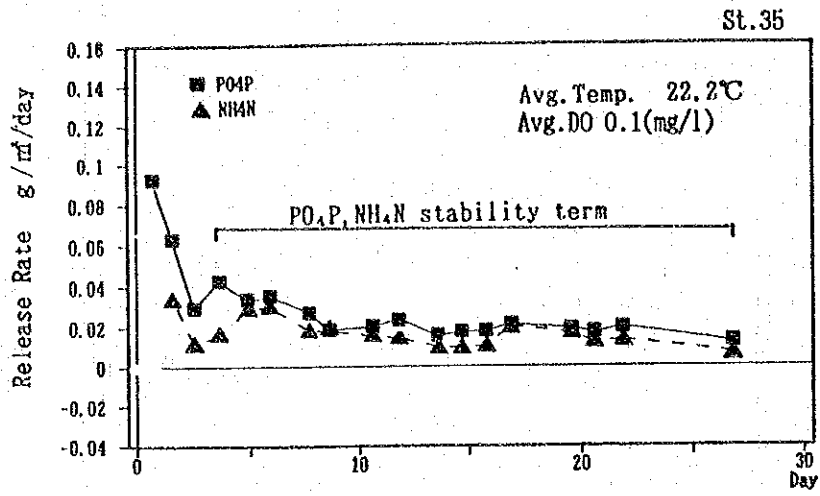
Fig. 5.5- 8(2)   Change of Release Rate obtained in Phase 3

5 - 5 0

5.5.3 Settling Rate of Particles

Laboratory experiments were carried out on samples taken from the upper layers at 6 stations (**Fig. 5.5-6**) to determine the settling rate of the nutrients and organic particles in Guanabara Bay.

(1) Experimental Apparatus and Theory

A vinyl tube with an internal diameter of 0.1m and a length of 1.1 m was the apparatus used in this experiment.

Settling rate of particles is calculated as the distance the particles move downwards per unit time. The product of the particle concentration by the settling rate is represented as the amount of mass transmitting per unit area per unit time.

The settling rate was computed using the following equation;

$$V = F/C$$

where V = Settling rate   (m/day)
F = Flux $(mg/m^2/day)$
C = Concentration of particles in the water (mg/l)

(2) Outline and Results of the Experiment

An shown in **Fig. 5.5-6**, the samples were extracted from the upper layers at 3 stations. The experiment was carried out in a dark room over 3 days.

The COD(Mn), TOC, KN and TP contents in the samples were analyzed using "Standard Methods" (16ed).

The results of the measurements are in **Table 5.5-4**.

The settling rates of TP, TN and COD(Mn) were observed to be high in the southern part of the Bay (Stns. 41 and 42) and in Botafogo.

A slower settling rate was obtained in the water from the inner part of the Bay where higher Chl-a concentrations are usually found.

The settling rate is considered to depend on the quality of the

particles, and particles in the inner Bay area are supposed to be mainly composed of phytoplanktons, because higher Chl-a concentration is always found there. Phytoplankton, in particular,chain forming diatons, are commonly highly buoyant and it results in a small settling rate.

By using the settling rate, we estimated at each stations the mean annual concentrations of COD(Mn), KN, and TP (**Table 5.5-5**).

Table 5.5-4   Results of Settling Test

St.	Setlling rate (m/day)			
	T-P	K-N	COD (Mn)	TOC
38	0.156	0.087	0.041	0.056
39	0.084	0.039	0.047	0.033
40	0.060	0.038	0.081	0.042
41	0.145	0.108	0.084	0.128
42	0.203	0.207	0.065	0.143
43	0.152	0.152	0.084	0.096

Table 5.5-5   Settling Amount

St.	Settling Amount (g/m2/day)		
	TP	KN	COD(Mn)
38	0.023	0.013	0.206
39	0.017	0.056	0.231
40	0.016	0.067	0.268
41	0.017	0.093	0.221
42	0.023	0.178	0.171
43	0.015	0.142	0.198

5.5.4 Oxygen Consumption by Sediment

The samples extracted from 3 stations during Phase 2 and 3 were examined in the laboratory to determine the amount of oxygen absorbed by the sediments in Guanabara Bay.

(1) Experimental Apparatus and Theory

The experimental apparatus used in the release test (5.5.2) was employed (see Supporting Report IV in detail).

The base equation from which C(DO) was derived is:

$$V \frac{dC}{dt} = C_A Q - CQ - D_B V - k_1 L V$$

    C   = Concentration of DO in the reactor
    Ca   = Concentration of DO in influent water
    O_B = O_2 consumption rate
    k_1 = Deoxidation constant
    k_3 = Settling constant
    V   = Volume of water in the reactor
    Q   = Flow Rate

    See schematic diagram **Fig. 5.5-9**

(2) Outline and Results of the Experiment

The sampling stations used in the experiment were the same as those used in the release test.

Phase 2 measurements were carried out over 6 days. Phase 3 measurements were carried out over 29 days.

To create aerobic conditions in the reaction bottles, aeration was carried out in the reservoir.

DO concentrations in the inflow and outflow and the water temperature were measured.

The results are showed in **Fig. 5.5-10** and **Fig. 5.5-11**.

The mean O_2 consumption rate and O_2 amount consumpted amount in

the entire Bay area were calculated including values measured at all stations (see No.1 below), and, except for the value measured at Station 22 (see No.2 below); for the same reason used for the release rate.

1.   When all values measured at all stations were included:
            O_2 Consumption Rate   : 0.74 g/m²/day
            O_2 Amount Consumed   : 250 ton/day

2.   When the value measured in Station 22 was excluded
            O_2 Consumption Rate   : 0.72 g/m²/day
            O_2 Amount Consumed   : 250 ton/day

If we take DO concentration in Guanabara Bay to be about 7 mg/l, and if no DO were to be supplied.   Applying the O_2 consumption rate (above) a DO=0 state would be reacted after about 60 days.

As indicated in the water quality survey results, the decomposition of organic material in the water and O_2 consumption by sediments are thought to largely affect constant low DO concentrations in the lower layers of Guanabara Bay.
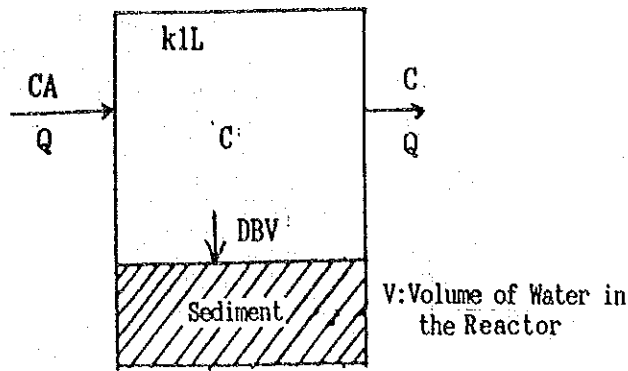
Fig. 5.5- 9   Mass balance of DO
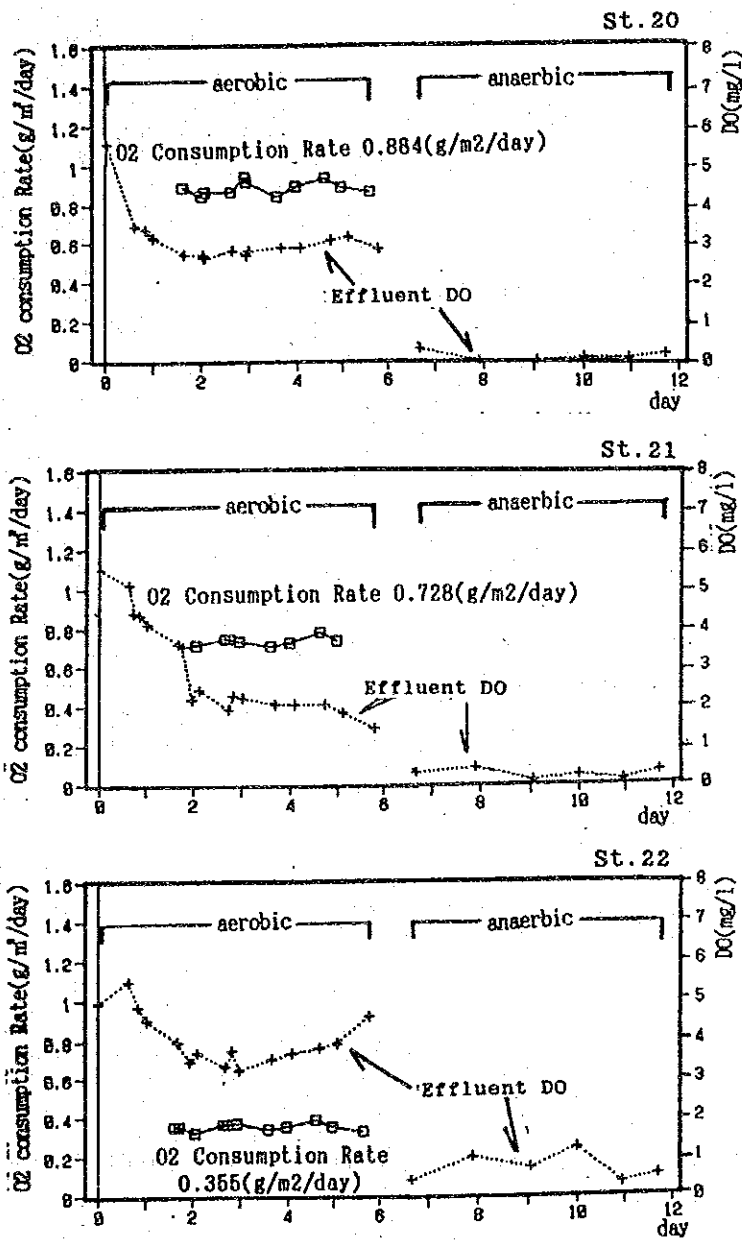
Fig. 5.5-10   Change in O_2 Consumption Rate obtained in Phase 2
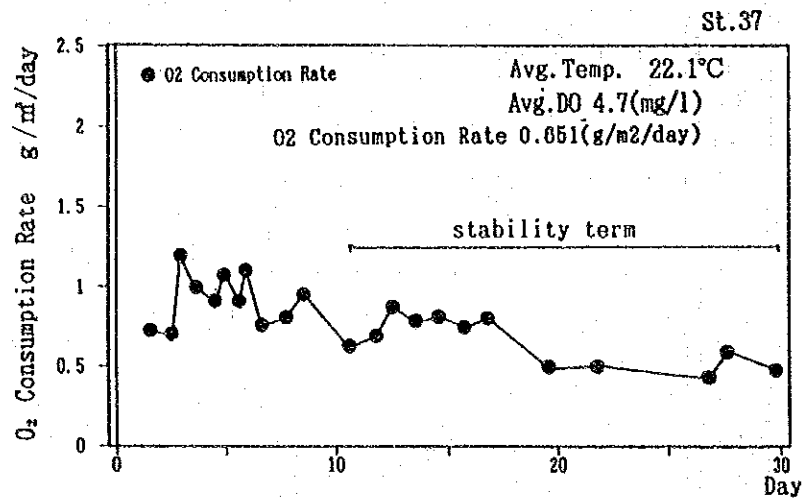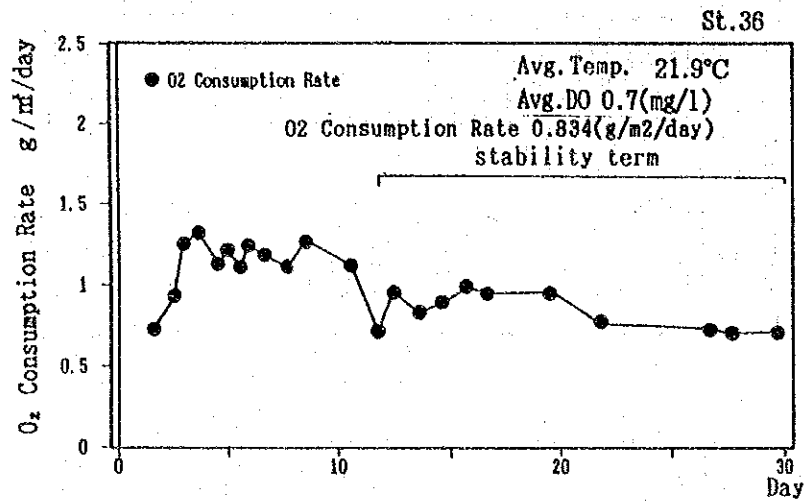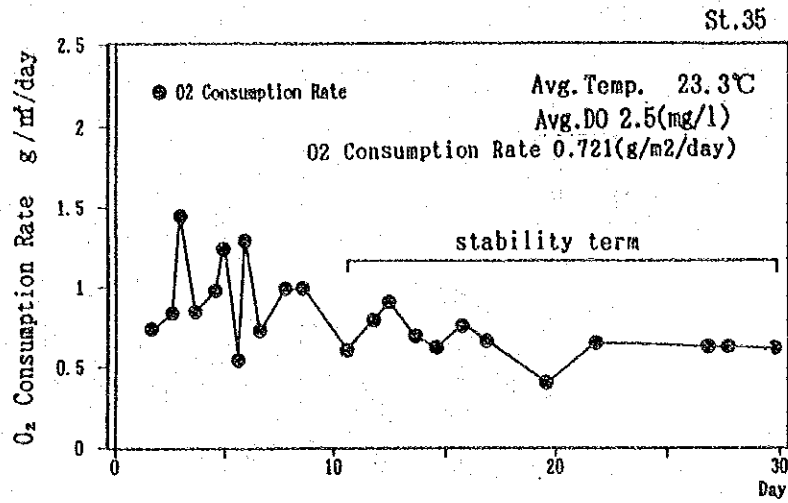
Fig. 5.5-11   Change in O_2 Consumption Rate obtained in Phase 3

5.6 Nutrient Balance in the Bay

Internal production in Guanabara bay was active, supposedly large-ly causing organic pollution in the bay, because of the bay's highly closed estuary and very high water temperature all year round. Hence, the nutrient balance in the bay was quantitatively determined using data obtained during the survey period.

5.6.1 Water Mass Balance in the Bay

Prior to determining the nutrient balance in the bay, water mass balance which is the basis for nutrient balance determination was examined.

Water flowing into the bay is the sum of the water from the rivers in the basin, wastewater directly flowing into the bay from the pollution source existing on the coast, rain water and offshore water inflowing through the bay mouth.

The results of the regular discharge measurements of rivers, which is summarized in Chapter 9, were used as river water amount. The amount of wastewater from pollution sources was very small and was disregarded therefore. The amount of rain water on the bay surface was determined from the results of the meteorological observation during the study period. Offshore water flowing into the bay was determined based on the results of the tidal observation summarized in Chapter 4.

Bay water outflow takes place through evaporation and the flow of water to the open seas through the bay mouth. Evaporation on clear and rainy days was calculated by dividing the mean annual evaporation of 1240 mm/year at 20° south latitude of the Atlantic ocean by the number of clear (213) and rainy (152) days during the survey period. The method used to calculate water inflow in the bay was also used to determine bay water outflow.

The determined results are sited in **Table 5.6-1**

5.6.2 Determination of Standing Stock

When the nutrient balance in the bay is examined, the standing stock of each parameter should be calculated firstly.

Table 5.6-1 Water Mass Balance in the Bay

		Dry Season	Wet Season
Input	Precipitation (x 10⁻6 m3/day)	0.71	2.62
	Discharge from Rivers (x 10⁻6 m3/day)	15.38	24.39
	Inflowing through the Bay Mouth (x 10⁻6 m3/day)	94.18	91.58
	Total Inflowing Water Volume (x 10⁻6 m3/day)	110.27	118.59
Output	Outflowing through the Bay Mouth (x 10⁻6 m3/day)	109.73	115.78
	Evaporation (x 10⁻6 m3/day)	1.47	1.02
	Total Outflowing Water Volume (x 10⁻6 m3/day)	111.10	116.80
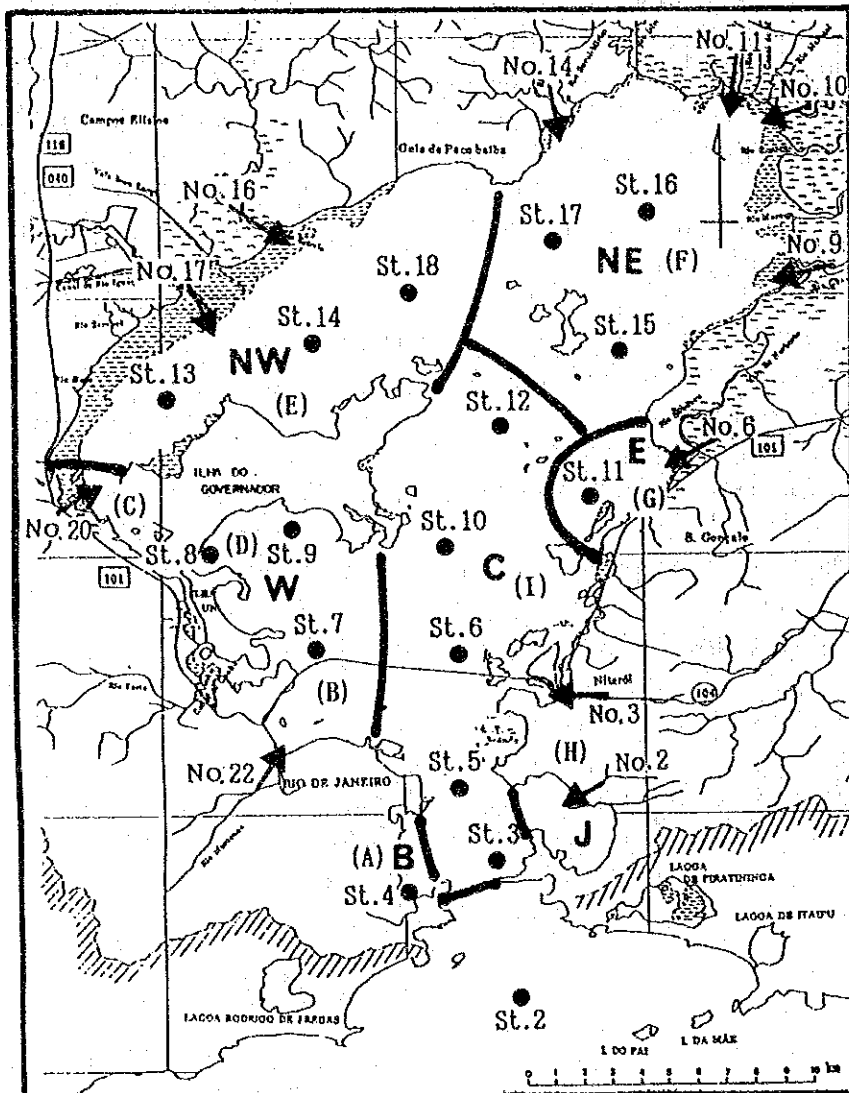
Fig. 5.6-1 Area Division based on the Degree of Pollution

Based on the degree of pollution, the bay was divided into seven sub-areas including two small bays(See **Fig. 5.6-1**), and each water area was divided into two layers, the euphotic layer (upper) and the decomposing layer (lower). The depth of the euphotic layers was determined by Secchi-disk depth multiplied by a factor of 2.1 in the dry season and 2.9 in the wet season. Both factors were empirically obtained from the bay.

The concentrations of nutrients in the euphotic and the decomposing layers were calculated from the analytical values at each station in each layer using the weighted average method, which took the depth of the samples into consideration.

The standing stock of nutrients was calculated for the dry season (from April to September 1992) and for the wet season (from October 1992 to March 1993), since the pollution condition under the two seasons differed considerably.

The calculated standing stock in each area and each layer in both seasons are shown in **Table 5.6-2**.

5.6.3 Characteristic Relationship between Nutrients and Phytoplankton in the Bay

A quantitative balance between the nutrient uptaken by phytoplankton and those recovered after decomposition is often found in the upper strata in the open sea area of the temperate region and in lakes under the stratification condition. This state of equilibrium indicates a linear relationship between the concentrations of Chl-a and nutrient in the water. However, such a relationship is hardly found in the estuaries.

Fig. 5.6-2 shows the relationship between Chl-a and T-P or T-N in the euphotic layer in the bay. The straight lines drawn in Figs. indicate the relationship between Chl-a and nutrient concentrations in the lake water under the equilibrium condition. Almost all points regarding T-P values are distributed under the straight line. This indicates the absence of equilibrium in the relationship of phytoplankton production and phosphorus recovery in Guanabara bay.

On the other hand, relationship between phytoplankton production and nitrogen recovery was observed to be in a state of equilibrium as TN values were found within the straight line.

Hence, the nutrient balance will be determined based on phosphorus concentration.

Table 5.6-2(1) Mean Standing Stock in sub-areas in the Dry Season

Area	Station	COD(Mn) (ton) Upper	Lower	TN (ton) Upper	Lower	TON (ton) Upper	Lower	DIN (ton) Upper	Lower	TP (ton) Upper	Lower	POP (ton) Upper	Lower	PO4-P (ton) Upper	Lower
J	J	100.8	12.3	36.3	6.3	30.2	5.0	6.0	1.3	4.5	0.7	-	-	0.8	0.2
E	11	66.1	29.5	22.2	10.6	17.9	8.6	4.6	2.2	3.9	1.5	1.8	0.1	0.6	0.2
NE	15	151.6	20.1	61.1	9.1	50.4	6.3	11.2	2.8	5.8	0.8	3.1	0.3	1.4	0.3
	16	146.7	20.3	55.0	7.9	41.2	5.0	13.8	3.0	5.9	0.8	3.6	0.4	1.6	0.3
	17	333.4	373.1	55.1	60.7	46.2	42.5	9.0	18.2	6.9	7.4	3.8	3.4	3.6	4.3
	Sub total	631.7	413.5	171.2	77.7	137.8	53.8	34.0	24.0	18.6	9.0	10.5	4.1	6.6	4.9
NW	13	381.1	5.2	118.8	1.6	81.1	1.1	64.4	1.0	18.7	0.2	6.2	0.1	9.8	0.1
	14	261.1	105.0	60.4	30.0	39.5	18.7	20.9	11.3	9.6	3.0	3.6	1.3	4.8	1.7
	18	343.6	482.0	50.9	89.1	40.8	61.5	14.6	30.4	7.9	10.8	0.9	5.1	3.7	5.4
	Sub total	985.8	592.2	230.1	120.7	161.4	81.3	99.9	42.7	36.2	14.0	10.7	6.5	18.3	7.2
W	7	89.2	56.9	61.8	32.5	45.8	20.5	16.0	12.0	8.7	3.7	2.8	1.0	3.2	2.0
	8	34.2	9.0	28.4	7.2	22.9	5.3	11.7	3.0	4.4	1.1	1.1	0.2	2.4	0.6
	9	87.9	53.2	65.2	36.2	35.9	19.3	29.5	16.9	12.3	5.6	2.4	1.4	7.2	3.5
	Sub total	211.3	119.1	155.4	75.9	104.6	45.1	57.2	31.9	25.4	10.4	6.3	2.6	12.8	6.1
Central	3	41.9	108.7	32.6	92.5	22.7	61.4	9.9	31.2	3.6	8.6	0.8	1.1	1.9	5.1
	5	104.7	140.5	59.9	144.2	44.8	104.7	15.1	39.6	7.1	13.9	1.4	2.0	2.7	6.1
	6	163.0	186.2	51.7	81.7	52.8	82.2	18.6	42.1	9.3	14	1.7	4.3	2.9	5.8
	10	171.6	309.9	84.2	191.7	70.7	158.2	13.5	33.5	11.3	22.2	3.0	7.5	2.8	6.7
	12	84.2	221.6	51.9	140.7	35.1	94.1	16.7	46.7	5.1	12.4	2.3	3.1	1.2	4.1
	Sub total	565.4	966.9	280.3	650.8	226.1	500.6	73.8	193.1	36.4	71.1	9.2	18.0	11.5	27.8
	4	37.5	22.0	16.6	18.3	12.3	14.5	3.5	3.8	3.2	1.8	0.8	0.4	1.1	0.8
Total		2598.6	2155.5	912.1	960.3	690.3	708.9	279.0	299.0	128.2	108.5	39.3	31.7	51.7	47.2

* TN : Calculated from correlation with TP TN=5.2 x TP + 0.39
* TON = TN - TIN
* Mean values measured in April '93 in Jurujuba Bay are used for dry and wet seasons.

Table 5.6-2(2) Mean Standing Stock in Sub-areas in the Wet Season

Area	Station	COD(Mn) (ton) Upper	Lower	TN (ton) Upper	Lower	TON (ton) Upper	Lower	DIN (ton) Upper	Lower	TP (ton) Upper	Lower	POP (ton) Upper	Lower	PO4-P (ton) Upper	Lower
J	J	52.2	21.9	18.8	21.9	15.7	17.4	3.1	4.5	2.3	2.3	-	-	0.4	0.6
E	11	144.0	37.9	32.3	11.9	27.2	9.1	5.1	2.8	3.8	1.2	1.9	0.5	0.4	0.2
NE	15	382.5	172.9	63.8	62.1	56.8	44.3	7.0	17.8	7.6	6.1	5.9	4.3	0.1	1.4
	16	474.4	0.0	66.9	0.0	55.4	0.0	10.7	0.0	6.7	0.0	4.4	0.0	1.6	0.3
	17	517.8	818.8	163.1	241.0	144.3	196.0	18.7	45.2	26.6	37.5	4.0	2.5	2.0	4.8
	Sub total	1374.7	991.7	293.8	303.1	257.5	240.3	36.4	63.0	40.9	43.6	14.3	6.8	3.7	6.5
NW	13	132.3	129.6	66.1	71.4	41.3	39.6	24.8	31.8	9.4	10.3	3.7	4.6	4.0	5.3
	14	428.5	709.2	153.6	281.0	138.2	236.2	15.8	46.9	18.2	31.9	10.4	11.5	1.6	5.2
	18	703.8	818.8	163.1	241.0	144.3	196.0	18.7	45.2	26.6	37.5	16.4	29.8	2.0	4.8
	Sub total	1264.6	1657.6	382.8	593.4	323.8	471.6	59.3	123.9	54.2	79.7	30.5	45.9	7.6	15.3
W	7	225.3	214.5	74.8	66.7	59.7	46.7	15.1	20.0	11.1	8.2	5.7	4.7	2.6	3.5
	8	54.8	3.5	28.4	2.0	18.4	1.3	9.9	0.7	4.0	0.3	1.6	6.5	1.9	0.1
	9	162.5	179.8	74.1	59.8	55.0	41.5	22.9	28.9	13.0	13.7	7.0	4.2	3.5	4.8
	19	13.2	24.5	4.6	8.7	2.0	2.4	2.6	6.3	0.8	1.6	0.2	0.3	0.4	0.9
	Sub total	455.8	422.3	181.9	137.2	135.1	91.9	50.5	55.9	28.9	23.8	14.5	15.7	8.4	9.3
Centr	3	150.8	188.3	14.2	18.0	12.5	14.2	12.6	19.9	5.7	7.7	2.7	2.0	1.6	3.0
	5	105.4	294.0	34.5	131.3	27.6	105.5	6.9	25.8	3.5	11.7	1.1	5.4	0.7	5.1
	6	415.3	979.3	80.6	285.0	69.9	213.8	12.3	60.2	10.2	30.5	6.2	9.5	1.1	11.4
	10	362.9	678.3	105.5	342.8	95.7	261.3	9.8	81.5	13.1	37.3	9.5	16.4	2.1	11.8
	12	290.7	511.1	80.8	205.0	76.0	154.1	4.8	50.9	10.0	21.2	4.5	6.1	1.3	8.3
	Sub total	1325.1	2651.0	315.6	982.1	281.7	748.9	46.4	238.3	42.5	108.4	24.0	39.4	6.8	39.6
	4	46.0	30.1	16.0	13.4	12.1	9.5	3.9	3.9	1.6	1.4	1.0	0.6	0.5	0.6
Total		4662.4	5812.5	1241.2	2063.0	1053.1	1588.9	204.7	492.3	174.2	260.4	86.2	108.9	27.8	72.1

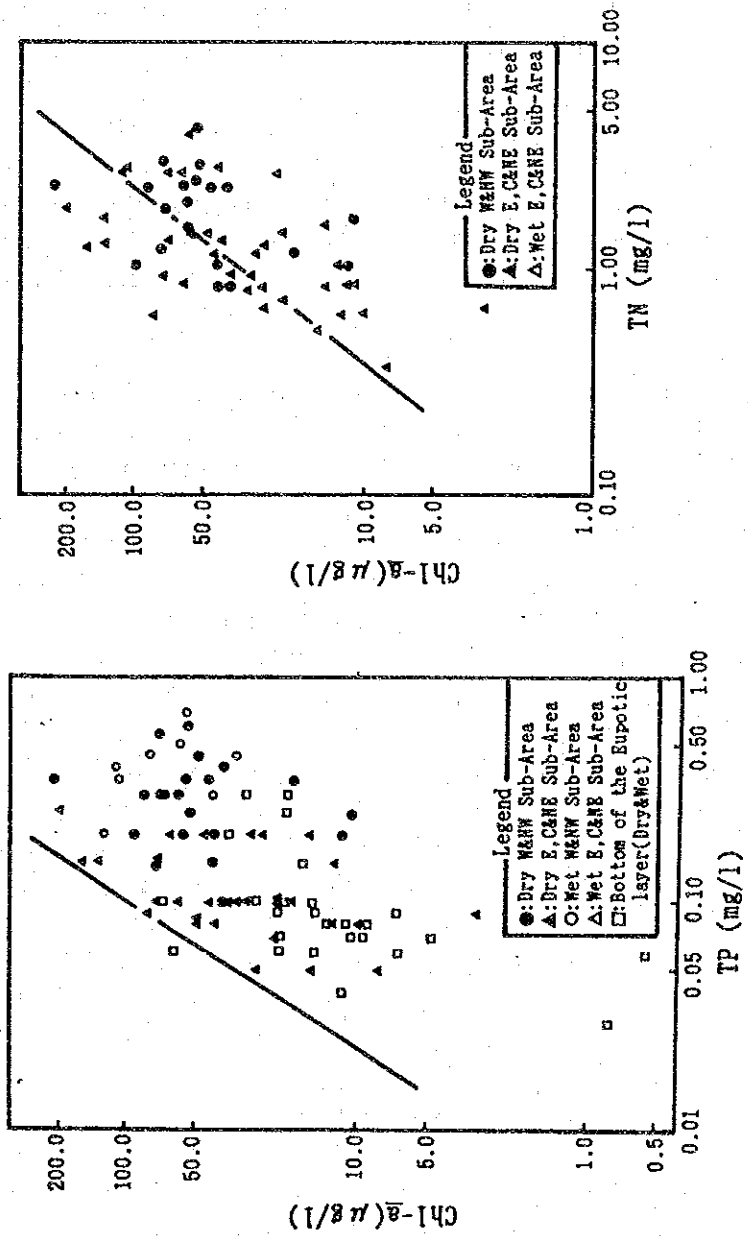* Calculated using TN=5.2 TP + 0.30: obtained by this survey

Fig. 5.6-2 Relationship between Chl-a and Nutrient Salts in the Euphotic Layer

5.6.4   Determination of Additional and Subtracted Phosphorus

The major factors that increased the standing stock of phosphorus
(additional factors) obtained during the survey period are phos-
phorus content in water inflowing through the rivers, phosphorus
in the direct inflow from the pollution sources at the coast,
phosphorus in rain water flow, phosphorus recovered through the
respiration and decomposition of phytoplankton, phosporus released
from bottom sediments and those in water inflowing from off shore.

The amount of phosphorus in water inflowing through   rivers is
shown in **Table 9.3-6** and those from the pollution sources is shown
in **Table 8.4-1.** The amount of phosphorus brought about by rain
water was obtained by multiplying precipitation by phosphorus
concentration in rainwater measured in this survey (see Supporting
Report I).

The amount of phosphorus flowing into the bay from offshore was
calculated based on the inflowing amount and phosphorus concentra-
tions in the lower layer of the water area nearest to the bay
mouth (see Supporting Report I)

On the other hand, the principal factors obseved in this survey
that   decreased the standing stock of phosphrus (subtracted fac-
tors) were the uptaken amount by the phytoplankton, outflowing
amount to the open sea and the amount that settled at the bottom.

The uptaken amount by phytoplankton was calculated from   the
measured *DO* values obtained through the primary production meas-
urements and the equation (2). The amount of phosphorus outflowing
to the open sea area was calculated from the outflowing water
volume and the concentration of the sea water in the upper layer
of the bay mouth area. The amount of settled phosphorous was
calculated using the settling rate obtained through the laboratory
works.

The tidal current observation results confirm the superiority of
the outflowing current in the upper layer and the inflowing cur-
rent in the lower layer. Conclusively, it was calculated that
phosphorus in the bay outflows through the upper layer and inflows
from the offshore through the lower layer.

Table 5.6-3, 4 show the additional and subtractive phosphorus in each water area obtained through the processes mentioned above.

Strong winds, which causes water mixing, accelerates the ratio of recurrence to the upper layer of the released DIP and DIP from the offshore water or adjacent sub-areas inflowing through the lower layer. Gentle winds, on the other hand, maintain stratification and reduce the recurrence of the released DIP to the upper layer. Balance-1 is the result under the former condition (Total additional DIP - Total subtractive DIP) and Balance-2 is the result under the latter condition (Total additional excluding released and exchange DIP - Total subtractive DIP). High ratio of strong windy days is found in the rainy season, therefore, more cases of Balance-1 than Balance-2 are considered to be found in this season.

5.6.5 Phosphorus Balance in the Bay

Fig. 5.6-3,4 schematically show the phosphorus cycle in the dry and rainy seasons based on Table 5.6-3,4

The results of both Balance-1 and Balance-2 showed negative values in almost all sub-areas in the dry and the rainy seasons. There are two ways in order to compensate these negative values: increase of the additional DIP or decrese of subtractive DIP.

Factors that will increase the additional DIP in addition to the measured ones are considered to be: (1) decomposition of POP to DOP, (2) ionization of POP and DOP to DIP, (3) extracellular production of phytoplankton, (4) excretion by zooplankton, (5) vertical diffusion and (6) recurrence by stirring up bottom sediment. While, the factor that will decrease the substractive DIP is considered to be (7) grazing of phytoplankton by zooplankton.

Since the survey found the zooplankton amount in the bay to be considerably small, factors (4) and (7) are considered to seemingly have no effect on the P cycle. Factor (5) is also considered to be negligibly small.
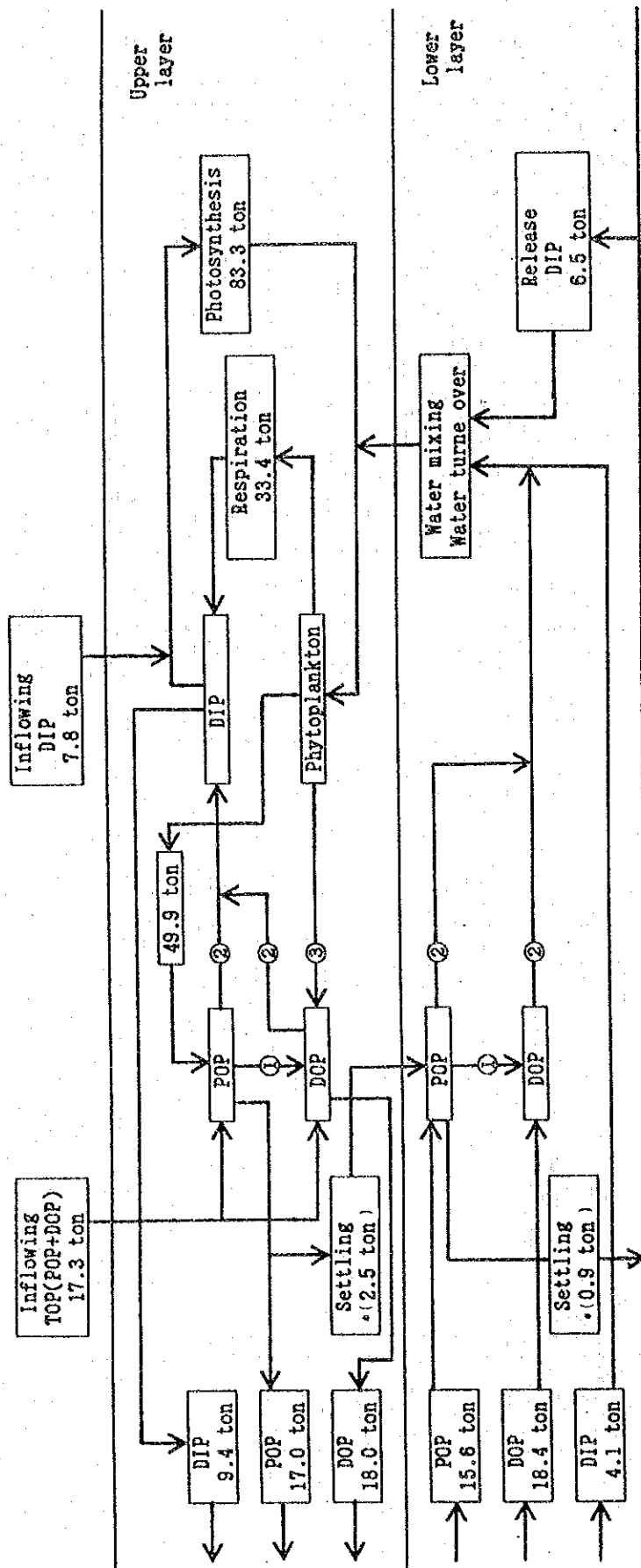
In contrast to these factors, the decomposition and ionization rate are deemed to be great, due to the high temperature throughout the year in the bay, and these factors affect the cycle significantly.

Table 5.6-3 Phosphorus Balance in the Dry Season in Sub-areas

Area		Jurujuba	Eastern	N-eastern	N-western	Western	Central	Botafogo	Entire Bay
Standing stock (ton)									
Upper layer	TP	4.5	3.9	18.6	36.2	25.4	36.4	3.2	128.2
	POP	-	1.8	10.6	10.8	6.2	9.2	0.8	39.4
	DOP	-	1.5	1.4	7.1	5.3	15.7	1.3	36.0
	DIP	0.8	0.6	6.6	18.3	13.9	11.5	1.1	52.8
Lower layer	TP	0.7	1.5	9.0	14.0	10.4	71.1	1.8	108.5
	POP	-	0.05	4.1	6.5	2.6	18.0	0.5	31.8
	DOP	-	1.25	0	0.3	0.9	25.3	0.5	28.8
	DIP	0.2	0.2	4.9	7.2	6.9	27.8	0.8	48.0
Additional									
Inflowing (ton/day)	TP	0.43	1.34	2.95	13.54	5.44	0.65	1.25	25.60
	TOP	0.29	0.79	1.92	9.38	3.61	0.43	0.86	17.28
	DIP	0.13	0.35	0.94	4.17	1.63	0.20	0.38	7.80
Respiration (37 %) (ton/day)	Day time	0.30	0.40	3.83	4.86	4.21	4.60	0.24	18.44
	Night time	0.25	0.33	3.10	3.94	3.41	3.73	0.20	14.96
	Total	0.55	0.73	6.93	8.80	7.62	8.33	0.44	33.40
Release (ton/day)	DIP	0.11	0.17	2.15	1.74	0.75	1.55	0.01	6.48
Exchange (in) (ton/day)	POP	0.48	0.73	1.69	1.64	2.57	8.13	0.39	15.63
	DOP	0.42	1.02	0.73	1.53	5.21	9.44	0.75	19.10
	DIP	0.39	0.15	0.48	0.00	0.10	3.02	0.00	4.14
Total additional (ton/day)	TOP	1.19	2.54	4.34	12.55	11.39	18.00	2.00	52.01
	DIP	1.18	1.40	10.50	14.71	10.10	13.10	0.83	51.82
Subtractive									
P-uptake (ton/day)	Gross-1	1.12	1.49	14.17	18.00	15.58	17.04	0.89	68.29
	Net	0.82	1.09	10.34	13.14	11.37	12.44	0.65	49.85
	Gross-2	1.37	1.82	17.27	21.94	18.99	20.77	1.09	83.25
Exchange (out) (ton/day)	POP	-	1.46	1.74	2.67	2.80	6.14	2.16	16.97
	DOP	-	1.08	1.67	1.45	2.80	10.26	3.46	20.72
	DIP	0.26	0.22	0.31	1.55	1.41	5.63	0.03	9.41
Settling (POP) (ton/day)	(%)	4.2	6.8	6.3	4.8	3.1	6.1	5.5	5.1
	1	0.034	0.074	0.651	0.631	0.352	0.759	0.036	2.54
	2	0.022	0.055	0.148	0.109	0.091	0.542	0.023	0.93
Total subtractive (ton/day)	POP	4.20	8.26	8.04	7.47	5.90	12.24	7.66	22.07
	DOP	-	1.08	1.67	1.45	2.80	10.26	3.46	20.72
	DIP	1.63	2.04	17.58	23.49	20.40	26.40	1.12	92.66
Balance-1 (ton/day)	DIP	-0.45	-0.64	-7.08	-8.78	-10.30	-13.30	-0.29	-40.84
Balance-2 (ton/day)	DIP	-0.95	-0.96	-9.71	-10.52	-11.15	-17.87	-0.30	-51.46
Expected decomposition or ionization rate (Time/day)	1	0.7	0.8	0.8	0.8	1.0	1.0	0.7	0.9
	2	1.1	0.9	1.0	0.9	1.0	1.2	0.7	1.0

Gross-1 : Gross P-uptake during a day
Gross-2 : Gross P-uptake during a day and at night
Settling-1 : Settling of POP produced by photosynthesis from the upper layer to the lower layer
Settling-2 : Settling of POP to the bottom in the lower layer which is settled from the upper layer and added
　　　　　by the water excahnge
Balance-1 : Released and exchanged DIP supplied to the upper layer by water mixing or turnover
　　　　　(Total Additional DIP - Total Substractive DIP)
Balance-2 : Neither released nor exchanged DIP
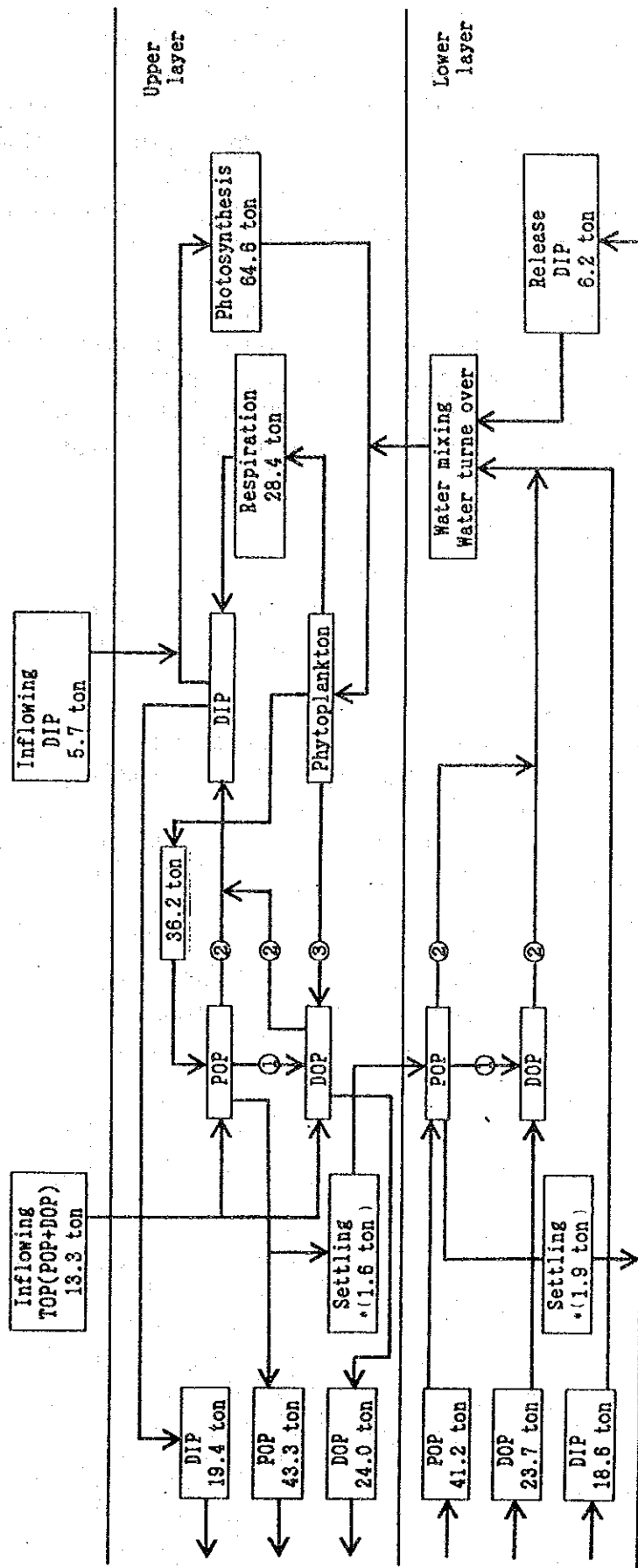　　　　　(Inflowing DIP + Respired DIP - Total Substractive DIP)

Table 5.6-4　Phosphorus Balance in the Wet Season in Sub-areas

Area		Jurujuba	Eastern	N-eastern	N-western	Western	Central	Botafogo	Entire Bay
Standing stock (ton)									
Upper layer	TP	2.3	3.8	40.9	54.2	28.9	42.5	1.6	174.2
	POP	-	1.9	14.3	30.5	14.5	24.9	1.0	87.1
	DOP	-	1.5	22.9	16.1	6.0	10.8	0.1	59.3
	DIP	0.4	0.4	3.7	7.6	8.4	6.8	0.5	27.8
Lower layer	TP	2.3	1.2	44.2	79.7	23.6	109.7	1.4	262.1
	POP	-	0.5	6.8	45.9	9.1	39.4	0.6	102.3
	DOP	-	0.5	30.9	22.4	5.2	30.7	0.2	91.6
	DIP	0.6	0.2	6.5	11.4	9.3	39.6	0.6	68.2
Additional									
Inflowing (ton/day)	TP	0.32	0.87	2.35	9.63	3.85	0.55	0.86	18.43
	TOP	0.15	0.57	1.59	6.63	2.57	0.37	0.59	13.29
	DIP	0.10	0.26	0.71	2.98	1.18	0.17	0.26	5.66
Respiration (%)		65	58	58	52	51	40	65	
(ton/day)	Day time	0.33	0.61	5.16	2.31	2.45	6.49	0.16	17.52
	Night time	0.15	0.32	2.67	1.34	1.44	4.87	0.07	10.86
	Total	0.48	0.93	7.83	3.65	3.90	11.36	0.23	28.37
Release (ton/day)	DIP	0.12	0.17	1.90	1.84	0.68	1.41	0.05	6.17
Exchange (in) (ton/day)	POP	0.38	1.16	1.20	1.66	3.52	32.53	0.75	41.20
	DOP	0.08	0.05	1.10	3.02	2.17	16.30	1.00	23.72
	DIP	0.71	1.12	1.33	2.09	2.81	9.16	1.40	18.62
Total additional (ton/day)	TOP	0.61	1.78	3.89	11.31	8.26	49.2	2.34	78.21
	DIP	1.41	2.48	11.77	10.56	8.57	22.10	1.94	58.82
Subtractive									
P-uptake (ton/day)	Gross-1	0.88	1.67	14.06	6.76	7.26	22.72	0.40	53.75
	Net	0.50	1.06	8.90	4.45	4.81	16.23	0.24	36.19
	Gross-2	0.98	1.99	16.73	8.10	8.71	27.59	0.47	64.56
Exchange (out) (ton/day)	POP	-	1.60	6.80	12.61	9.92	9.94	2.54	43.41
	DOP	-	1.25	4.32	6.24	4.57	7.13	0.46	23.97
	DIP	0.76	0.25	3.33	2.21	2.97	8.52	1.32	19.36
Settling (POP) (ton/day)	(%)	8.4	6.9	7.8	2.4	2.8	4.5	2.8	4.5
	1	0.042	0.073	0.694	0.107	0.135	0.730	0.007	1.63
	2	0.035	0.085	0.146	0.042	0.102	1.497	0.021	1.93
Total subtructive (ton/day)	POP	0.04	1.67	6.95	12.65	10.02	11.44	2.56	45.34
	DOP	-	1.25	4.32	6.24	4.57	7.13	0.46	23.97
	DIP	1.74	2.24	20.06	10.31	11.68	36.11	1.79	83.92
Balance-1 (ton/day)	DIP	-0.33	0.24	-8.29	0.25	-3.11	-14.01	0.15	-25.10
Balance-2 (ton/day)	DIP	-1.16	-1.05	-11.52	-3.68	-6.6	-24.58	-1.3	-49.89
Expected decomposition or ionization rate (Time/day)	1	0.8		0.9		0.8	0.9		0.8
	2	2.3	1.0	1.1	0.9	1.2	1.2	2.3	1.2

Gross-1　: Gross P-uptake during a day
Gross-2　: Gross P-uptake during a day and at night
Settling-1 : Settling of POP produced by photosynthesis from the upper layer to the lower layer
Settling-2 : Settlin of POP to the bottom in the lower layer which is sttled from the upper layer and added by the water exchange
Balance-1　: Released and exchanged DIP supplied to the upper layer by water mixing or turnover
(Total Additional DIP - Total Substractive DIP)
Balance-2　: Neither released nor exchanged DIP
(Inflowing DIP + Respired DIP - Total Substractive DIP)

Fig. 5.6-3 Phosphorus Cycle in the Dry Season

* The value of settling rate seems to be underestimated considering the values of release rate

① Decomposition
② Ionization
③ Extracellular production

Fig. 5.6-4 Phosphorus Cycle in the Wet Season

* The value of settling rate seems to be underestimated considering the values of release rate

① Decomposition
② Ionization
③ Extracellular production

It is assumed that the negative values of Balance-1 and Balance-2 are compensated by recurrences of DIP produced by decomposition and ionization. The calculated results are 0.9 times/day (dry season) and 0.8 times/day (rainy season) for Balance-1 in the entire bay and 1.0 times/day (dry season) and 1.2 times/day (rainy season) for Balance-2. These values indicate that phytoplankton after uptaking P decompose within a day and recurs as DIP which is reused again for phytoplankton production.

Balance-1 may become larger than the calculated one, in the rainy season, where strong winds are frequent, because the bottom sediment (factor (6) in the above) gets stirred. Recovery to the upper layers also occurs on these windy days. Increased Balance-1 will lead to decrease the values of expected decomposition and ionization rates.

5.6.6 Organic Matter in the Bay

277 tons/day of COD(Mn), which is the one of the main parameters of organic matter, flows into the bay directly in the dry season (see Chapter 9).

Using the conversion factor of 13.2 from POP to COD(Mn), which was obtained empirically from the bay, gross production of COD(Mn) in the dry season becomes 1099 tons/day and net production becomes 659 tons/day, respectively. Internal production of COD(Mn) are four (gross) and two and a half times (net) of the inflowing load through rivers in the dry season.

While, inflowing load of COD(Mn) in the rainy season was 383 tons/day. The gross production was 852 tons/day and net production was 473 tons/day.

CHAPTER 6

AQUATIC ORGANISMS

CHAPTER 6

AQUATIC ORGANISMS

Environmental deterioration generally results in decrease of biological diversity and increase in specific species population. Accordingly, the clarification of the inhabiting species and population of the living organisms is of extreme importance in estimating the amount of biological resources and the environmental quality level.

The species and population of phytoplankton, zooplankton, benthic organisms, fouling organisms and fishes obtained from two field surveys are shown in this chapter as bases in clearly identifying the structure of the Guanabara Bay ecosystem and the influences of the water quality and bottom material deterioration on the ecosystem.

6.1 Phytoplankton Community

6.1.1 Phytoplankton Biomass Variation

Accompanying three (3) simultaneous sampling surveys performed in 1992, Chl-a and phytoplankton samples were collected from the water surface and bottom at the eighteen (18) stations previously established in the Guanabara Bay.

As it can be seen in **Fig. 6.1-1**, chlorophyll-a, which is representative of phytoplankton biomass, is more highly concentrated on the west side and in the inner part of the Bay, with lower concentrations in the central regions and the lowest concentration near the mouth of the bay. This type of algae biomass variation coincides, reasonably, with the distribution of nutrients in the bay, particularly phosphorus.

Besides the state reffered to above, a large vertical variation in the algae pigment; higher at the water surface and lower in the bottom layer was observed at most of the sampling stations. This phenomenon is caused by the characteristics of Oscillatoria sp., the absolute predominant phytoplankton, in terms of biomass, in the bay, associated with water mass stratification regime, resulting in the algae bloom or water bloom.
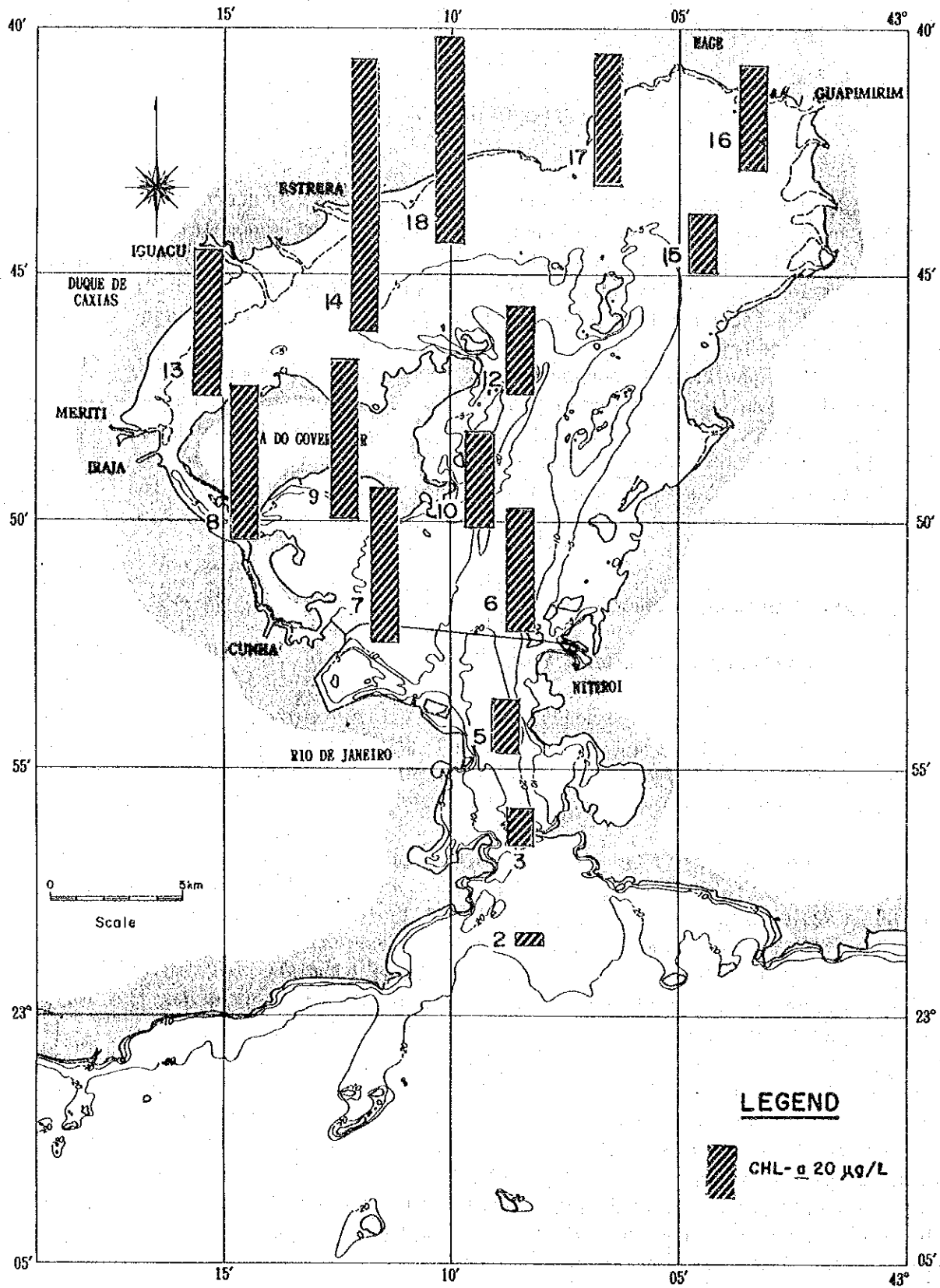
Fig. 6.1- 1   Phoytoplankton Biomass (Chl-a) Distribution on Guanabara Bay

6.1.2 Phytoplankton Species

The results of classification and quantification of phytoplankton of all the samples taken are shown in the Supporting Report.

The general condition of the phytoplankton community obtained through all the surveys performed in the Bay is shown graphically in **Fig. 6.1-2**.

The results obtained at low tide, in May 1992, showed that the phytoplankton population increased towards the inner Bay area. Nostocophyceae, consisting of mostly Oscillatoris sp., was predominant in the two layers at all sampling stations, except St. 18, where Dinophyceae (Pretoperidium trochoideun sp., one of the red tide organisms) was predominant followed by Prasinophyceae (Tretraselmis sp.).

However, the results obtained during high tide, in June 92 describe a very different distribution pattern from the above case. Although the tendency of increasing phytoplankton population towards the inner part of the Bay was confirmed, remarkable changes in the phytoplankton composition occured, in stead of Nostocophyceae, Bacillariophyceae composed principally by Nitzschia sp. was the predominant species in the central area of the Bay and also in the east side of the inner part of the Bay (St.15,16 and 18). The stations located on the west side (St.8,9, 13 and 14) maintained Nostocophyceae predominance in the water surface layer. However, in the bottom layer, Bacillariophyceae predominance extended into this area and almost all sampling stations in the bay, except stations 8 and 18. This condition/situation strongly suggests the influence of the inflow of ocean water into the bay, particularly in the deep layer, interfering considerably with the phytoplankton community.

Regarding the Nostocophyceae group; with the decrease in the Oscillatoria sp. population there was an increase in the Synechosystes sp. population, in the central and inner Bay area.

The phytoplankton survey performed in the wet season caused the recuperation of the Nostochophyceae predominance accompanied, in this case, by an appreciable proliferation of Synechosystes sp., as well as Oscillatoria sp.. The density index as well as the similarity index, calculated statistically, showed that 56 different species existed. This figure is considered below satisfactory and is a consequence of the high degree of eutrophication that has developed throughout Guanabara Bay.
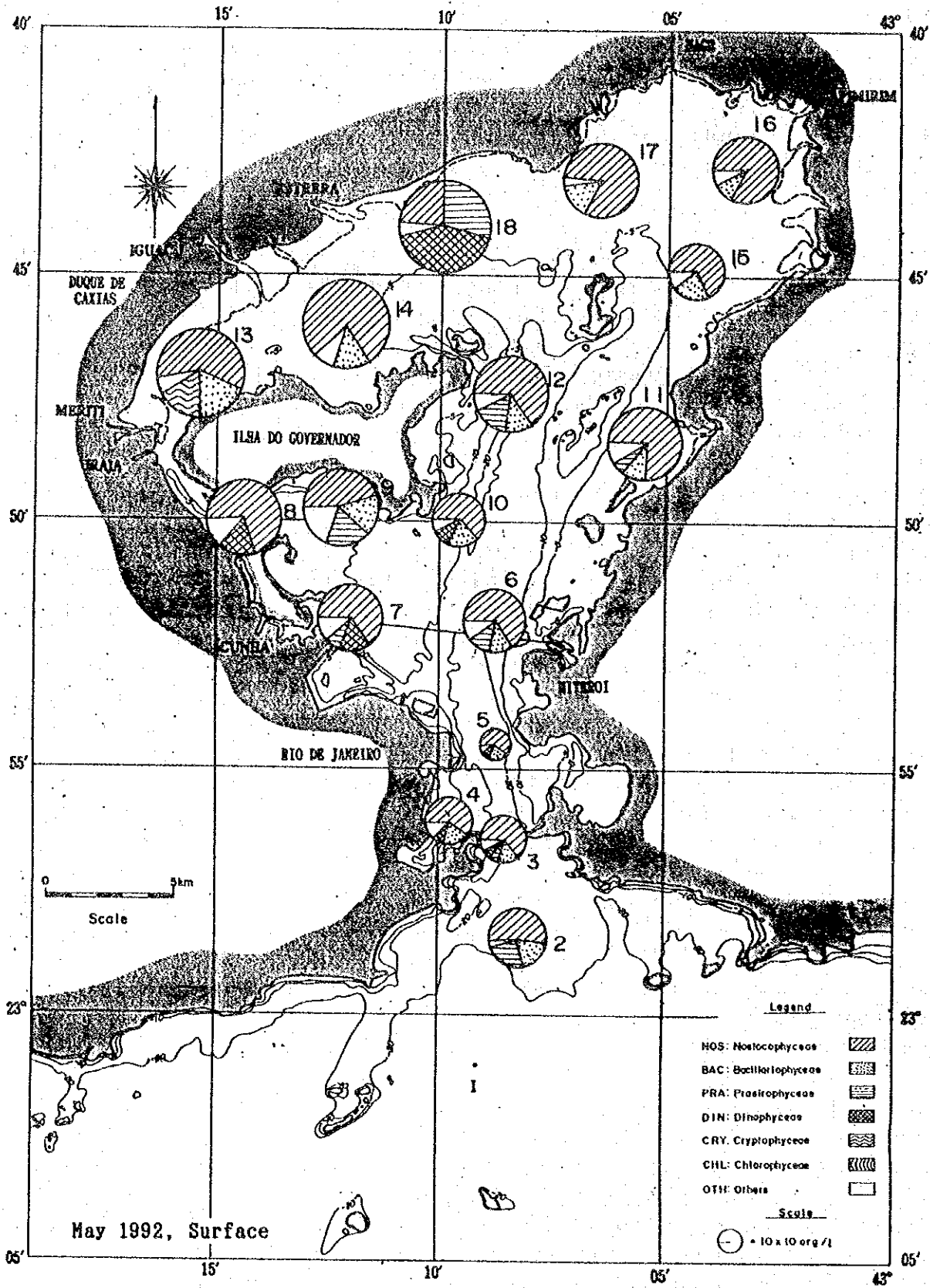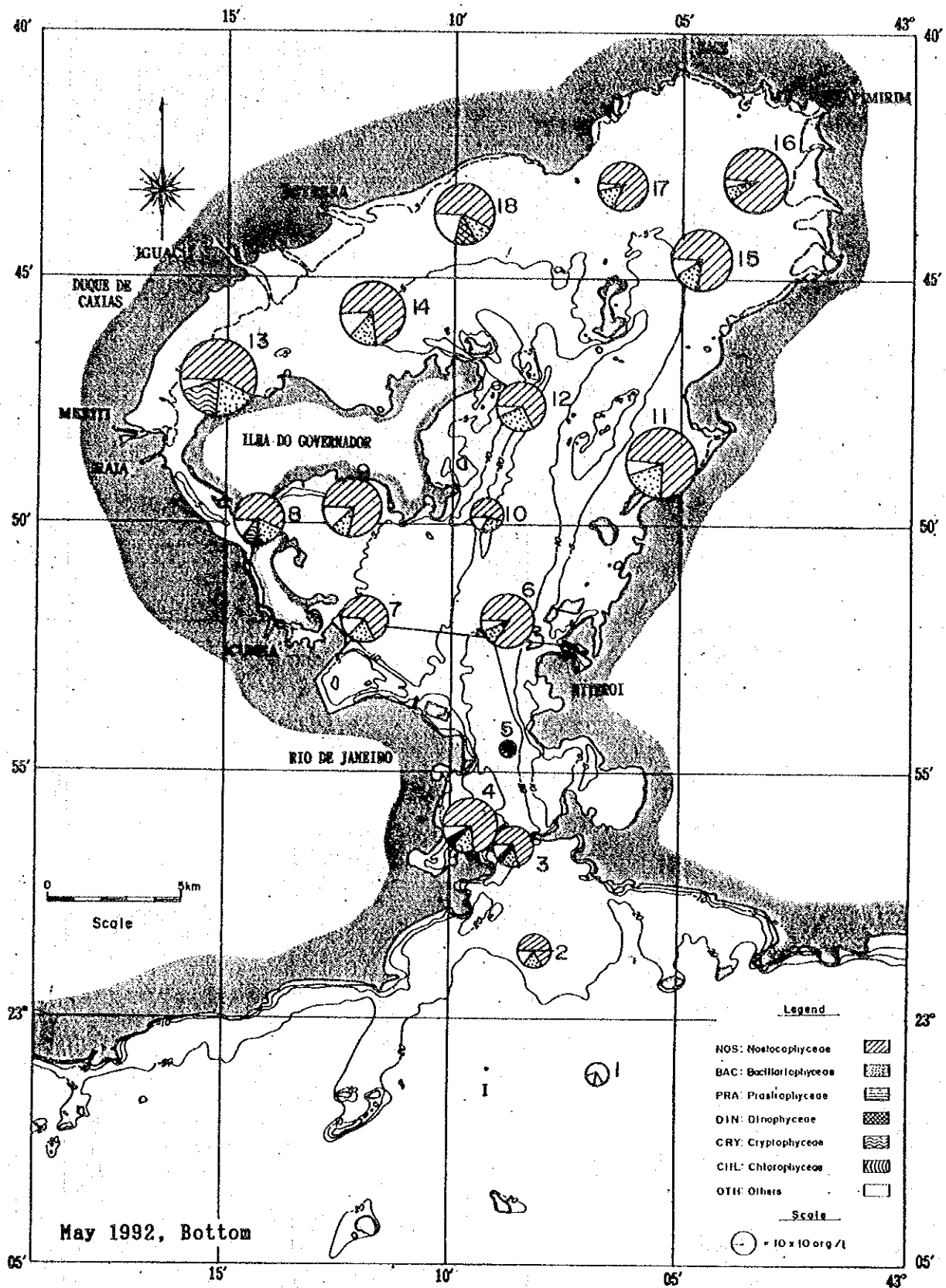
Fig. 6.1- 2(1) Distribution of Phytoplankton Population

Fig. 6.1- 2(2) Distribution of Phytoplankton Population