Chapter 4 Pilot Water Quality Monitoring

4.1 Planning for Pilot Water Quality Monitoring

The quality of water, water current and water sediment is affected by the movement of materials between them. Weather conditions, biological processes and activities on land can always initiate a change in water quality, such that a changed in concentration of pollutants is identified at times. Hydrological conditions can also lead to changes in water quality by advection and dispersion, as evidenced by the adverse effects of these two factors in bays and lagoons. Data on water current, on the other hand, is required in the formulation of a water quality simulation model. The hydrological environment also has a bearing on the condition of sediments. For example, in the Tampico Area fine silt and pollutants are not stable and never accumulate at the bottom under fast current speeds. On the contrary, in closed or semi-closed water areas such as Pueblo Viejo Lagoon and Conejo Lagoon, fine silt sediment is found at the bottom, making it easier for pollutants to accumulate. As a result, as sediment particle size becomes smaller, the pollutant content in the sediment increases to higher concentration. It is necessary to identify environmental changes in order to monitor sediment quality because sediment quality depends on the historical changes in water quality. Since the water area is the habitat of aquatic fauna, biological tests can provide environmental assessment from the viewpoint of its biological impact on organisms.

Monitoring areas in Tampico cover various types of water bodies such as coastal water, river water, brackish water and fresh water. The following water areas have been chosen to represent the aforementioned four water bodies (see Table 4.1):

Table 4.1 Pilot Water Quality Monitoring Areas

Types of Water Bodies	Monitoring Areas
Coastal water area	Coastal area from the mouth of Panuco River to Altamira
River water area	Panuco River
Brackish water area	Pueblo Viejo Lagoon
Fresh water area	Conejo Lagoon

Source: JICA Study Team

As stated earlier, the quality of water bodies is affected by various factors. Furthermore, there is no such thing as uniformity in various water areas; there are concentration gradients horizontally and vertically. It is required that horizontal and vertical profiles be identified. Around the mouth of Panuco River, which is affected by river water, monitoring stations were distributed radially. In another coastal area, monitoring points are set on grid meshes.

For water quality monitoring, in general, samples are taken from surface water. However, vertical profile should be considered especially in the coastal area and deep lakes. Water samples from two layers are proposed for the Pilot Water Quality Monitoring based on the influence of river water and biological reaction. According to the results of the preliminary field survey on February 4, 1999 conducted by the *CNA* and JICA Study Team, surface water at a depth of 5 to 6 m was affected by fresh water from Panuco River. There is an active layer from the viewpoint of biological process called photosynthesis reaction that has an effect on the surface layer. As a consequence, the lower layer was set at 10 m below water surface, where it is assumed that water is not much affected by fresh water and biological processes. However, in the shallow water area no more than 11 m in depth, water sample should be taken 1 m above the sea bottom and the riverbed, because it is possible that drifting mud may have contaminated water very close to the seabed and riverbed.

The JICA Study Team has prepared a simulation model to demonstrate the process for selection of monitoring points and evaluation of survey method, as well as the correlation with pollution sources. Accordingly, a water current survey was carried out in the rainy season at two typical water bodies, the coastal area and Pueblo Viejo Lagoon. Some parameters taken are utilized in the simulation model.

Intensive water quality survey has never been conducted in the Tampico Area so that a number of parameters were analyzed during the Pilot Water Quality Monitoring. The analyzed water quality indices included physical index, eutrophication index and pollution index. Routine monitoring of all of these parameters, however, was not necessary.

4.2 Water Current Survey

4.2.1 Method of Water Current Survey

(1) Observation Period

During the rainy season, the Water Current Survey was conducted on the following dates (see Table 4.2):

Table 4.2 Schedule of Water Current Survey

Water body	Survey dates
Coastal Area	from July 16 to July 31 (new moon – July 12, full moon - July 28)
Pueblo Viejo Lagoon	from August 3 to August 18 (new moon – August 11, full moon – August 26)

Source: JICA Study Team

(2) Observation Points and Layers

The location of observation points is shown in Figure 4.1(1), Figure 4.1(2) and Table 4.3. In the coastal area, water currents were observed at two layers: at 3.5 m and 11 m below surface. Each observation layer was located in the middle depth of the upper or lower layer. In Pueblo Viejo Lagoon, water currents were observed at one layer, 0.5 m from the bottom, because the water depth of Pueblo Viejo Lagoon is less than 2 m.

Table 4.3 Location of Observation Points

Water body	Point	Latitude (N)	Longitude (W)
Coastal Area	CSA-1	22 17.65'	97 46.50'
	CSA-2	22 24.00'	97 49.00'
	CSA-3	22 30.25'	97 50.25'
Pueblo Viejo lagoon	PLC-3	22 10.33'	97 53.77'
	PLC-4	22 09.72'	97 52.39'
	PL-5*	22 06.75'	97 52.50'

Source: JICA Study Team

* PL-5 is also the station for water quality monitoring.

(3) Method for Setting up Current Meters

The method for setting up current meters (RCM9) is shown in Figure 4.2(1) and Figure 4.2(2). RCM9 for this Study has a water current velocity and direction sensor (Doppler Current Sensor), a water temperature sensor and a pressure (water depth) sensor. In addition, RCM9 can be equipped with a conductivity (salinity) sensor, a turbidity sensor and a dissolved oxygen sensor, but these three sensors are beyond the scope of the Study.

(4) Measurement Parameters

Pertinent information about the water current survey is shown in Table 4.4.

Table 4.4 Survey Brief on Water Current Measurement

Items	contents
Survey period	15 days including spring tide and a neep tide
Measurement interval	10-minute
Measurement parameter	Current direction and speed (Doppler Current Sensor) Water temperature Water depth (pressure) Salinity (conductivity)
Instrument	RCM 9 (Aanderaa Inc.)

Source: JICA Study Team

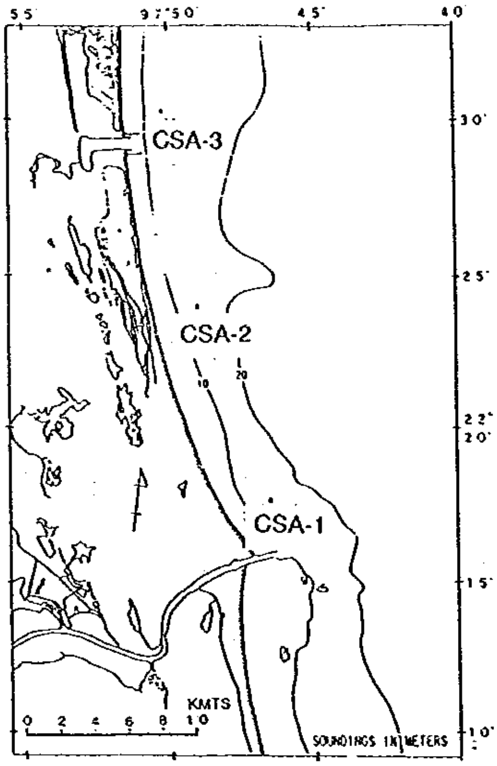


Figure 4.1 (1) Location of Observation Points for Water Current Survey in the Coastal Water Area

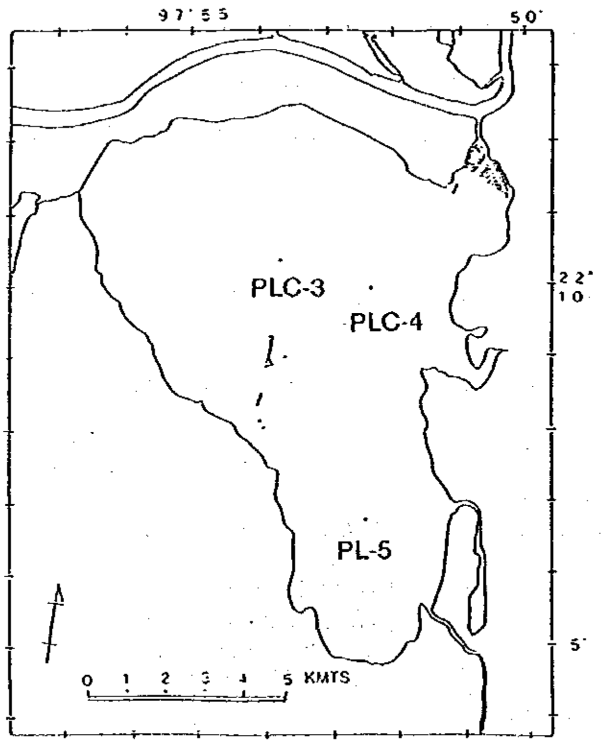


Figure 4.1 (2) Location of Observation Points for Water Current Survey in Pueblo Viejo Lagoon

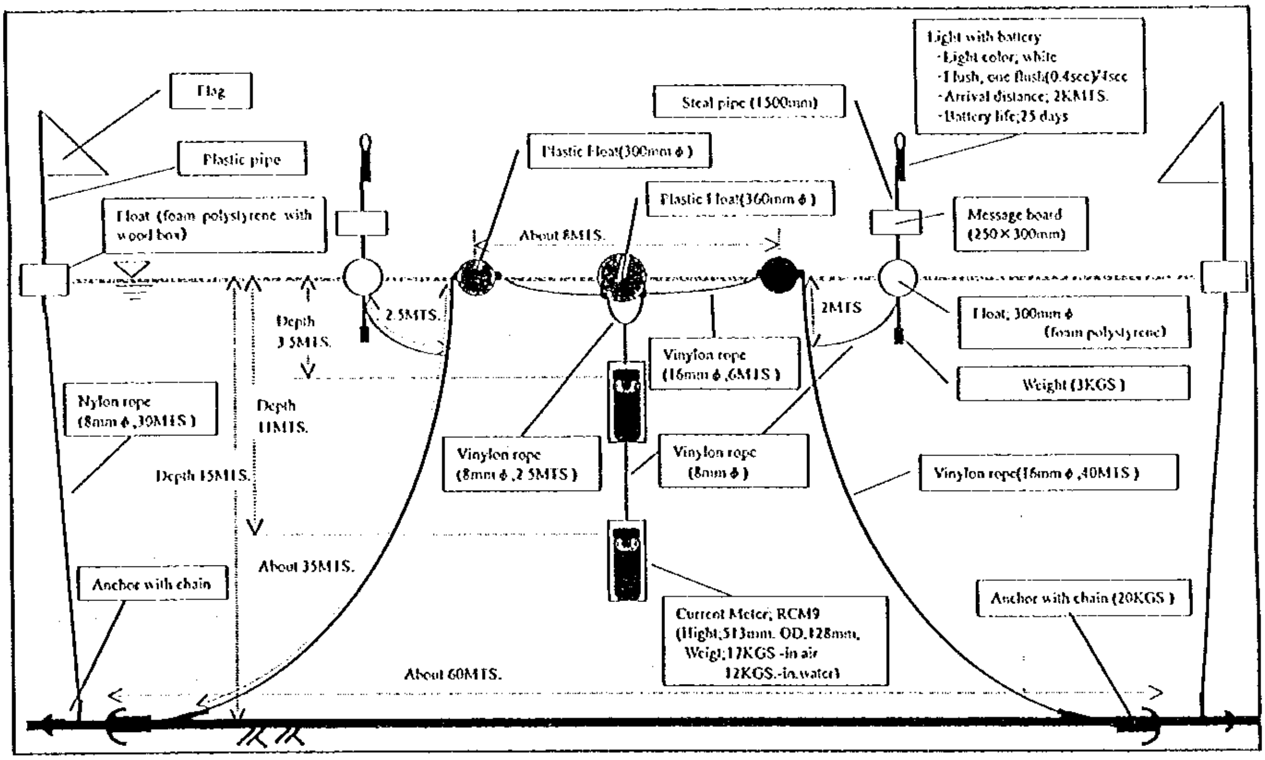


Figure 4.2 (1) Method for Setting up in the Coastal Area

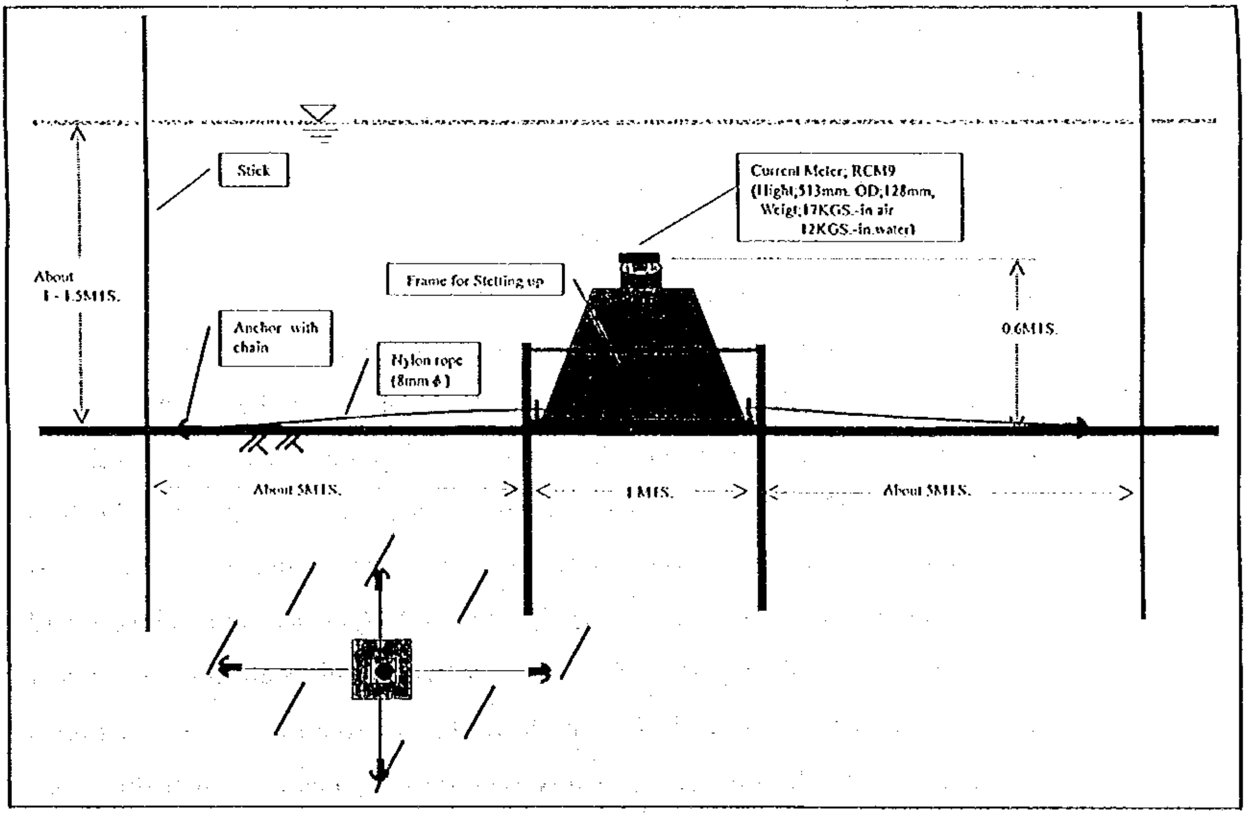


Figure 4.2 (2) Method for Setting up in the Lagoon

4.2.2 Results of Water Current Survey

(1) Hydraulic Regime

In the coastal area, characteristics of current during the water current survey are as follows:

a) Variability of current direction was small and current direction in the lower layer (surface - 11 m) was similar to the upper layer (surface - 3.5 m) at each point.

b) At the south point (CSA-1) water current flows southward almost always, on the other hand, at the central and north points (CSA-2 and CSA-3), water current flows northward almost always. These phenomena are clearly seen on diagrams of current directions shown in Figure 4.3.

c) However, water currents in the upper and lower layer flow in opposite direction. Water moved southward in the upper layer at CSA-2 and CSA-3 on July 20 to 21, but northward in the lower layer. It was supposed that these phenomena were influenced by the inflow of warm water mass from the open sea, because for the period July 19 to 24 water temperatures in the upper layer had been high as compared with the other period.

d) At each observation point, the variability of current speed in the upper layer had been large, while it was small in the lower layer. The maximum current speed in the upper layer was about 30 to 40 cm/sec, and that in the lower layer,10 to 20 cm/sec.

In Pueblo Viejo Lagoon, characteristics of water current during the survey are as follows:

a) At each observation point, water current has a diurnal periodicity in current direction and current speed.

b) However, at each observation point the periodicity of water current differs. At PLC-3 the amplitude of east-west velocity component was larger than that of north-south velocity component. At PLC-4 the amplitude of east-west velocity component was almost equal to that of north-south velocity component. At PL-5 the amplitude of north-south velocity component was larger than that of east-west velocity component. Therefore, it was clear that at PLC-3 eastward and westward water currents dominate, at PLC-4 northeastward and southwestward water currents dominate, and at PLC-5 northward and southward water currents dominate. These phenomena are clearly seen on diagrams of current directions shown in Figure 4.4.

c) At each observation point, the maximum current speed was about 5 to 10 cm/sec.

(2) Data analysis

a) Coastal Area

Autocorrelation coefficients and power spectrums are shown in Figure 4.5, Figure 4.6(1) and Figure 4.6(2). However, no spectral peak was evident within any period at each observation point, so that it is supposed that the coastal area has no particular periodicity and is an irregular current field.

Therefore, the mean current during the entire period of observation should be simulated with a current model to be used in the water quality simulation in the coastal area. Additionally, in order to calculate the diffusion coefficient, turbulent velocities that were removed from the mean velocity during the entire period of observation should be used. The diffusion coefficients are shown in Table 4.5.

Table 4.5 Diffusion Coefficients in Coastal Area for Water Quality Simulation

Point	Observation layer *	East-west component	North-south component
CSA-1	3.5m	1.83×10^6 cm^2/s	4.77×10^5 cm^2/s
	11m	1.39×10^5 cm^2/s	6.36×10^5 cm^2/s
CSA-2	3.5m	6.65×10^6 cm^2/s	3.97×10^5 cm^2/s
	11m	3.71×10^5 cm^2/s	2.96×10^5 cm^2/s
CSA-3	3.5m	9.94×10^6 cm^2/s	6.01×10^5 cm^2/s
	11m	3.77×10^5 cm^2/s	3.37×10^5 cm^2/s

* depth below surface water.

b) Pueblo Viejo Lagoon

Autocorrelation coefficients and power spectrums are shown in Figure 4.7 and Figure 4.8 respectively. Particular spectral peak with a period of near 24 hours is recognized at each observation point, so that it is supposed that a periodicity of about 24 hours dominates in Pueblo Viejo Lagoon.

Therefore, the diurnal tidal current (K1, O1) and the mean current during the entire period of observation should be simulated with a current model to be used for water quality simulation in Pueblo Viejo Lagoon. Furthermore, in order to calculate the diffusion coefficient, turbulent velocities removed from 25-hour running mean velocity should be used.

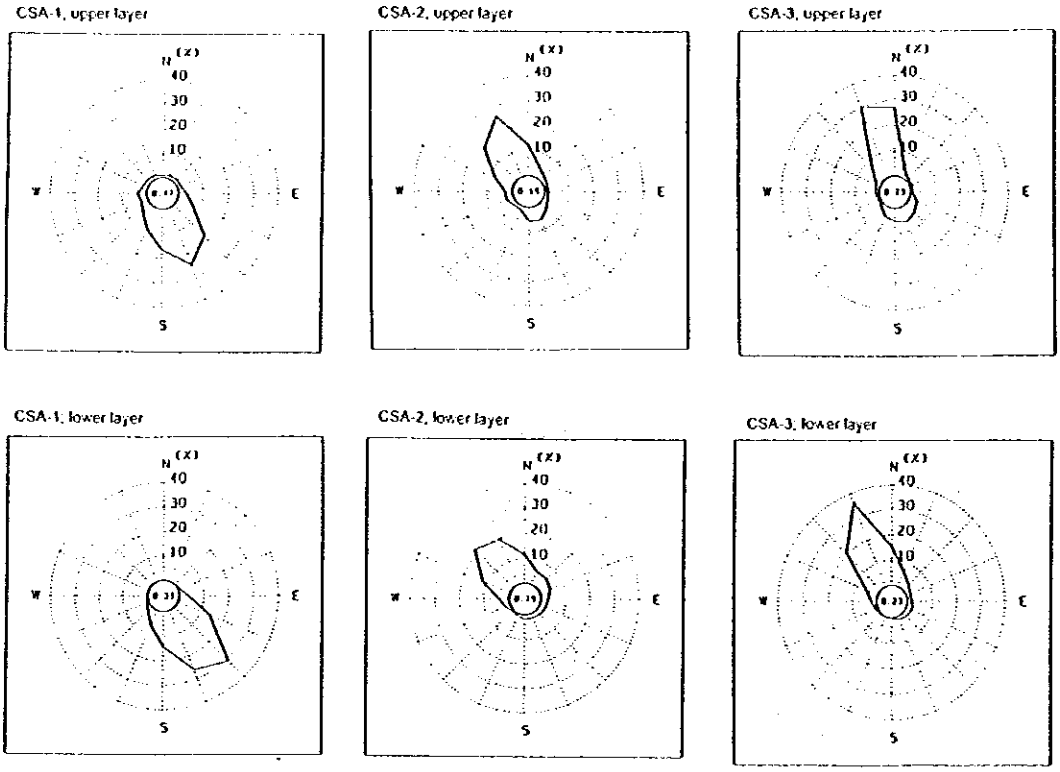


Figure 4.3 Diagram of Current Direction in the Coastal Area

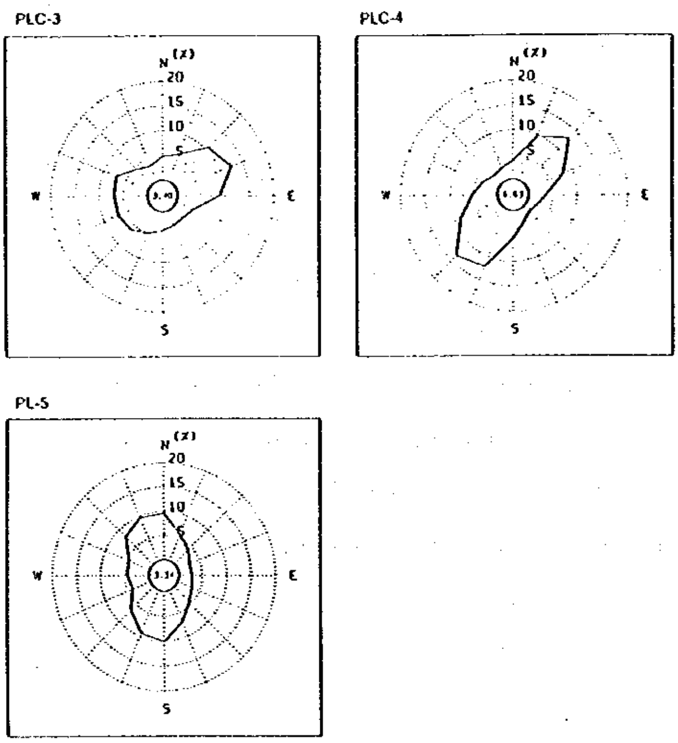


Figure 4.4 Diagram of Current Direction in Pueblo Viejo Lagoon

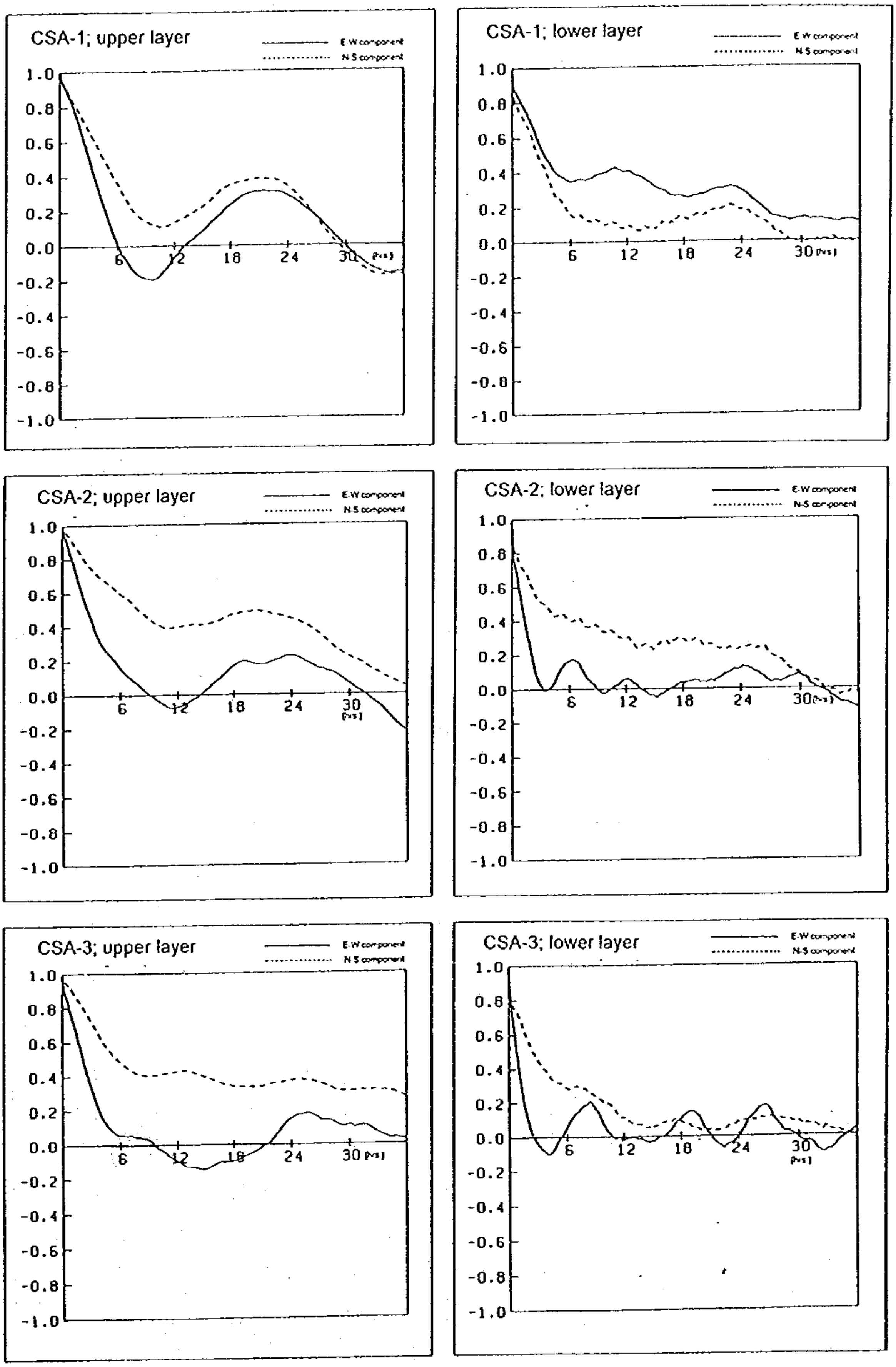


Figure 4.5 Autocorrelation Coefficient of Water Current in the Coastal Area

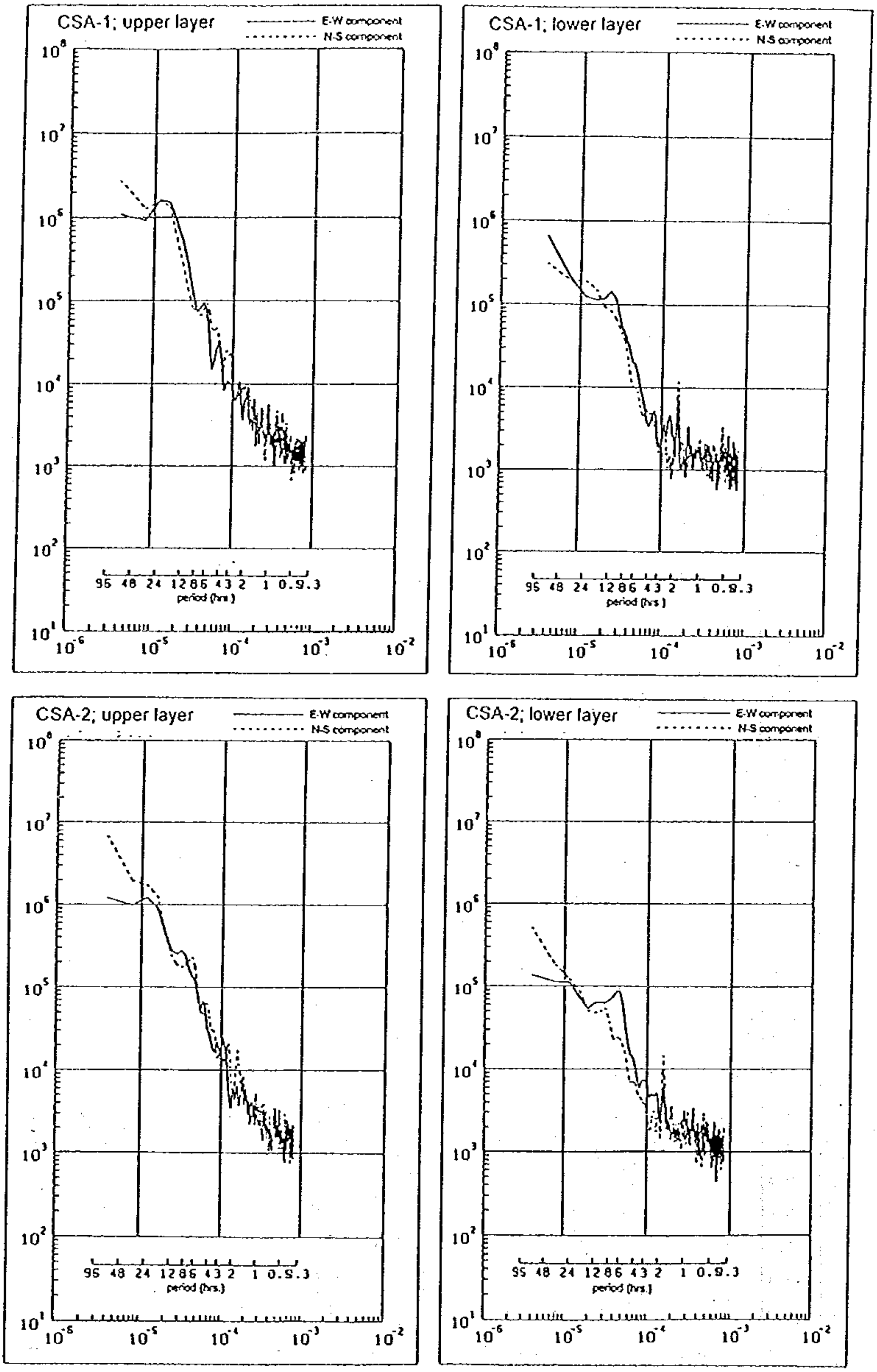


Figure 4.6(1) Power Spectrum of Water Current in the Coastal Area

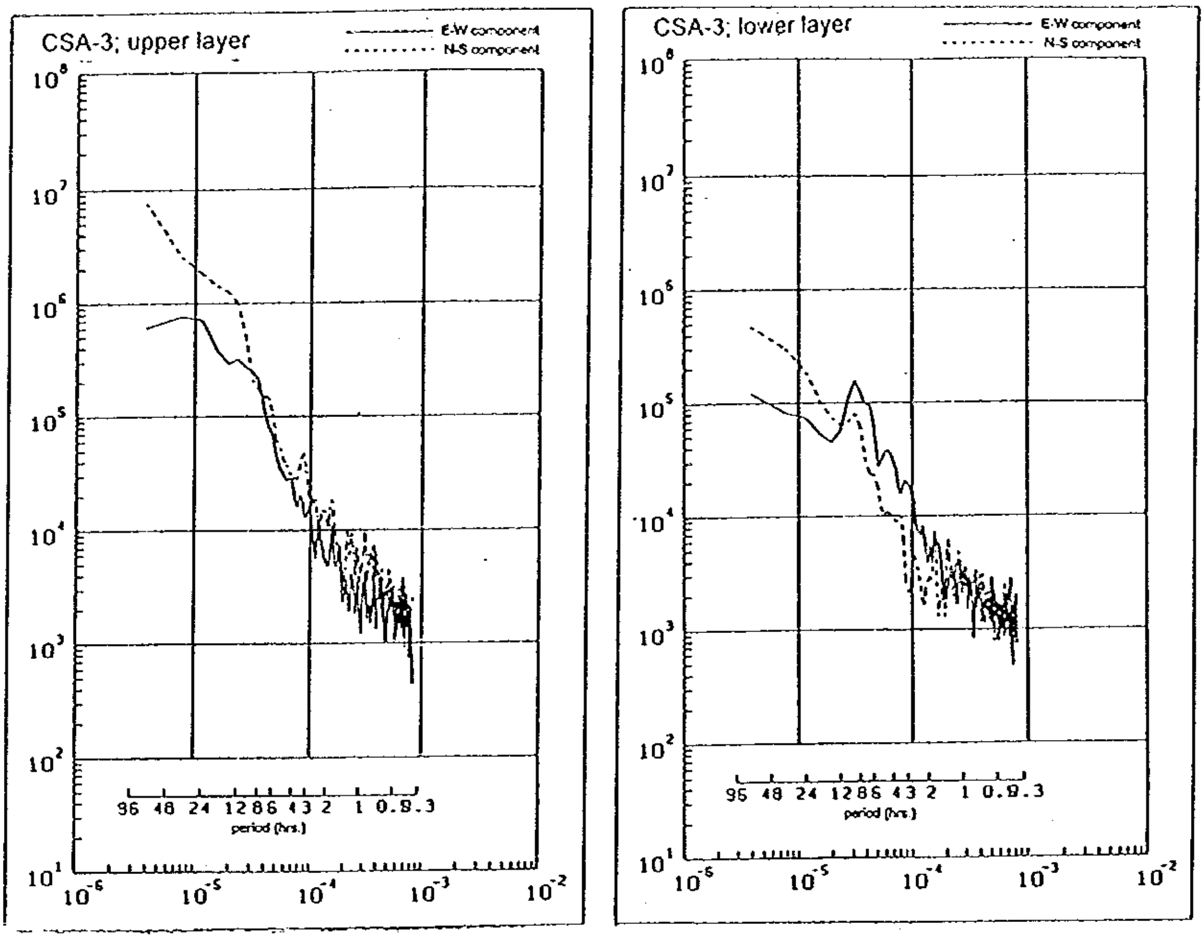


Figure 4.6(2) Power Spectrum of Water Current in the Coastal Area

For reference, the sampling of water current was conducted at 10-minute intervals, so that 25 hours running mean velocity is calculated by equation (4.1).

$$u_{25}(n) = 1/151 \sum_{m=n-75}^{m=n+75} u(m) \qquad (4.1)$$

Where $u_{25}(n)$ is a 25 hours running mean velocity, n and m are sequential numbers of raw data (mean time).

The diffusion coefficients are shown in Table 4.6.

Table 4.6 Diffusion Coefficients in Pueblo Viejo Lagoon for Water Quality Simulation

Point	Observation layer *	East-west component	North-south component
PLC-3	-1.0m	2.05×10^3 cm^2/s	5.84×10^3 cm^2/s
PLC-4	-1.0m	9.55×10^3 cm^2/s	7.37×10^3 cm^2/s
PL-5	-1.0m	5.64×10^3 cm^2/s	2.17×10^3 cm^2/s

* distance from sea bottom

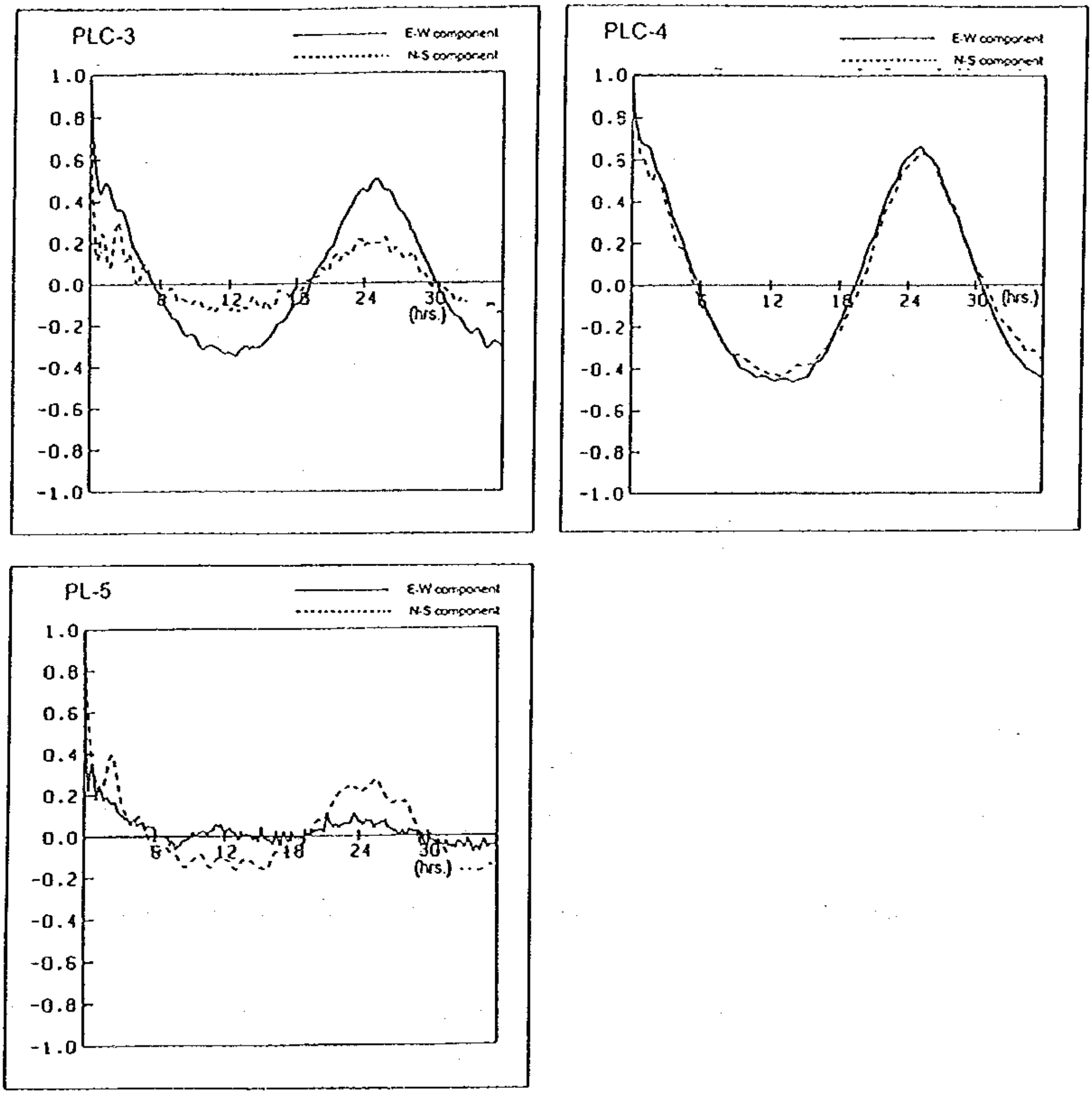


Figure 4.7 Autocorrelation Coefficient of Water Current in Pueblo Viejo Lagoon

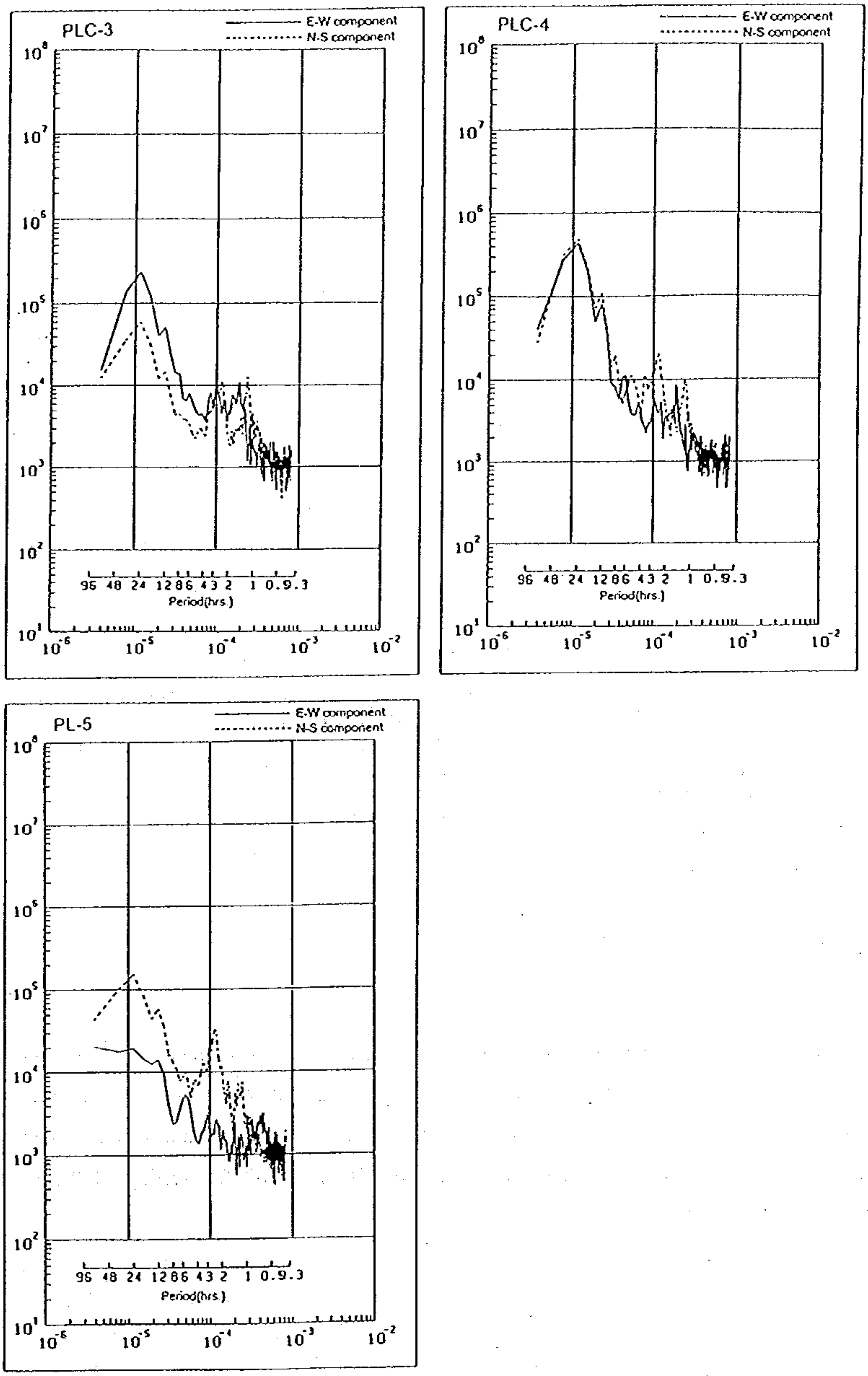


Figure 4.8 Power Spectrum of Water Current in Pueblo Viejo Lagoon

4.3 Water Quality Monitoring

4.3.1 Method

(1) Monitoring Period

As mentioned earlier, the Pilot Water Quality Monitoring was conducted during the following two seasons:

Dry season (Site work I) : March 1, 2, 8 and 9, 1999

Rainy season (Site work II) : July 19, 20, 21 and 22, 1999

(2) Monitoring Areas and Points

The water quality samples were taken from two layers at 23 monitoring points and one layer at 16 monitoring points, as shown in Table 4.7. The observation layers were as follows:

1-layer monitoring points : 0.5 m below surface water

2-layer monitoring points : 0.5 m below surface water

10 m below surface water (If water depth is less than 11m, sample is taken 1m from the bottom.)

Table 4.7 Monitoring Areas and Points

Monitoring Areas	1 Layer Sampling Points	2 Layer Sampling Points	Water & Salinity by STD*
Coastal Area	7	20	6
Panuco River	2	3	
Pueblo Viejo Lagoon	5		
Conejo Lagoon	2		
Total	16	23	6

*The monitoring was carried out in rainy season.

Table 4.8 and Figure 4.9 give the location of water quality monitoring points.

(3) Monitoring Parameters and Analytical Method

The monitoring parameters and the analytical methods are shown in Table 4.9. Although a reference material entitled "A Practical Handbook of Seawater Analysis" was used for the basic parameters, some of the parameters have been analyzed by a common Japanese method for water analysis, the Japan Industrial Standards (JIS) K0102 for Testing Methods for Industrial Wastewater.

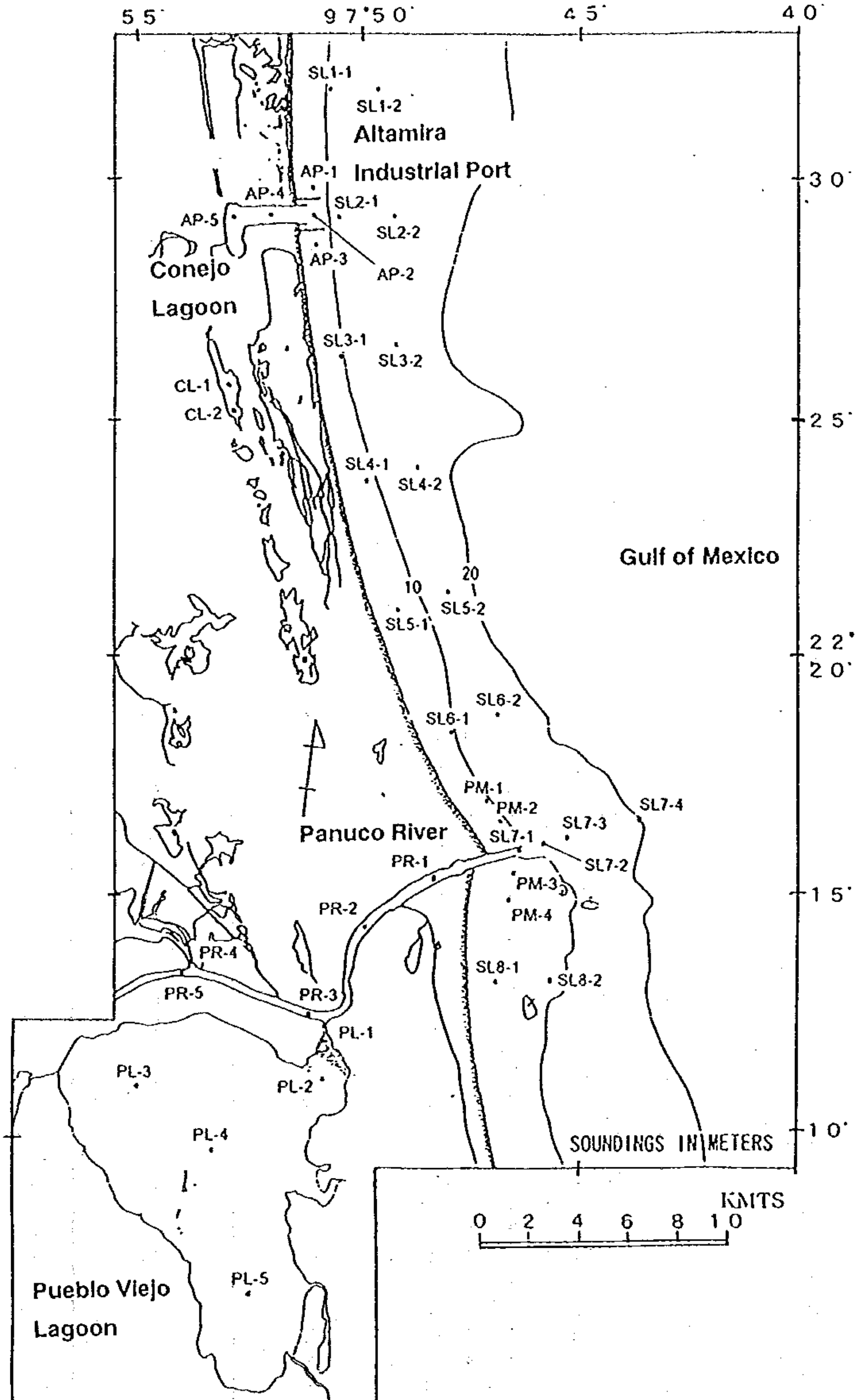


Figure 4.9 Location of Monitoring Points for Water Quality and Sediment

Table 4.8 Sampling Locations of Monitoring Survey

Station	GPS Name	Latitude (N)	longitude (W)	Sample		
				Water Quality		Sediment
				Basic parameter	Toxic Parameter	
Panuco River						
PR - 1	PR1	22° 15.20'	97° 48.36'	◎	O	O
PR - 2	PR2	22° 14.15'	97° 49.90'	O		
PR - 3	PR3	22° 12.40'	97° 51.08'	◎	O	O
PR - 4	PR4	22° 13.61'	97° 53.84'	O		
PR - 5	PR5	22° 13.35'	97° 53.98'	◎	O	O
Pueblo Viejo Lagun						
PL - 1	PL1	22° 12.14'	97° 50.79'	O		
PL - 2	PL2	22° 11.20'	97° 50.79'	O	O	O
PL - 3	PL3	22° 11.15'	97° 55.00'	O		
PL - 4	PL4	22° 09.61'	97° 53.30'	O	O	O
PL - 5	PL5	22° 06.75'	97° 52.50'	O	O	O
El Conejo Lagun						
CL - 1	CL1	22° 25.50'	97° 53.05'	O	O	O
CL - 2	CL2	22° 25.08'	97° 52.80'	O		
Altamira Industrial Port						
AP - 1	AP1	22° 29.82'	97° 51.10'	O		
AP - 2	AP2	22° 29.19'	97° 51.10'	◎	O	O
AP - 3	AP3	22° 28.54'	97° 51.10'	O		
AP - 4	AP4	22° 29.19'	97° 52.11'	◎		
AP - 5	AP5	22° 29.19'	97° 53.11'	◎	O	O
Coastal Sea Area						
SL1 - 1	SL11	22° 31.88'	97° 50.95'	◎	O	O
SL1 - 2	SL12	22° 31.88'	97° 49.70'	O		
SL2 - 1	SL21	22° 29.19'	97° 50.55'	◎	O	O
SL2 - 2	SL22	22° 29.19'	97° 49.29'	◎	O	O
SL3 - 1	SL31	22° 26.28'	97° 50.51'	◎		
SL3 - 2	SL32	22° 26.60'	97° 49.30'	O		
SL4 - 1	SL41	22° 23.64'	97° 49.85'	◎	O	O
SL4 - 2	SL42	22° 23.95'	97° 48.69'	◎	O	
SL5 - 1	SL51	22° 20.99'	97° 49.07'	◎		
SL5 - 2	SL52	22° 21.28'	97° 47.95'	O		
SL6 - 1	SL61	22° 18.35'	97° 47.91'	◎	O	O
SL6 - 2	SL62	22° 18.80'	97° 46.81'	◎	O	O
SL7 - 1	SL71	22° 15.92'	97° 46.25'	◎	O	O
SL7 - 2	SL72	22° 16.04'	97° 45.80'	◎		
SL7 - 3	SL73	22° 16.16'	97° 45.20'	◎	O	O
SL7 - 4	SL74	22° 16.55'	97° 43.50'	O		
SL8 - 1	SL81	22° 13.03'	97° 46.85'	◎	O	O
SL8 - 2	SL82	22° 13.13'	97° 45.60'	O		
PM - 1	PM1	22° 16.99'	97° 47.05'	◎	O	O
PM - 2	PM2	22° 16.50'	97° 46.80'	◎		
PM - 3	PM3	22° 15.38'	97° 46.50'	◎		
PM - 4	PM4	22° 14.87'	97° 46.60'	◎	O	O
SLA - 1	SLA1	22° 16.40'	97° 46.09'	△		
SLA - 2	SLA2	22° 16.85'	97° 45.80'	△		
SLA - 3	SLA3	22° 18.23'	97° 44.71'	△		
SLB - 1	SLB1	22° 15.52'	97° 45.90'	△		
SLB - 2	SLB2	22° 15.20'	97° 45.41'	△		
SLB - 3	SLB3	22° 14.28'	97° 43.95'	△		

◎ : 2 layers sampling point
O : 1 layer sampling point
△ : For only measurement using STD

Table 4.9 List of Monitoring Parameters and Analytical Methods for Water Quality

	Parameter	Method	Reference
Basic Parameter	Transparency	Secchi disc on boat	
	Water temperature	STD on boat	
	Salinity	STD on boat	
	pH	Glass-electrode method	JIS K 0102 12, EPA 150.1
	DO	Winkler-sodium azide modification	PHSA I-3, JIS K 0102 32.1
	COD	Alkaline-iodine method	JIS K 0102 19
	TOC	Non purgeable organic carbon method	JIS K 0102 22, EPA 415.1 By TOC Analyzer
	SS	Gravimetric method	JIS K 0102 14
	NH4-N	Indophenol blue absorptiometry	PHSA II-9
	NO2-N	Naphthylethlen diamine absorptiometry	PHSA II-7, JIS K 0102 43.1, EPA 354.1
	NO3-N	Cd-Cu column reduction method	PHSA II-6, JIS K 0102 43.2, EPA 353.3
	T-N	Cd-Cu column reduction method	JIS K 0102 45.4
	PO4-P	Molybdenum blue absorptiometry	JIS K 0102 46.1, PHSA II-2
	T-P	Molybdenum blue absorptiometry	JIS K 0102 46.3
	Chlorophyll-a	Spectrophotometric determination	PHSA IV-3-1
	Total coliform, Fecal coliform	Membrane filter method	SMEWW 922A, 922D
Toxic Parameter	Hexane extracts	Liquid-liquid extraction, Gravimetric	JIS K 0102 24
	Phenols	4-aminoantipyrine absorptiometry	JIS K0102 28.1.2,
	Cyanide	4-pyridine carboxylic acid - pyraxolone absorptiometry	JIS K 0102 38
	Cr	Diphenylcarbazide absorptiometry	JIS K 0102 65.1.1
	Cr^{6+}	Diphenylcarbazide absorptiometry	JIS K 0102 65.2.1, EPA 7196A
	Cd	Atomic absorption spectrometry	JIS K 0102 55, EPA 7131A
	Pb	Atomic absorption spectrometry	JIS K 0102 54, EPA 7421
	Cu	Atomic absorption spectrometry	JIS K 0102 52, EPA 7211
	Zn	Atomic absorption spectrometry	JIS K 0102 53, EPA 7521
	Ni	Atomic absorption spectrometry	JIS K 0102 59, EPA 7951
	As	Atomic absorption spectrometry using hydride system	JIS K 0102 61.2, EPA 7062
	T-Hg	Atomic absorption spectrometry using vapor reduction system	JIS K 0102 66.1, EPA 7470A
	Alkyl-mercury	Gas chromatography with ECD	JIS K 0102 66.2
	Organo phosphorus	Gas chromatography with FID	Notification No.46(1)
	Trichloroethylene	Gas chromatography with ECD	JIS K 0125 5.5, EPA 8021B
	Tetrachloroethylene	Gas chromatography with ECD	JIS K 0125 5.5, EPA 8021B
	Carbon tetrachloride	Gas chromatography with ECD	JIS K 0125 5.5, EPA 8021B
	PCB	Gas chromatography with ECD	EPA 8082, JIS K 0093(Pretreatment)
	HCB	Gas chromatography with ECD	EPA 8081A, Tentative Survey Manual(2)
	Aldrin	Gas chromatography with ECD	EPA 8081A, Tentative Survey Manual(2)
	Endrin	Gas chromatography with ECD	EPA 8081A, Tentative Survey Manual(2)
	Dieldrin	Gas chromatography with ECD	EPA 8081A, Tentative Survey Manual(2)
	DDT	Gas chromatography with ECD	EPA 8081A, Tentative Survey Manual(2)
	Chlordane	Gas chromatography with ECD	EPA 8081A, Tentative Survey Manual(2)

Notes:
STD : Salinity, Temperature, Depth Measuring System
PHSA : A Practical Handbook on Seawater Analysis
JIS : Japan Industrial Standard
SMEWW : Standard Method for Examination of Water and Wastewater
EPA : Environmental Protection Agency
(1) Notification No. 46, 1971 of the Japanese Environmental Agency
(2) Tentative Survey Manual of External Factor Endocrine Disturbance Chemical Substance
TOC was analyzed in dry season.

For toxic parameters, the *Laboratorio Ambiental Nuevo Tamaulipas* was subcontracted for most of the analysis of dry season survey results. However, some analytical methods have been changed due to the lack of equipment and reagent. On the other hand, the JICA Study Team and *CNA*'s Tampico Laboratory analyzed all of the parameters for the rainy season survey. Most of the toxic parameters had been analyzed using JIS K0102 and the US Environmental Protection Agency (EPA) methods.

4.3.2 Results of Water Quality Survey

(1) Dry Season

The results of water quality analysis in dry season are shown in Table 4.10(1), Table 4.10(2) and Table 4.11. Summarized results are also given in Tables 4.12 and 4.13.

a) Basic Parameters

Transparency was lower than 1 m at all monitoring points of Panuco River, Pueblo Viejo Lagoon, and Conejo Lagoon. In the coastal area, transparency was comparatively low, which is probably a common characteristic in this area.

The distribution of salinity showed a common distinctive feature at the mouth of Panuco River. During the preliminary field survey, it was found that low saline water bodies at upper layer had spread up to 5 km away from the river's mouth. On the other hand, river water extended offshore at 1 km from the mouth of the river in dry season. It was also observed that saline water gradually intruded into Panuco River at the lower layer. At the junction of Tamesi River, a salinity of 30 was identified in the lower layer. Typical thermocline and salinocline can be seen in the study area of Panuco River, from its mouth up to the junction of Tamesi River.

The spatial changes in DO were found in the river and lagoon areas, and there was a little change in the coastal area. Especially in Panuco River, it was comparatively higher in the surface layer than in the lower layer. DO of monitoring points was fairly low in Conejo Lagoon as compared with other water areas.

The distribution of suspended substances (SS) indicated a high value in Pueblo Viejo Lagoon. In Panuco River, it was comparatively high in the surface layer, ranging from 10 to 27 mg/l. For the others, including the coastal area, it was generally low, however, some of the monitoring points showed remarkably high values of SS.

COD, which indicates organic matters, showed high concentrations from 7 to 9 mg/l in Panuco River and Conejo Lagoon, especially at PR3, PR5, CL-1, CL-2. The concentration is also comparatively high in the coastal area, from 1 to 2 mg/l.

Nutrient salt, such as ammonium nitrogen, nitrite nitrogen, nitrate nitrogen and phosphate phosphorus, was observed to be at a low level. Except for a few points, it is necessary to conduct continuous monitoring to determine the trend of change in those parameters.

In Panuco River and Conejo Lagoon, high values of chlorophyll-a were found ranging from 40 to 70 μg/l.

This distribution of chlorophyll-a corresponded with the presence of COD, which indicated a correlation between COD and chlorophyll-a as depicted in Figure 4.10. It may be derived from the figure that the high value of COD is due to the increase of chlorophyll-a, or what is called inner production of phytoplankton. The intersecting point of approximate line and Y-axis should be a positive value, but as seen in the figure, it had a negative value. One of the reasons for this is the method used, which is called spectrophotometric determination. It is not very sensitive and the zero point of the spectrophotometer fairly fluctuated.

Total coliform group number was remarkably high in Panuco River, and indicated that half of Pueblo Viejo Lagoon was contaminated with bacteria. Continuous observation is now required in those areas. For the coastal area, total and fecal coliform in the mouth of Panuco River was higher than in any other sections of the coastal area.

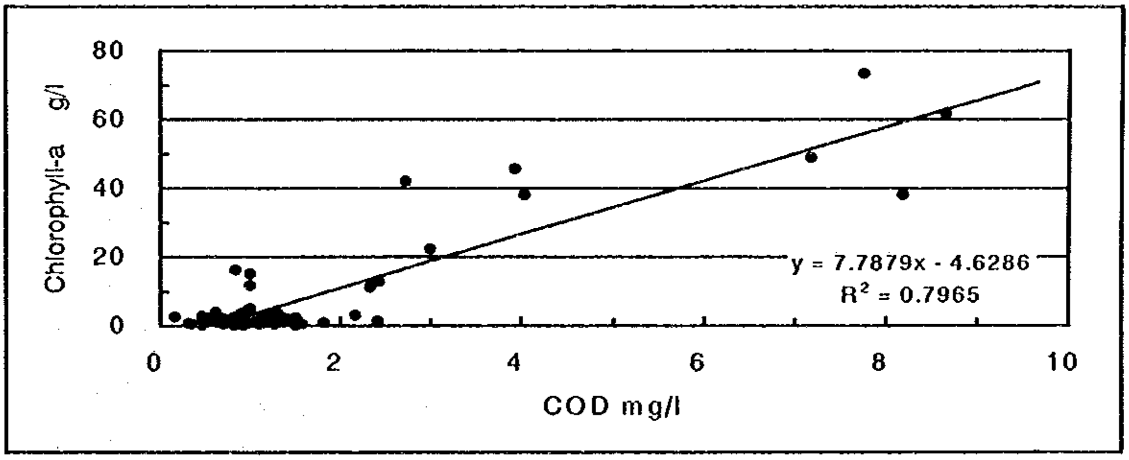


Figure 4.10Relationship between COD and Chlorophyll-a in the Monitoring Area

Table 4.10 (1) Results of Water Quality Analysis in Dry Season [Basic Parameters]

Point No.	Sampling Depth (m)	Depth (m)	Transparency (m)	Forel Color No	Water Temperature ( )	Salinity	pH	DO (mg/l)	COD mg/l)	SS (mg/l)
PR-1	0.5	10	0.5	17	23.9	12.56	8.2	9.2	2.7	27
	9.0				22.7	33.83	8.0	5.9	0.8	16
PR-2	0.5	12	0.7	17	23.7	14.09	8.3	10	4.1	15
PR-3	0.5	9.5	0.7	16	24.2	6.27	8.5	13	7.2	21
	8.5				22.7	33.91	8.1	5.2	1.0	11
PR-4	0.5	7.2	0.6	16	24.4	7.21	8.5	13	3.9	11
PR-5	0.5	9.0	0.8	18	25.1	3.06	8.6	15	7.8	25
	8.0				22.8	33.31	8.0	4.2	1.0	13
PL-1	0.5	5.8	0.6	18	24.4	13.85	8.3	7.7	3.0	25
PL-2	0.5	1.3	0.1	20	24.1	17.16	8.1	7.5	2.4	130
PL-3	0.5	1.0	0.3		25.6	18.82	8.2	7.2	1.0	63
PL-4	0.5	1.2	0.2	19	25.6	18.00	8.2	7.6	2.3	68
PL-5	0.5	1.1	0.4	20	26.4	16.40	8.3	11	2.2	71
AP-1	0.5	3.0	1.6	7	23.3	35.96	8.1	6.6	0.2	3
AP-2	0.5	14	6.0	6	23.7	35.64	8.1	7.1	0.5	6
	10				22.5	36.05	8.1	6.4	0.5	9
AP-3	0.5	7.2	2.1	6	24.0	35.59	8.1	6.8	0.5	3
AP-4	0.5	13	5.0	6	23.5	35.53	8.1	6.9	0.5	5
	10				22.6	36.06	8.1	7.5	1.1	8
AP-5	0.5	13	1.5	6	23.5	35.47	8.2	7.2	0.3	5
	10				22.9	35.59	8.2	6.4	1.3	2
CL-1	0.5	2.3	0.7	16	25.9	1.23	8.1	5.8	8.2	13
CL-2	0.5	0.7	0.5	17	26.0	1.24	8.0	3.1	8.7	22
SL1-1	0.5	11	1.5	9	23.7	36.14	8.1	6.5	0.9	6
	10				22.9	36.22	8.1	6.2	1.2	5
SL1-2	0.5	15	2.5	9	23.7	36.10	8.2	7.0	1.0	5
SL2-1	0.5	13	1.5	10	23.7	36.15	8.2	6.7	1.1	4
	10				23.0	36.22	8.2	5.9	0.8	9
SL2-2	0.5	18	2.6	8	23.8	36.14	8.2	6.5	0.8	3
	10				22.7	36.30	8.3	6.3	1.3	4
SL3-1	0.5	9.5	2.0	10	23.5	36.18	8.2	6.6	2.4	4
	8.5				22.8	36.29	8.2	6.1	1.4	14
SL3-2	0.5	20	2.5	8	23.5	36.02	8.2	6.4	1.4	3
SL4-1	0.5	13	2.0	13	23.2	36.21	8.2	6.9	0.7	8
	10				22.8	36.29	8.2	6.4	0.6	7
SL4-2	0.5	17	2.7	8	24.1	36.04	8.2	6.9	0.9	45
	10				22.8	36.29	8.2	5.9	0.8	26
SL5-1	0.5	8.0	2.0	8	23.4	36.10	8.2	6.6	1.5	6
	7.0				22.7	36.28	8.2	5.7	0.6	4
SL5-2	0.5	20	2.5	8	24.0	36.08	8.2	6.6	1.8	5
SL6-1	0.5	11	2.7	10	23.4	36.02	8.2	6.5	1.1	5
	10				22.7	36.28	8.2	6.0	1.5	4
SL6-2	0.5	20	1.7	10	24.7	35.72	8.2	6.7	0.9	7
	10				22.8	36.27	8.2	5.9	0.7	10
SL7-1	0.5	15	1.0	16	24.9	33.41	8.2	6.6	1.6	20
	10				24.3	36.08	8.2	6.1	0.8	14
SL7-2	0.5	14	1.0	14	25.2	33.11	8.2	7.1	1.5	22
	10				24.1	36.25	8.2	6.7	1.3	11
SL7-3	0.5	14	2.1	10	24.2	36.25	8.2	6.5	0.9	4
	10				23.9	36.27	8.3	6.8	0.7	10
SL7-4	0.5	25	4.0	6	24.0	36.27	8.3	6.6	0.8	1
SL8-1	0.5	6.8	1.5	10	24.5	36.27	8.3	6.7	1.6	7
	5.8				24.3	36.26	8.2	6.5	1.1	7
SL8-2	0.5	12	2.0	8	24.1	36.27	8.2	4.8	0.4	14
PM-1	0.5	12	2.0	10	23.4	36.11	8.2	6.2	0.8	6
	10				22.6	36.30	8.2	6.0	1.3	8
PM-2	0.5	9.0	1.1	13	23.6	36.17	8.2	6.3	1.3	12
	8.0				22.7	36.29	8.2	6.0	1.2	14
PM-3	0.5	5.4	1.1	16	24.7	36.22	8.2	6.8	1.4	18
	4.4				24.6	36.21	8.2	6.8	0.8	27
PM-4	0.5	6.0	1.2	15	24.5	36.23	8.2	6.7	0.9	50
	5.0				24.4	36.23	8.2	6.5	1.0	29

Note:
Sampling Dates:
March 1, 1999 at PR-1 to PR-5, PL-1 to PL-5
March 2, 1999 at AP-1 to AP-5, CL-1 to CL-2
March 8, 1999 at SL6-1 to SL8-2, PM-1 to PM-4
March 9, 1999 at SL1-1 to SL5-2

Table 4.10 (2) Results of Water Quality Analysis in Dry Season [Basic Parameters]

Sampling Depth (m)	NH_4-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Total Nitrogen (mg/l)	PO_4-P (mg/l)	Total Phosphorus (mg/l)	Chlorophyll-a (g/l)	Total Coliform (Col./100 ml)	Fecal Coliform (Col./100 m)
0.5	<0.01	0.01	0.16	0.72	0.07	0.12	42	2.3×10^{3}	4.7×10^{2}
9.0	0.06	0.01	0.03	0.41	0.01	0.17	16		
0.5	0.02	0.02	0.18	0.65	0.07	0.23	38	4.9×10^{3}	4.0×10^{3}
0.5	0.02	0.02	0.16	0.56	0.07	0.25	49	5.8×10^{2}	5.7×10^{1}
8.5	0.04	0.02	0.05	0.39	0.02	0.21	5.0		
0.5	0.01	0.01	0.21	0.60	0.06	0.15	46	1.8×10^{2}	4.2×10^{1}
0.5	0.04	0.01	0.17	0.57	0.08	0.23	73	3.0×10^{0}	3.0×10^{0}
8.0	0.04	0.01	0.09	0.37	0.10	0.12	12		
0.5	0.04	0.01	0.13	0.65	0.07	0.11	22	1.6×10^{4}	1.6×10^{4}
0.5	0.03	0.01	0.14	0.42	0.06	0.10	13	2.3×10^{3}	8.3×10^{2}
0.5	0.03	<0.01	0.01	0.27	0.07	0.12	15	7.0×10^{0}	ND
0.5	<0.01	<0.01	<0.01	0.65	0.06	0.08	11	9.8×10^{2}	9.8×10^{2}
0.5	<0.01	<0.01	<0.01	0.65	0.05	0.08	3.2	6.0×10^{0}	2.0×10^{0}
0.5	<0.01	<0.01	0.01	0.13	0.02	0.04	2.7	1.5×10^{1}	1.0×10^{0}
0.5	<0.01	<0.01	0.01	0.16	0.02	0.15	0.2	4.0×10^{0}	ND
10	<0.01	<0.01	<0.01	0.09	0.01	0.05	2.2		
0.5	<0.01	<0.01	<0.01	0.13	0.01	0.09	1.2	8.0×10^{0}	1.0×10^{0}
0.5	<0.01	<0.01	<0.01	0.09	0.01	0.08	2.9	1.4×10^{1}	1.0×10^{0}
10	<0.01	<0.01	<0.01	0.12	0.01	0.05	0.6		
0.5	<0.01	<0.01	<0.01	0.20	0.03	0.10	0.7	1.1×10^{1}	5.0×10^{0}
10	<0.01	<0.01	<0.01	0.18	0.01	0.03	2.7		
0.5	0.02	<0.01	<0.01	1.4	0.07	0.12	38	3.8×10^{1}	2.9×10^{1}
0.5	0.02	<0.01	<0.01	1.6	0.15	0.17	62	1.8×10^{2}	3.2×10^{1}
0.5	<0.01	<0.01	0.05	0.09	0.05	0.08	0.1	ND	ND
10	<0.01	<0.01	0.02	0.17	0.06	0.11	2.0		
0.5	<0.01	<0.01	0.02	0.02	0.02	0.09	0.7	ND	ND
0.5	0.01	<0.01	0.02	0.14	0.05	0.07	1.8	ND	ND
10	0.01	<0.01	0.03	0.08	0.04	0.10	1.4		
0.5	<0.01	<0.01	0.04	0.24	0.04	0.04	1.9	ND	ND
10	0.01	<0.01	0.03	0.23	0.04	0.08			
0.5	0.01	<0.01	0.02	0.28	0.03	0.12	1.6	ND	ND
8.5	0.01	<0.01	0.02	0.20	0.05	0.09	1.2		
0.5	<0.01	<0.01	0.02	0.02	0.08	0.15	2.1	ND	ND
0.5	0.01	<0.01	0.02	0.13	0.02	0.07	2.1	ND	ND
10	<0.01	<0.01	0.02	0.15	0.03	0.11	4.0		
0.5	<0.01	<0.01	0.02	0.11	0.04	0.11	0.6	ND	ND
10	0.01	<0.01	0.02	0.16	0.05	0.11	0.1		
0.5	0.01	<0.01	0.02	0.13	0.04	0.06	2.3	ND	ND
7.0	<0.01	<0.01	0.03	0.13	0.04	0.09	1.8		
0.5	0.02	<0.01	0.03	0.14	0.04	0.05	0.9	1.4×10^{1}	9.0×10^{0}
0.5	<0.01	<0.01	0.03	0.18	0.03	0.07	1.4	5.0×10^{0}	ND
10	0.01	<0.01	0.04	0.21	0.03	0.06	0.2		
0.5	<0.01	<0.01	0.02	0.12	0.04	0.07	1.0	1.0×10^{0}	ND
10	<0.01	<0.01	0.03	0.18	0.03	0.08	0.7		
0.5	<0.01	<0.01	0.01	0.35	0.05	0.10	0.5	9.1×10^{1}	6.7×10^{1}
10	0.01	<0.01	0.02	0.32	0.03	0.07	1.8		
0.5	<0.01	<0.01	0.03	0.36	0.10	0.13	2.4	1.4×10^{1}	8.0×10^{0}
10	<0.01	<0.01	0.01	0.01	0.02	0.04	0.6		
0.5	<0.01	<0.01	0.01	0.01	0.04	0.04	0.3	ND	ND
10	<0.01	<0.01	0.01	0.15	0.04	0.08	0.5		
0.5	<0.01	<0.01	0.01	0.12	0.03	0.05	0.5	ND	ND
0.5	<0.01	<0.01	0.01	0.20	0.03	0.04	0.6	ND	ND
5.8	<0.01	<0.01	0.03	0.04	0.07	0.10	0.6		
0.5	0.01	<0.01	0.01	0.05	0.03	0.12	0.5	ND	ND
0.5	0.01	<0.01	0.02	0.13	0.03	0.04	2.8	3.0×10^{0}	ND
10	0.02	<0.01	0.03	0.05	0.04	0.04	1.0		
0.5	0.01	<0.01	0.02	0.11	0.04	0.20	3.7	1.6×10^{1}	ND
8.0	0.01	<0.01	0.04	0.10	0.04	0.13	2.9		
0.5	<0.01	<0.01	0.03	0.19	0.03	0.04	1.4	-	-
4.4	<0.01	<0.01	0.01	0.14	0.03	0.04	2.0		
0.5	0.01	<0.01	0.11	0.30	0.04	0.06	3.7	ND	ND
5.0	0.02	<0.01	<0.01	0.15	0.04	0.08	4.4		

Note:
Sampling Dates:
March 1, 1999 at PR-1 to PR-5, PL-1 to PL-5
March 2, 1999 at AP-1 to AP-5, CL-1 to CL-2
March 8, 1999 at SL6-1 to SL8-2, PM-1 to PM-4
March 9, 1999 at SL1-1 to SL5-2

Table 4.11 Results of Water Quality Analysis in Dry Season [Toxic Parameters]

Point No.	Sampling Depth (m)	Hexane Extract (mg/l)	Phenols (mg/l)	Cyanide (mg/l)	Cr (mg/l)	Cr^{6+} (mg/l)	Cd (mg/l)	Pb (mg/l)	Cu (mg/l)	Zn (mg/l)	Ni (mg/l)	As (mg/l)	Hg (mg/l)
PR-1	0.5	1.2	<0.001	<0.006	<0.01	<0.01	<0.002	0.01	<0.005	0.033	<0.005	0.002	<0.001
PR-2	0.5	1.5		-	-	-	-	-	-	-	-	-	-
PR-3	0.5	1.4	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.019	<0.005	0.004	<0.001
PR-4	0.5	1.7	-	-	-	-	-	-	-	-	-	-	-
PR-5	0.5	1.9	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.023	<0.005	0.004	<0.001
PL-2	0.5	1.3	<0.001	<0.006	0.02	<0.01	<0.002	<0.01	<0.005	0.049	<0.005	0.004	<0.001
PL-4	0.5	1.7	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.050	<0.005	0.002	<0.001
PL-5	0.5	1.9	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.037	<0.005	0.001	<0.001
AP-2	0.5	1.7	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.041	<0.005	<0.001	<0.001
AP-4	0.5	2.0	-	-	-	-	-	-	-	-	-	-	-
AP-5	0.5	1.5	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.045	<0.005	0.002	<0.001
CL-1	0.5	2.8	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.023	<0.005	<0.001	<0.001
SL1-1	0.5	1.0	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.004	0.006	<0.001	<0.001
SL2-1	0.5	0.7	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.010	0.005	<0.001	<0.001
SL2-2	0.5	2.2	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.006	<0.005	<0.001	<0.001
SL3-1	0.5	1.4	-	-	-	-	-	-	-	-	-	-	-
SL4-1	0.5	1.2	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.011	<0.005	<0.001	<0.001
SL4-2	0.5	1.2	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.010	<0.005	<0.001	<0.001
SL6-1	0.5	1.7	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.004	<0.005	<0.001	<0.001
SL6-2	0.5	1.0	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.002	<0.005	<0.001	<0.001
SL7-1	0.5	1.1	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.016	<0.005	<0.001	<0.001
SL7-3	0.5	0.9	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.002	<0.005	<0.001	<0.001
SL8-1	0.5	0.7	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.002	0.005	<0.001	<0.001
PM-1	0.5	0.6	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.004	0.007	<0.001	<0.001
PM-4	0.5	1.2	<0.001	<0.006	<0.01	<0.01	<0.002	<0.01	<0.005	0.007	<0.005	<0.001	<0.001

Point No.	Sampling Depth (m)	Alkyl-Hg (mg/l)	Organo Phosphorous (mg/l)	Trichloroethylene (mg/l)	Tetrachloro-ethylene (mg/l)	Carbon Tetrachloride (mg/l)	PCB (mg/l)	HCB (mg/l)	Aldrin (mg/l)	Endrin (mg/l)	Dieldrin (mg/l)	DDT (mg/l)	Chlordane (mg/l)
PR-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-2	0.5	-	-	-	-	-	-	-	-	-	-	-	-
PR-3	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-4	0.5	-	-	-	-	-	-	-	-	-	-	-	-
PR-5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-4	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-4	0.5	-	-	-	-	-	-	-	-	-	-	-	-
AP-5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CL-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL1-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL2-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL2-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL3-1	0.5	-	-	-	-	-	-	-	-	-	-	-	-
SL4-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL4-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL6-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL6-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL7-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL7-3	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL8-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-4	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note

Sampling Dates:

March 1,1999 at PR-1 to PR-5, PL-2,PL-4, PL-5

March 2,1999 at AP-2, AP-4, AP-5, CL-1

March 8,1999 at SL6-1, SL6-2, SL7-1, SL7-3, SL8-1, PM-1, PM-4

March 9,1999 at SL1-1, SL2-1, SL2-2, SL3-1, SL4-1, SL4-2

ND means "Not Detected".

Table 4.12 Summarized Results of Pilot Water Quality Monitoring in Dry Season [Basic Parameters]

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area (River Mouth)	Coastal Area
Transparency(m)	0.5-0.8	0.1-0.6	S:0.5-0.7	1.5-6.0	1.0-4.0	1.5-2.7
Water temperature(℃)	S:23.7-25.1, B22.7-22.8	S:24.1-26.4	S:25.9-26.0	S:23.3-24.0, D:22.5-22.9	S:23.4-25.2, D:22.6-24.6	S:23.2-24.1, D:22.7-23.0
Salinity	S:3.06-14.09, B33.31-33.91	S:13.85-18.82	S:<2	S:35.47-35.96, D:35.59-36.06	S:33.11-36.27, D:36.08-36.30	S:36.02-36.21, D:36.22-36.30
pH	S:8.2-8.6, B:8.0-8.1	S:8.1-8.3	S:8.0-8.1	S:8.1-8.2, D:8.1-8.2	S:8.2-8.3, D:8.2-8.3	S:8.1-8.2, D:8.1-8.3
DO(mg/l)	S:9.2-15, B:4.2-5.9	S:7.2-11	S:3.1-5.8	S:6.6-7.2, D:6.4-7.5	S:4.8-7.1, :5.9-6.8	S:6.4-7.0, D:5.7-6.4
COD(mg/l)	S:2.7-7.8, B:0.8-1.0	S:1.0-1.3	S:8.2-8.7	S:0.2-0.5, D:0.5-1.3	S:0.4-1.6, D:0.7-1.5	S:0.7-8.7 D:0.6-1.4
SS(mg/l)	S:11-27, B:11-16	S:25-130	S:13-22	S:3-6, D:2-9	S:1-50, D:4-29	S:3-45, D:4-26
NH_4-N(mg/l)	S:<0.01-0.04, B:<0.04-0.06	S:<0.01-0.04	S:0.02	S:<0.01, D:<0.01	S:<0.01-0.01, D:<0.01-0.02	S:<0.01-0.02, D:<0.01-0.01
NO_2-N(mg/l)	S:0.01-0.02, B:0.01-0.02	S:<0.01-0.01	S:<0.01	S:<0.01, D:<0.01	S:<0.01, D:<0.01	S:<0.01, D:<0.01
NO_3-N(mg/l)	S:0.16-0.21, B:0.03-0.09	S:<0.01-0.14	S:<0.01	S:<0.01-0.01, D:<0.01	S:0.01-0.11, D:<0.01-0.04	S:0.02-0.05, D:0.02-0.03
T-N(mg/l)	S:0.56-0.72, B:0.37-0.41	S:0.27-0.65	S:1.4-1.6	S:0.09-0.20, D:0.09-0.18	S:0.01-0.36, D:0.01-0.32	S:0.02-0.28, D:0.08-0.23
PO_4-P(mg/l)	S:0.06-0.08, B:0.01-0.10	S:0.05-0.07	S:0.07-0.15	S:0.01-0.03, D:0.01-0.03	S:0.03-0.10, D: 0.02-0.07	S:<0.02-0.08, D: 0.03-0.06
T-P(mg/l)	S:0.12-0.25, B:0.12-0.21	S:0.08-0.12	S:0.12-0.17	S:0.04-0.15, D:0.03-0.05	S:0.04-0.20, D:0.04-0.13	S:0.04-0.15, D:0.08-0.11
Chlorophyll-a(μg/l)	S:38-73, B:5.0-16	S:3.2-22	S:38-62	S:0.2-2.9, D:0.6-2.7	S:0.3-3.7, D0.2-4.4	S:0.1-2.3, D:0.1-4.0
Total coliform(Col./100ml)	S:1.8×10^2-4.9×10^3	S:6.0×10^0-1.6×10^4	S:3.8×10^1-1.8×10^2	S:4.0×10^0-1.5×10^1	S:ND-9.1×10^1	S:ND-1.4×10^1
Fecal coliform(Col./100ml)	S:3.0×10^0-4.0×10^3	S:ND-1.6×10^4	S:2.9×10^1-3.2×10^1	S:ND-5.0×10^0	S:ND-6.7×10^1	S:ND-9.0×10^0

Note: S: Surface (0.5 m layer); B: 1 m from the bottom; D: 10 m below surface water, but if water depth is less than 10 m, 1 m from the bottom is indicated.
Coastal Area means the points of SL1-SL15 lines; Coastal Area (river mouth) means the points of SL-6, SL-7, SL-8 and PM lines.
ND means not detected.

Table 4.13 Summarized Results of Pilot Water Quality Monitoring in Dry Season [Toxic Parameters]

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area(River Mouth)	Coastal Area
Phenols (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cyanide (mg/l)	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Cr (mg/l)	<0.01	<0.01-0.024	<0.01	<0.01	<0.01	<0.01
Cr^{6+} (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cd (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Pb (mg/l)	<0.01-0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005-0.006	<0.005
Zn (mg/l)	0.028	0.019-0.023	0.028	0.037-0.05	0.002-0.016	0.004-0.01
Ni (mg/l)	<0.005	<0.005	<0.005	<0.005-0.006	<0.005-0.006	<0.005-0.007
As (mg/l)	0.002-0.004	0.001-0.004	<0.001	<0.001-0.002	<0.001	<0.001
T-Hg (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Alkyl-mercury(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Methyl parathion(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Parathion(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Trichloroethylene(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Tetrachloroethylene(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Carbon tetrachloride(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
PCB(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
HCB (mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Aldrin (mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Endrin(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Dieldrin(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
DDT(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Chlordane(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D

Note
Coastal Area(River Mouth) means the points of SL6, SL7, SL8 and PM lines.
Coastal Area means the points of SL1-SL5 lines.
All samples were taken under the surface.

b) Toxic Parameters

Nineteen out of the 25 parameters analyzed, e.g. cyanide, hexavalent chromium, pesticides, PCB, showed low concentrations at below minimum detection limit in all monitoring points.

The hexane extracts of most of the monitoring points range from 1 to 2 mg/l. Provided that water contains 0.1 to 0.01 mg/l of mineral oil as hexane extracts, fishes and shellfishes should give out an oily smell in general. It is necessary to observe this condition very carefully from now on.

Three heavy metals of chromium, copper and nickel were detected above minimum detection limit only at one point, but they did not get beyond three times the minimum detection limit.

Arsenic, which has a minimum detection limit of 0.001 mg/l, was detected at an amount of 0.001-0.004 mg/l in seven monitoring points. But the amounts were below the permissible level for marine water in coastal areas, as established by *CNA* (with a criteria of 0.04 mg/l) and the Japanese environmental criteria (0.01 mg/l).

Zinc concentrations at all points showed values above the minimum detection limit. The concentrations in each water area are as follows:

Pueblo Viejo Lagoon	:	0.04 - 0.05 mg/l,
Altamira Industrial Port	:	0.04 - 0.05 mg/l,
Panuco River	:	0.02 - 0.03 mg/l
Coastal Area	:	0.002- 0.02 mg/l.

Although *CNA's* permissible value of zinc is 0.09 mg/l, a conclusive statement on the above conditions cannot be made.

(2) Rainy Season

The results of water quality analysis in raining season are shown in Table 4.14(1), Table 4.14(2) and Table 4.15. Summarized results are presented in Tables 4.16 and 4.17.

a) Basic Parameters

As a whole, the results in the rainy season, when the survey was done at ebb tide, indicated a low level of salinity. Especially in Panuco River there was still fresh water at the mouth of the river, even the bottom layer. The high saline water mass found at the bottom layer in dry season had disappeared and that effect reached the northeast area of Pueblo Viejo Lagoon. The level of salinity had dropped to below half of the dry season level in the large part of the lagoon.

Table 4.14 (1) Results of Water Quality Analysis in Rainy Season [Basic Parameters]

Point No.	Sampling Depth(m)	Depth (m)	Transparency (m)	Forel Color No	Water Temperature ( )	Salinity	pH	DO (mg/l)	COD mg/l	TOC (mg/l)	SS (mg/l)
PR-1	0.5	9.1	0.3	20	27.3	<2	7.6	5.2	3.6	6.5	280
	8.1				27.2	<2	7.8	5.1	4.1	5.9	370
PR-2	0.5	5.5	0.3	18	26.9	<2	7.7	5.2	3.6	3.2	210
PR-3	0.5	13	0.4	20	26.8	<2	7.6	5.5	3.9	2.5	310
	10				26.7	<2	7.8	5.2	5.4	4.2	560
PR-4	0.5	6.9	0.3	17	29.2	<2	7.6	4.9	4.4	7.5	43
PR-5	0.5	9.1		19			7.6	5.5	4.4	6.5	380
		(Uncollected)									
PL-1	0.5	5.4	0.3	18	27.1	<2	7.0	5.8	1.8	2.3	130
PL-2	0.5	1.1	0.5	12	27.7	<2	7.0	5.9	1.3	2.2	30
PL-3	0.5	1.0	0.6	17	28.9	10.60	8.0	6.0	4.3	6.8	21
PL-4	0.5	1.3	0.5	17	28.7	8.36	8.3	6.0	5.2	7.6	55
PL-5	0.5	1.3	0.7	19	28.7	6.96	8.0	6.4	6.8	10	13
AP-1	0.5	4.1	2.6	8	27.9	31.97	8.2	6.8	3.4	1.6	5
AP-2	0.5	8.5	2.5	9	28.4	29.75	8.2	7.4	1.0	2.3	4
	7.5				24.7	34.45	8.0	4.0	1.0	1.7	10
AP-3	0.5	4.7	1.0	9	27.3	32.51	8.2	6.3		1.7	11
AP-4	0.5	11	1.3	9	27.0	32.85	8.2	8.2	1.6	2.5	10
	10				22.7	36.12	7.9	3.6	0.9	1.2	13
AP-5	0.5	13	1.1	21	26.5	32.12	8.2	8.9	4.8	5.1	12
	10				22.7	36.09	7.9	3.3	2.6	1.3	10
CL-1	0.5	2.1	0.4	12	29.3	0.92	7.3	3.1	8.2	12	24
CL-2	0.5	1.2	0.4		29.6	0.86	7.2	<0.5	8.9	13	20
MA-1	0.3	0.2	0.2	15	32.5	13.31	9.0	12	10	32	100
MA-2	1.0	0.5	0.3	16	31.1	12.25	9.0	10	10	35	37
MA-3	0.5	0.2	0.3	14	31.3	12.80	8.9	4.4	10	33	30
SL1-1	0.5	9.1	3.1	8	27.8	32.12	8.1	7.0	0.8	2.8	1
	8.1				24.2	35.13	8.0	4.7	2.1	2.3	5
SL1-2	0.5	15	4.0	6	27.8	32.38	8.2	8.3	2.2	2.5	2
SL2-1	0.5	11	4.0	8	28.0	32.37	8.2	7.2	1.9	2.5	2
	10				22.5	36.30	7.9	3.8	3.0	2.5	6
SL2-2	0.5	18	3.8	6	27.6	32.47	8.2	7.1	1.5	2.2	3
	10				22.9	36.29	8.0	6.0	0.9	1.8	1
SL3-1	0.5	9.4	3.5	8	27.0	33.05	8.2	6.0	1.7	2.8	3
	8.4				23.2	36.08	7.3	3.2	1.8	2.6	22
SL3-2	0.5	17	4.0	7	27.0	32.76	8.2	7.0	1.4	2.5	2
SL4-1	0.5	9.6	3.6	8	27.2	32.16	8.2	6.9	2.0	2.5	2
	8.6				23.3	35.98	8.0	4.9	1.7	2.3	3
SL4-2	0.5	17	4.6	7	27.0	33.01	8.2	7.0	2.5	2.3	1
	10				23.4	36.27	8.1	6.0	1.1	1.7	1
SL5-1	0.5	9.3	2.8	8	27.5	32.65	8.2	9.0	1.3	3.3	3
	8.3				23.0	36.17	3.1	7.2	1.7	3.0	5
SL5-2	0.5	17	3.0	6	27.7	33.15	8.2	8.6	1.6	3.1	3
SL6-1	0.5	12	2.1	17	27.8	32.57	8.3	9.2	1.9	3.2	5
	10				22.8	36.25	8.1	5.6	1.1	2.5	5
SL6-2	0.5	20	2.3	16	27.1	33.40	8.1	8.5	3.8	2.8	4
	10				22.7	36.27	8.0	5.6	1.0	2.3	3
SL7-1	0.5	14	1.0	17	26.4	19.77	8.1	6.8	2.9	3.5	19
	10				22.7	36.31	8.0	5.6	1.7	2.3	3
SL7-2	0.5	15	1.5	14	25.8	33.01	8.1	6.9	3.0	3.4	15
	10				22.6	36.31	8.1	5.9	0.7	2.2	3
SL7-3	0.5	14	1.0	16	26.2	32.10	8.2	7.5	2.3	3.5	16
	10				22.7	36.26	8.1	6.5	1.7	2.4	3
SL7-4	0.5	21	1.5	17	26.5	35.53	8.2	8.6	1.7	3.2	9
SL6-1	0.5	5.7	1.2	17	26.8	34.69	8.3	8.7	2.0	3.4	13
	4.7				26.1	35.25	8.1	6.6	1.5	2.3	3
SL8-2	0.5	9.7	1.3	15	26.8	34.94	8.2	8.1	2.0	3.1	11
PM-1	0.5	14	1.9	14	27.3	31.72	8.2	8.9	2.1	3.0	5
	10				22.9	36.24	8.1	5.8	2.6	2.4	6
PM-2	0.5	12	2.5	17	26.9	31.63	8.3	8.8	3.8	2.6	5
	10				22.9	36.17	8.1	6.0	1.2	2.4	5
PM-3	0.5	5.8	1.0	18	26.7	30.99	8.0	6.3	1.8	3.2	22
	4.8				26.0	34.79	8.0	6.0	0.8	2.2	7
PM-4	0.5	4.1	0.9	17	27.3	26.45	8.1	8.4	2.7	3.1	31
	3.1				26.5	35.05	8.2	6.7	2.4	3.3	13

Note

Bottom sample at PR-5 could not be taken because of strong flow.

Sampling Dates:

July 19, 1999 at SL6-1 to SL8-2, PM-1 to PM-4

July 20, 1999 at SL1-1 to SL5-2

July 21, 1999 at PR-1 to PR-5, PL-1 to PL-5, AP-1 to AP-5

July 22, 1999 at CL-1 to CL-2

Table 4.14 (2) Results of Water Quality Analysis in Rainy Season [Basic Parameters]

Point No.	Sampling Depth(m)	NH_4-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Total Nitrogen (mg/l)	PO_4-P (mg/l)	Total Phosphorus (mg/l)	Chlorophyll-a (g/l)	Total Coliform (Col./100 ml)	Fecal Coliform (Col./100 ml)
PR-1	0.5	0.007	0.01	0.84	1.2	0.10	0.10	5.8	3.6×10^{3}	2.9×10^{3}
	8.1	0.020	0.011	0.34	0.54	0.12	0.13	5.1		
PR-2	0.5	<0.007	0.007	0.49	0.64	0.10	0.11	4.5	2.7×10^{3}	2.1×10^{3}
PR-3	0.5	<0.007	0.007	0.44	0.88	0.11	0.11	4.7	3.0×10^{3}	1.8×10^{3}
	10	0.008	0.006	0.93	1.1	0.11	0.30	7.0		
PR-4	0.5	0.020	0.007	0.19	0.37	0.060	0.086	18	2.4×10^{2}	1.2×10^{2}
PR-5	0.5	0.010	0.007	0.35	1.1	0.13	0.17	4.8	3.5×10^{3}	2.4×10^{3}
PL-1	0.5	<0.007	0.007	0.61	0.68	0.091	0.10	27	1.7×10^{3}	1.3×10^{3}
PL-2	0.5	<0.007	0.006	0.48	0.51	0.10	0.11	3.7	1.3×10^{3}	5.5×10^{2}
PL-3	0.5	0.020	<0.002	0.01	0.51	0.044	0.067	12	1.4×10^{3}	1.1×10^{3}
PL-4	0.5	0.030	0.005	0.04	0.55	0.048	0.053	16	1.8×10^{3}	7.0×10^{1}
PL-5	0.5	<0.007	0.006	0.01	0.35	0.062	0.072	13	5.8×10^{3}	1.8×10^{3}
AP-1	0.5	<0.007	<0.002	0.01	0.34	0.005	0.038	1.1	ND	ND
AP-2	0.5	<0.007	<0.002	0.02	0.36	0.010	0.048	3.4	8.0×10^{2}	2.0×10^{2}
	7.5	0.010	0.002	0.01	0.17	0.013	0.030	6.7		
AP-3	0.5	<0.007	0.001	0.01	0.32	0.007	0.022	1.8	3.0×10^{1}	1.0×10^{1}
AP-4	0.5	<0.007	0.002	0.01	0.42	0.026	0.037	4.7	6.0×10^{3}	2.0×10^{3}
	10	0.030	0.004	0.02	0.41	0.003	0.010	1.4		
AP-5	0.5	0.010	0.003	0.01	0.54	0.12	0.13	6.8	1.3×10^{2}	1.1×10^{2}
	10	0.040	0.007	0.02	0.37	0.017	0.030	1.3		
CL-1	0.5	<0.007	<0.002	0.01	0.77	0.067	0.20	90	6.1×10^{2}	1.8×10^{2}
CL-2	0.5	0.010	0.007	0.02	1.3	0.12	0.51	103	2.0×10^{3}	ND
MA-1	0.3	0.010	0.004	0.03	1.2	0.03	0.19	120	ND	ND
MA-2	1.0	0.007	0.004	0.08	0.1	0.04	0.36	160	ND	ND
MA-3	0.5	0.007	0.015	0.04	1.1	0.04	0.35	140	ND	
SL1-1	0.5	<0.007	<0.002	0.02	0.19	<0.003	0.024	0.5	1.0×10^{0}	ND
	8.1	<0.007	0.002	0.03	0.36	<0.003	0.034	2.6		
SL1-2	0.5	<0.007	<0.002	0.01	0.32	0.004	0.042	0.8	-	-
SL2-1	0.5	<0.007	<0.002	0.01	0.32	0.007	0.033	0.5	ND	ND
	10	0.009	0.002	0.01	0.38	0.007	0.053	6.0		
SL2-2	0.5	<0.007	<0.002	0.01	0.18	<0.003	0.011	1.1	ND	ND
	10	<0.007	<0.002	0.01	0.22	0.005	0.029	0.8		
SL3-1	0.5	<0.007	0.001	0.01	0.29	0.004	0.025	0.8	ND	ND
	8.4	<0.007	<0.002	0.01	0.37	<0.003	0.037	6.1		
SL3-2	0.5	<0.007	<0.002	0.01	0.24	<0.003	0.027	1.3	ND	ND
SL4-1	0.5	<0.007	<0.002	0.02	0.24	<0.003	0.030	1.4	1.0×10^{0}	ND
	8.6	<0.007	<0.002	0.01	0.33	<0.003	0.040	5.5		
SL4-2	0.5	<0.007	<0.002	0.01	0.29	0.009	0.023	2.5	1.0×10^{1}	ND
	10	<0.007	<0.002	0.01	0.20	0.009	0.030	0.6		
SL5-1	0.5	<0.007	0.002	0.02	0.27	<0.003	0.050	3.2	1.0×10^{2}	ND
	8.3	<0.007	<0.002	0.01	0.04	<0.003	0.055	7.3		
SL5-2	0.5	<0.007	<0.002	0.08	0.27	<0.003	0.041	3.0	3.0×10^{0}	ND
SL6-1	0.5	<0.007	<0.002	0.03	0.35	<0.003	0.065	4.3	1.0×10^{1}	ND
	10	<0.007	<0.002	0.04	0.15	<0.003	0.055	6.0		
SL6-2	0.5	<0.007	<0.002	0.01	0.34	<0.003	0.042	5.5	ND	ND
	10	<0.007	<0.002	0.02	0.22	<0.003	0.046	1.6		
SL7-1	0.5	0.030	0.003	0.13	0.13	0.008	0.085	6.5	3.8×10^{3}	3.0×10^{3}
	10	<0.007	<0.002	0.02	0.24	<0.003	0.056	1.5		
SL7-2	0.5	0.030	0.003	0.26	0.37	0.020	0.076	7.5	4.8×10^{3}	4.1×10^{3}
	10	<0.007	<0.002	0.02	0.21	<0.003	0.034	1.2		
SL7-3	0.5	<0.007	<0.002	0.15	0.57	0.007	0.080	9.0	3.2×10^{3}	2.0×10^{3}
	10	<0.007	<0.002	0.02	0.28	<0.003	0.081	0.7		
SL7-4	0.5	<0.007	0.002	0.09	0.43	0.005	0.070	8.5	3.6×10^{2}	2.8×10^{2}
SL8-1	0.5	0.010	0.003	0.08	0.22	0.006	0.092	17	2.0×10^{0}	1.0×10^{0}
	4.7	<0.007	<0.002	0.02	0.16	<0.003	0.026	4.0		
SL8-2	0.5	<0.007	0.003	0.13	0.15	0.004	0.024	13	1.1×10^{1}	7.0×10^{0}
PM-1	0.5	<0.007	<0.002	0.01	0.33	<0.003	0.028	4.6	5.0×10^{0}	ND
	10	<0.007	<0.002	0.01	0.36	<0.003	0.007	8.5		
PM-2	0.5	<0.007	<0.002	0.01	0.39	<0.003	0.18	4.1	3.0×10^{0}	3.0×10^{0}
	10	<0.007	<0.002	0..01	0.18	<0.003	0.047	8.4		
PM-3	0.5	<0.007	0.003	0.14	0.53	0.022	0.024	21	2.6×10^{2}	2.1×10^{2}
	4.8	<0.007	0.012	0.02	0.24	<0.003	0.010	62		
PM-4	0.5	<0.007	0.003	0.04	0.58	0.013	0.081	20	2.0×10^{0}	ND
	3.1	<0.007	0.002	0.08	0.36	0.011	0.085	17		

Note

Sampling Dates:

July 19, 1999 at SL6-1 to SL8-2, PM-1 to PM-4

July 20, 1999 at SL1-1 to SL5-2

July 21, 1999 at PR-1 to PR-5, PL-1 to PL-5, AP-1 to AP-5

July 22, 1999 at CL-1 to CL-2

Table 4.15 Results of Water Quality Analysis in Rainy Season [Toxic Parameters]

Point No.	Sampling Depth (m)	Hexane Extract (mg/l)	Phenols (mg/l)	Cyanide (mg/l)	Cr (mg/l)	Cr^{6+} (mg/l)	Cd (mg/l)	Pb (mg/l)	Cu (mg/l)	Zn (mg/l)	Ni (mg/l)	As (mg/l)	Hg (mg/l)
PR-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0014	0.0056	0.0017	0.0034	<0.02	<0.0003
PR-3	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0046	0.0058	0.0017	0.0050	<0.02	<0.0003
PR-5	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0049	0.0034	0.0021	0.0010	<0.02	<0.0003
PL-2	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0016	0.0043	0.0012	0.0002	<0.02	<0.0003
PL-4	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0006	0.0036	<0.0005	0.0003	<0.02	<0.0003
PL-5	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0003	0.0035	<0.0005	0.0003	<0.02	<0.0003
AP-2	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0004	0.0044	<0.0005	0.0001	<0.02	<0.0003
AP-5	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0004	0.0025	0.0018	0.0002	<0.02	<0.0003
CL-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0006	0.0002	0.0013	0.0011	<0.02	<0.0003
MA-2	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0003	<0.0002	<0.0005	0.0004	<0.02	<0.0003
SL1-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0005	0.0021	<0.0005	0.0008	<0.02	<0.0003
SL2-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0004	0.0031	0.0011	0.0002	<0.02	<0.0003
SL2-2	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0003	0.0031	0.0008	0.0003	<0.02	<0.0003
SL4-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0003	0.0006	0.0013	0.0010	<0.02	<0.0003
SL4-2	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0003	0.0003	0.0010	0.0004	<0.02	<0.0003
SL6-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0002	<0.0002	0.0009	0.0018	<0.02	<0.0003
SL6-2	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0004	<0.0002	0.0011	0.0007	<0.02	<0.0003
SL7-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0013	<0.0002	0.0016	0.0020	<0.02	<0.0003
SL7-3	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0005	<0.0002	0.0017	0.0016	<0.02	<0.0003
SL8-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0005	<0.0002	<0.0005	0.0007	<0.02	<0.0003
PM-1	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0003	<0.0002	<0.0005	0.0005	<0.02	<0.0003
PM-4	0.5	<0.5	<0.001	<0.01	<0.003	<0.003	<0.0005	0.0011	<0.0002	0.0020	0.0011	<0.02	<0.0003

Point No.	Sampling Depth (m)	Alkyl-Hg (mg/l)	Organo Phosphorous (mg/l)	Trichloroethylene (mg/l)	Tetrachloro-ethylene (mg/l)	Carbon Tetrachloride (mg/l)	PCB (mg/l)	HCB (mg/l)	Aldrin (mg/l)	Endrin (mg/l)	Dieldrin (mg/l)	DDT (mg/l)	Chlordane (mg/l)
PR-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-2	0.5	-	-	-	-	-	-	-	-	-	-	-	-
PR-3	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-4	0.5	-	-	-	-	-	-	-	-	-	-	-	-
PR-5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-4	0.5	ND	ND	ND	ND	ND	ND	ND	ND	0.0008	ND	ND	ND
PL-5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-4	0.5	-	-	-	-	-	-	-	-	-	-	-	-
AP-5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CL-1	0.5	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND	ND	ND
MA-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL1-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL2-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL2-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL3-1	0.5	-	-	-	-	-	-	-	-	-	-	-	-
SL4-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL4-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL6-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL6-2	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL7-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL7-3	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL8-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-4	0.5	ND	ND	ND	ND	ND	ND	ND	0.001	ND	ND	ND	ND

Note

Sampling Dates:

July 19, 1999 at SL6-1, SL6-2, SL7-1, SL7-3, SL8-1, PM-1, PM-4

July 20, 1999 at SL1-1, SL2-1, SL2-2, SL3-1, SL4-1, SL4-2

July 21, 1999 at PR-1 to PR-5, PL-2, PL-4, PL-5, AP-2, AP-4, AP-5

July 22, 1999 at CL-1

ND means "Not Detected".

Table 4.16 Summarized Results of Water Quality Monitoring in Rainy Season [Basic Parameters]

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area (River Mouth)	Coastal Area
Transparency(m)	0.3-0.4	S:0.3-0.7	S:0.4	1.0-2.6	0.9-2.5	2.8-4.6
Water temperature(℃)	S:26.8-29.2, B26.7-27.2	S:27.1-28.9	S:29.3-29.6	S:26.5-28.4, D:22.7-24.7	S:25.8-27.8, D:22.6-26.5	S:27.0-28.0, D:22.5-24.2
Salinity	S:<2, B:<2	S:<2-10.60	S:<2	29.75-32.85, D:34.45-36.12	S:19.77-35.53, D:34.79-36.31	S:32.12-33.15, D:35.13-36.30
pH	S:7.6-7.7, B:7.8	S:7.0-8.3	S:7.2-7.3	S:8.2, D:7.9-8.0	S:8.0-8.3, D:8.0-8.2	S:8.1-8.2, D:7.3-8.1
DO(mg/l)	S:4.9-5.5, B:5.1-5.2	S:5.8-6.4	S:<0.5-3.1	S:6.3-8.9, D:3.3-4.0	S:6.3-9.2, :5.6-6.7	S:6.0-9.0, D:3.2-7.2
COD(mg/l)	S:3.6-4.4, B:4.1-5.4	S:1.3-6.8	S:8.2-8.9	S:1.0-4.8, D:0.9-2.6	S:1.7-3.8, D:0.7-2.6	S:0.8-2.5, D:0.9-3.0
TOC(mg/l)	S:2.5-7.5, B:4.2-5.9	S:2.2-10	S:12-13	S:1.6-5.1, D:1.2-1.7	S:2.6-3.5, D:2.2-3.3	S:2.2-3.3, D:1.7-3.0
SS(mg/l)	S:43-380, B:370-560	S:13-130	S:20-24	S:4-12, D:10-13	S:4-31, D:3-13	S:1-3, D:<1-22
NH_4-N(mg/l)	S:<0.007-0.020, B:0.008-0.020	S:<0.007-0.030	S:<0.007-0.010	S:<0.007-0.010, D:0.01-0.040	S:<0.007-0.030, D:<0.007	S:<0.007, D:<0.007-0.009
NO_2-N(mg/l)	S:0.007-0.010, B:0.006-0.011	S:<0.002-0.007	S:<0.002-0.007	S:<0.002-0.003, D:0.002-0.007	S:<0.002-0.003, D:<0.002-0.012	S:<0.002-0.002, D:<0.002-0.002
NO_3-N(mg/l)	S:0.19-0.84, B:0.34-0.93	S:0.01-0.61	S:0.01-0.02	S:0.01-0.02, D:0.01-0.02	S:0.01-0.26, D:0.01-0.08	S:0.01-0.08, D:0.01-0.03
T-N(mg/l)	S:0.37-1.2, B:0.54-1.1	S:0.35-0.68	S:0.77-1.3	S:0.32-0.54, D:0.17-0.41	S:0.13-0.58, D:0.15-0.36	S:0.18-0.32, D:0.04-0.38
PO_4-P(mg/l)	S:0.060-0.13, B:0.11-0.12	S:0.044-0.10	S:0.070-0.12	S:0.005-0.12, D:0.003-0.017	S:<0.003-0.022, D: <0.003-0.011	S:<0.003-0.009, D: <0.003-0.009
T-P(mg/l)	S:0.086-0.17, B:0.13-0.30	S:0.053-0.11	S:0.20-0.51	S:0.022-0.13, D:0.010-0.030	S:0.024-0.18, D:0.007-0.045	S:0.011-0.050, D:0.029-0.055
Chlorophyll-a(μg/l)	S:4.5-18, B:5.1-7.0	S:2.7-16	S:90-100	S:1.1-6.8, D:1.3-6.7	S:4.1-21, D0.7-17	S:0.5-3.2, D:0.6-7.3
Total coliform(Col./100ml)	S:2.4×10^2-3.6×10^3	S:1.4×10^1-1.7×10^3	S:6.1×10^2-2.0×10^3	S:ND-1.3×10^2	S:ND-4.8×10^3	S:ND-3.0×10^0
Fecal coliform(Col./100ml)	S:1.2×10^2-2.9×10^3	S:7.0×10^0-1.3×10^3	S:1.8×10^2-1.5×10^3	S:ND-1.1×10^2	S:ND-4.1×10^3	S:ND

Note: S: Surface (0.5 m layer); B: 1 m from the bottom; D: 10 m below surface water, but if water depth is less than 10 m, 1 m from the bottom is indicated.
Coastal Area means the points of SL1-SL15 lines; Coastal Area (river mouth) means the points of SL-6, SL-7, SL-8 and PM lines.
ND means not detected.

Table 4.17 Summarized Results of Water Quality Monitoring in Rainy Season [Toxic Parameters]

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area(River Mouth)	Coastal Area
Phenols (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cyanide (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr (mg/l)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cr^{6+} (mg/l)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Cd (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pb (mg/l)	0.0014-0.0049	0.00003-0.0016	0.0006	0.0003-0.0016	0.0002-0.0013	0.0003-0.0005
Cu (mg/l)	0.0034-0.0058	0.0035-0.0043	0.0002	0.0025-0.0044	<0.0002	0.0003-0.0031
Zn (mg/l)	0.0017-0.0021	<0.0005-0.0012	0.0013	<0.0005-0.0018	<0.0005-0.0020	<0.0005-0.0013
Ni (mg/l)	0.0010-0.0050	0.0002-0.0003	0.0011	0.0001-0.0002	0.0005-0.0018	0.0003-0.0010
As (mg/l)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
T-Hg (mg/l)	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Alkyl-mercury(mg/l)	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Parathion(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Trichloroethylene(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Tetrachloroethylene(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Carbon tetrachloride(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
PCB(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
HCB (mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Aldrin (mg/l)	N.D	N.D	0.002	N.D	N.D - 0.001	N.D
Endrin(mg/l)	N.D	N.D - 0.0008	N.D	N.D	N.D	N.D
Dieldrin(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
DDT(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D
Chlordane(mg/l)	N.D	N.D	N.D	N.D	N.D	N.D

Note

Coastal Area(River Mouth) means the points of SL6, SL7, SL8 and PM lines.
Coastal Area means the points of SL1-SL5 lines.
All samples were taken under the surface.

In the coastal area, salinity dropped to 32-33.5 in rainy season though it had been 36-36.3 in dry season except for some parts of the area. Low saline water flowed into sea from Panuco River; it then distributed 2-4 km from the river's mouth before finally expanding to Altamira Industrial Port.

Analysis of turbid conditions using parameters like transparency and SS (suspended substance) showed contrasting results between Panuco River and the coastal area. In Panuco River, the increased muddiness owing to floods resulted in over 300 mg/l of SS and cut into half the transparency of the dry season level.

By contrast, the transparency of the coastal area increased twice as much and SS concentration dropped to half of the dry season level, though it was seen that low saline water had affected river water in the surface layer. It was possible that strong winds disturbed the water, which then turned muddy.

There was low concentration of dissolved oxygen in the south area of Conejo Lagoon, even at the surface layer, and the central zone of Conejo Lagoon was oxygen deficient. In the coastal area, oxygen deficient water was found (3.3-3.6 mg/l) at the bottom layer of inner Altamira Industrial Port.

The level of COD was 3.5-5.5 mg/l in Panuco River and 8-9 mg/l in Conejo Lagoon. A low concentration of 1-2 mg/l of COD was found in Pueblo Viejo, in the northeast area near Panuco River, but it gradually showed high concentrations in areas from north to south (4-7 mg/l). The coastal area showed a distribution of 1-5 mg/l but it was higher within a 2-km area of the river mouth. At 3 km from the shoreline, COD of the bottom layer showed about half the value of surface layer.

There was a very high TOC concentration of 12-13 mg/l in Conejo Lagoon and a similar distribution of COD was recorded for the other water areas. Figure 4.11 shows the relation between COD and TOC concentration. It can be seen that there is a close comparative correlation between the two parameters.

Three forms of inorganic nitrogen and total nitrogen were analyzed. Ammonium nitrogen was detected at 0.01-0.03 mg/l in Panuco River, Pueblo Viejo Lagoon, and a point of Conejo Lagoon. The other water areas were almost below detection limit. In the inner part of Altamira Industrial Port where water at the bottom layer was oxygen deficient, a high concentration of ammonium nitrogen was detected. The concentration in the coastal area was below detection limit at almost all of the observation points, except near the river mouth where 0.01-0.03 mg/l of ammonium nitrogen had been detected.

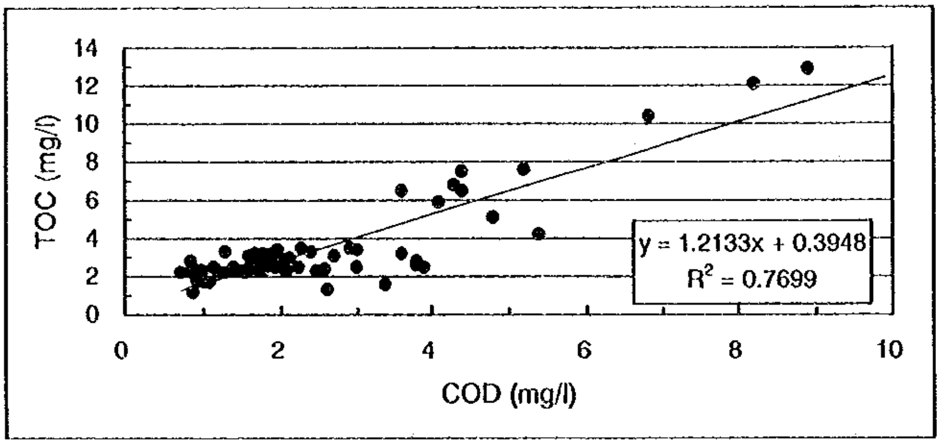


Figure 4.11 Correlation between COD and TOC of Water Quality in Rainy Season

Nitrite nitrogen showed a similar distribution as ammonium nitrogen. Nitrate nitrogen had the highest composition ratio in inorganic nitrogen of the three forms and a high concentration of 0.20-0.90 mg/l was detected in the northeast area of Pueblo Viejo Lagoon and Panuco River. The other areas showed low concentrations of 0.01-0.001 mg/l in almost all points.

Concentrations of total nitrogen were 0.4-1.2 mg/l in Panuco River, 0.4-0.7mg/l in Pueblo Viejo Lagoon, 0.3-0.5 mg/l in Altamira Industrial Port, 0.8-1.3 mg/l in Conejo Lagoon and 0.2 - 0.4 mg/l in the coastal area, except at the mouth of the river (0.4-0.6 mg/l). There was no difference noted in the total nitrogen concentration levels between the surface and bottom layers of Panuco River. But in the coastal area, the concentration at the bottom layer was lower than the surface layer 3 km from the shoreline; in shallow line points of 1 km away from shore line, the bottom layer showed a higher value than the surface layer.

High concentrations of phosphate phosphorus were detected in Panuco River, Pueblo Viejo Lagoon, Conejo Lagoon and the inner part of Altamira Industrial Port, but low concentrations of less than 0.01 mg/l were observed in almost all parts of the coastal area.

Total phosphorus showed high concentrations of 0.2-0.5 mg/l in Conejo Lagoon, Panuco River and around its mouth. The other water areas were low--below 0.01 mg/l--and no vertical difference was observed.

A high concentration of chlorophyll-a (20 g/l) was found at the point of Panuco River and Tamesi River. Conejo Lagoon had a higher concentration at 90-100 g/l. This trend of increased concentration of chlorophyll-a occurs from the north to the mouth of river in the coastal area. It may be attributed to the rapid growth of phytoplankton caused by large amounts of nutrients from the river.

In Panuco River, total coliform group number was higher in the rainy season than in the dry season, in spite of large amounts of water in the rainy season. In Conejo Lagoon and the northeast area of Pueblo Viejo Lagoon, which affects Panuco River, the detected level was 6.0×10^2 - 2.0×10^3 Col./100 ml. It was thought that those water areas were contaminated with bacteria throughout the year. One of the characteristics of rainy season is the presence of a high level of coliform (3.0×10^3 - 5.0×10^3 Col./100 ml) around the mouth of the river rather than in the river itself. This is probably caused by runoff from floods from the mouth of the river to the sea area.

b) Toxic Parameters

Hexane extracts were detected in high concentrations in the dry season, as a whole, but in the rainy season it was below detection limit (<0.5 mg/l).

Volatile organic compounds (VOC: trichloroethylene, tetrachloroethylene and carbon tetrachloride), total and alkyl mercury and hexavalent chromium showed concentrations below minimum detection limit in all monitoring points.

Some of the pesticide parameters, aldrin and endrin, were detected at several points. Aldrin was 0.002 mg/l at CL-1 and 0.001 mg/l at PM-4, while endrin was 0.0008 mg/l at PL-4. None was detected in dry season. Gas Chromatography (GC) method, which was used in this survey, could not completely identify every compound. It is therefore necessary to observe these pesticide parameters from now on, as well as

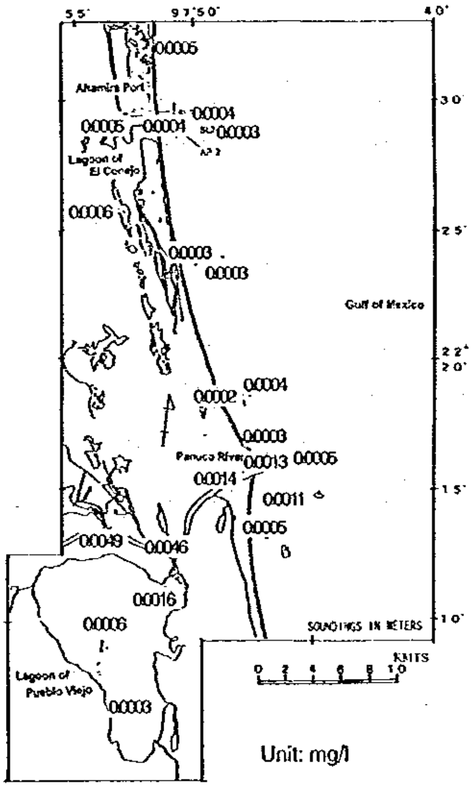


Figure 4.12 Horizontal Distribution of Lead in Water Quality (Rainy Season)

to develop another method which can completely identify every compound, for example Gas Chromatograph – Mass spectrometry (GC-MS) method.

There was water contamination by heavy metals such as copper, zinc and so on. All in all, the maximum concentration of heavy metals appeared in fresh and brackish water areas. Especially, the average concentration of copper, nickel, and lead in river and lagoon waters was twice the amount of the coastal area. The distribution of lead near Altamira Industrial Port and the mouth of Panuco River showed high values compared with other coastal areas, as shown in Figure 4.12. Besides, the distribution in the northern area (PL-2) of Pueblo Viejo lagoon was higher than that in the southern area (PL-5).

Therefore, it seems reasonable to conclude that the aforementioned pollutant sources were mainly derived from the urban areas.

4.4 Sediment Sampling Survey

4.4.1 Method

(1) Monitoring Period

The sediment survey was conducted on the same dates as the water quality survey, as shown below:

Dry season (Site work I) : March 1, 2, 8 and 9, 1999
Rainy season (Site work II) : July 19, 20, 21 and 22, 1999

(2) Monitoring Areas and Points

Sediment samples were collected from the 21 points where the samples for toxic parameters of water quality were also taken. However, the Ekman-Berge Sediment Sampler and Smith-McIntyre Sediment Sampler could not be used to take samples from three points in the coastal area in the dry season and also from one point in the rainy season. Table 4.18 shows the number of monitoring points at each water area.

Table 4.18 Monitoring Areas and Sampling Points

Monitoring Areas	Sampling Points	
	Dry Season	Rainy Season
Coastal Area	9	11
Altamira Industrial Port	2	2
Panuco River	3	3
Pueblo Viejo Lagoon	3	3
Conejo Lagoon	1	1
Total	18	20

Source: JICA Study Team

(3) Monitoring Parameters and Analytical Method

The monitoring parameters and the analytical methods are shown in Table 4.19. Most of the parameters were analyzed using three references: the Japanese standard "Handbook for Bottom Sediment, 1996," EPA 8021 and EPA 8081A. For elution test, JIS K0102 was used. Two types of test were used for sediment analysis. One was the content test; the other was the elution test. For the latter, 500 ml of water and 3% of sediment were shaken for 6 hours before the analysis.

Incidentally, the unit of the result of content test is used weight per weight of dried sediment sample.

4.4.2 Results of Sediment Survey

(1) Dry Season

The results of water quality analysis in dry season are shown in Table 4.20 (1) and Table 4.21. Summarized results are presented in Table 4.22.

a) Content Test

i) Basic Parameters

ORP was seen to have a positive voltage at the sandy sediment points, and negative voltage at the muddy sediment points. In the coastal area, ORP value indicated a positive voltage at the two points where fine silt had accumulated. Since Panuco River and the two lagoons have accumulated fine silt, it showed negative voltage, although they are not as high as those seen in contaminated areas.

The distribution of ignition loss was observed to have a similar pattern with the detected COD, although that of Concejo Lagoon is not so high. The ignition loss of PL-5, which is located at the southern part of Pueblo Viejo Lagoon, showed characteristics of high value.

Table 4.19 Monitoring Parameters and Analytical Methods for Sediment Survey

	Parameter	Method	Reference
Content Test Basic Parameter	Particle Size	Separation method with sieve	
	ORP	Glass-electrode method on boat	
	Ignition Loss	Gravimetric Method at 600	HBSS .4
	COD	Alkaline-iodine method	MAGWP 5.6
	TOC	Dry decomposition - non purgeable organic carbon method	By TOC Analyzer
	Sulfide	Heating Distillation Method	MAGWP 5.11
Toxic Parameter	Hexane extracts	Liquid-liquid extraction, Gravimetric method	EPA 9071A (Use hexane), MAGWP 5.11
	Cyanide	4-pyridine carboxylic acid - pyraxolone absorptiometry	HBSS II.14
	Cr	Acid digestion, Diphenylcarbazide absorptiometry	HBSS II.12.1, EPA 3050B, 3051, 3052 (Pretreatment)
	Cd	Acid digestion, Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS II.6, EPA 7131A
	Pb	Acid digestion, Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS II.7, EPA 7421
	Cu	Acid digestion, Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS II.8, EPA 7211
	Zn	Acid digestion, Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS II.9, EPA 7951
	As	Acid digestion, Atomic absorption spectrometry using hydride system	EPA 3050B (Digestion), HBSS II.13
	T-Hg	Atomic absorption spectrometry using vapor reduction system	HBSS II.5, EPA 7471A
	Alkyl-mercury	Gas chromatography with ECD	JIS K 0102 66.2, Notification No.127(3)
	Organophosphorus	Gas chromatography with FID	Notification No.46(1)
	Trichloroethylene	Gas chromatography with ECD	JJIS K 0125 5.5, EPA 8021B, Notification No.46(1)
	Tetrachloroethylene	Gas chromatography with ECD	JJIS K 0125 5.5, EPA 8021B, Notification No.46(1)
	Carbon tetrachloride	Gas chromatography with ECD	JJIS K 0125 5.5, EPA 8021B, Notification No.46(1)
	PCB	Gas chromatography with ECD	JIS K 0093, EPA 8082, Notification No.127(3)
	HCB	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual(2)
	Aldrin	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual(2)
	Endrin	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual(2)
	Dieldrin	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual(2)
	DDT	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual(2)
	Chlordane	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual(2)
Elution Test	Hexane extracts	Liquid-liquid extraction, Gravimetric method	JIS K 0102 24
	Cyanide	4-pyridine carboxylic acid - pyraxolone absorptiometry	JIS K 0102 38
	Cr^{6+}	Diphenylcarbazide absorptiometry	JIS K 0102 65.2.1, EPA
	Cd	Atomic absorption spectrometry	JIS K 0102 55, EPA 7131A
	Pb	Atomic absorption spectrometry	JIS K 0102 54, EPA 7421
	Cu	Atomic absorption spectrometry	JIS K 0102 52, EPA 7211
	Zn	Atomic absorption spectrometry	JIS K 0102 53, EPA 7521
	As	Atomic absorption spectrometry using hydride system	JIS K 0102 61.2, EPA 7062
	T-Hg	Atomic absorption spectrometry using vapor reduction system	JIS K 0102 66.1, EPA 7470A
	Alkyl-mercury	Gas chromatography with ECD	JIS K 0102 66.2
	Organophosphorus	Gas chromatography with FID	Notification No.46(1)
	PCB	Gas chromatography with ECD	EPA 8082, JIS K 0093(Pretreatment)

Notes:
HBSS : The Handbook of Bottom Sediment Survey; Japanese Standard
JIS : Japan Industrial Standard
EPA : Environmental Protection Agency
MAGWP : The Method of Analysis Guideline of Water Pollution
(1) Notification No. 46, 1971 of the Japanese Environmental Agency
(2) Tentative Survey Manual of External Factor Endocrine Disturbance Chemical Substance
(3) Notification No. 127 issued by Water Quality Control Section, Water Protection Department, Environmental Agency
TOC was analyzed in dry season.

In Conejo Lagoon, COD concentration was high at about 28 mg/g, while that of Panuco River ranged from 17 to 22 mg/g, and Pueblo Viejo Lagoon, from 12 to 14 mg/g. COD of the coastal area was remarkably low at less than 3 mg/g, which is attributable to its sandy bottom sediment, with the exception of two points where fine silt had accumulated.

ii) Toxic Parameters

All 15 out of the 21 parameters analyzed, e.g. organic compounds and cyanide, showed low toxic content compared with minimum detection limit or instrument detection level at all monitoring points. Hexane extracts as an indicator of oil pollution were seen to be comparatively high at all monitoring points, minimum 72 - maximum 1,400 mg/kg. At the monitoring points of Panuco River and Pueblo Viejo Lagoon where a high mercury content was detected, oil pollution was also remarkably high at 560 - 1,400 mg/kg. Sediments in the Panuco River and the northeastern region of Pueblo Viejo Lagoon have also become contaminated because of wastes dumped thereat.

There were also five heavy metals detected: As, at 1-9 mg/kg, Cr, at 3-30 mg/kg, Cu, at 2-26 mg/kg, Pb, at 10-35 mg/kg and Zn, at 9-150 mg/kg.

Mercury was found at 12 monitoring points at levels ranging from 0.03 -1.8 mg/kg; high amounts above 0.7 mg/kg were detected at six points in Panuco River, Pueblo Viejo Lagoon and the coastal area.

b) Elution Test

Elution test on sediment samples was conducted for 12 parameters. Four parameters concerning gas chromatograph, i.e., alkyl-mercury, organo-phosphorus and PCB, were not detected at all stations, which meant that the amounts of elution from sediment were below instrument detection level. The amount of elution of cadmium and mercury were also below minimum detection limit. Results of the elution test indicated the presence of three heavy metals, i.e. arsenic, copper and lead, at the points of Panuco River, Altamira Industrial Port and Pueblo Viejo Lagoon, but they were fairly low at only 2 - 6 times higher than the detected limit. About 1 - 6 mg/kg of zinc was detected from the sediments of Panuco River and Pueblo Viejo Lagoon. Hexane extracts and cyanide were also below minimum detection limit.

Table 4.20 (1) Results of Sediment Analysis in Dry Season [Basic Parameters]

Point No.	Condition of Sediment	Odor	Particle Size: 75-425 μm (%)	Particle Size: Under 75 μm (%)	Sediment Temperature	ORP (mV)	Ignition Loss (%)	COD (mg/g)
PR-1	Mud	No	9	91	23.1	-139	14	18
PR-3	Mud	No	13	87	23.1	-146	15	17
PR-5	Mud	No	10	90	23.0	-150	19	22
PL-2	Mud	No	11	87	23.6	-125	15	12
PL-4	Mud	No	5	94	23.8	-114	14	14
PL-5	Mud	No	4	95	23.8	-118	22	12
AP-2	Sand	No	86	13	26.5	-132	6.9	1.2
AP-5	Mud	No	28	65	26.5	-137	13	7.9
CL-1	Mud	No	77	22	-	-97	7.8	28
SL1-1	(uncollected)							
SL2-1	Sand	No	28	69	23.8	79	1.4	0.5
SL2-2	Sand	No	96	2	24.8	78	1.9	0.8
SL4-1	Sand	No	88	1	24.0	110	1.5	0.6
SL4-2	(uncollected)							
SL6-1	Sand	No	99	1	22.5	119	1.5	0.8
SL6-2	(uncollected)							
SL7-1	Muddy sand	No	-	-	24.0	-171	2.8	3.0
SL7-3	Mud	Sulfide smell	24	76	24.2	-218	11	15
SL8-1	Sand	No	100	0	24.4	169	2.2	0.5
PM-1	Sand	No	100	0	24.6	111	1.5	0.5
PM-4	Sand	No	100	0	24.3	147	1.6	<0.5

Note
Sampling Dates:
March 1,1999 at PR-1, PR-3, PR-5, PL-2,PL-4, PL-5
March 2,1999 at AP-2, AP-5, CL-1
March 8,1999 at SL6-1, SL6-2, SL7-1, SL7-3, SL8-1, PM-1, PM-4
March 9, 1999 at SL1-1, SL2-1, SL2-2, SL4-1

Table 4.20 (2) Results of Sediment Analysis in Rainy Season [Basic Parameters]

Point No.	Condition of Sediment	Odor	Particle Size: 75-425 μm (%)	Particle Size: Under 75 μm (%)	Sediment Temperature	ORP (mV)	Ignition Loss (%)	COD (mg/g)	TOC (mg/g)
PR-1	Mud	No	1	99	27.0	-186	14	25	13
PR-3	Mud	No	17	82	30.0	-321	21	19	13
PR-5	Sand	No	92	8	29.0	-115	1.7	1.0	0.9
PL-2	Mud	No	9	91	28.0	-298	10	17	9.0
PL-4	Mud	No	11	85	29.0	-231	12	11	6.6
PL-5	Mud	No	6	94	28.5	-286	12	8.7	7.2
AP-2	Mud	Sulfide smell	9	91	23.0	-236	16	18	9.3
AP-5	Mud	No	28	67	24.0	-189	12	6.8	2.6
CL-1	Mud	No	39	57	28.7	-371	28	160	84
SL1-1	Sand	No	95	3	25.5	-5	1.6	0.7	1.3
SL2-1	Sand	No	94	5	25.0	-181	1.9	<0.5	1.3
SL2-2	Sand	No	93	2	26.5	-195	2.0	1.0	1.3
SL4-1	Sand	No	96	4	24.5	131	1.5	0.8	1.3
SL4-2	(uncollected)								
SL6-1	Sand	No	99	1	24.5	105	2.5	1.2	1.3
SL6-2	Sandy Mud	No	53	43	23.0	111	7.3	7.2	2.6
SL7-1	Mud	No	1	99	22.5	-189	15	20	13
SL7-3	Mud	Sulfide smell	20	79	24.0	-227	13	17	10
SL8-1	Sand	No	94	2	25.5	-111	2.4	0.6	1.0
PM-1	Sand	No	96	3	24.0	102	1.5	0.6	2.6
PM-4	Sand	No	91	5	27.0	111	1.7	0.5	2.6

Note
Sampling Dates:
July 19, 1999 at SL6-1, SL6-2, SL7-1, SL7-3, SL8-1, PM-1, PM-4
July 20, 1999 at SL1-1, SL2-1, SL2-2, SL4-1
July 21, 1999 at PR-1, PR-3, PR-5, PL-2, PL-4, PL-5, AP-2, AP-5
July 22 1999 at CL-1

Table 4.21 Results of Sediment Analysis in Dry Season [Toxic Parameters]

Sediment - Content Test

Station	Hexane Extract (mg/kg)	Cyanide (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Hg (mg/kg)	Alkyl-Hg (mg/kg)
PR-1	650	<0.12	30	<1	27	24	110	8.2	0.78	ND
PR-3	1400	<0.12	25	<1	34	26	150	9.0	1.0	ND
PR-5	1100	<0.12	25	<1	27	21	120	5.8	0.69	ND
PL-2	570	<0.12	26	<1	34	22	120	8.4	1.8	ND
PL-4	970	<0.12	25	<1	34	16	78	4.3	0.95	ND
PL-5	440	<0.12	25	<1	27	11	78	3.4	0.29	ND
CL-1	1100	<0.12	5.2	<1	<10	2.9	25	1.2	0.04	ND
AP-2	410	<0.12	14	<1	<10	2.7	17	3.7	<0.03	ND
AP-5	130	<0.12	25	<1	10	8.8	37	3.2	<0.03	ND
SL1-1	-	-	-	-	-	-	-	-	-	-
SL2-1	72	<0.12	2.9	<1	<10	<2.5	9.1	2.3	<0.03	ND
SL2-2	400	<0.12	5.5	<1	<10	<2.5	12	2.2	<0.03	ND
SL4-1	82	<0.12	8.4	<1	<10	<2.5	11	1.7	0.04	ND
SL4-2	-	-	-	-	-	-	-	-	-	-
SL6-1	140	<0.12	4.0	<1	<10	<2.5	11	2.3	0.03	ND
SL6-2	-	-	-	-	-	-	-	-	-	-
SL7-1	72	<0.12	6.0	<1	<10	4.1	30	4.3	0.10	ND
SL7-3	220	<0.12	11	<1	13	17	65	3.3	0.76	ND
SL8-1	240	<0.12	7.8	<1	<10	4.8	41	2.0	0.19	ND
PM-1	290	<0.12	<2.5	<1	<10	<2.5	10	2.3	<0.03	ND
PM-4	210	<0.12	<2.5	<1	<10	2.6	26	3.0	0.12	ND

Sediment - Content Test

Station	Organo Phosphorous (mg/kg)	Trichloro-ethylene (mg/kg)	Tetrachloro-ethylene (mg/kg)	Carbon Tetrachliride	PCB (mg/kg)	HCB (mg/kg)	Aldrin (mg/kg)	Endrin (mg/kg)	Dieldrin (mg/kg)	DDT (mg/kg)	Chlordane (mg/kg)
PR-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CL-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL1-1	-	-	-	-	-	-	-	-	-	-	-
SL2-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL2-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL4-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL4-2	-	-	-	-	-	-	-	-	-	-	-
SL6-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL6-2	-	-	-	-	-	-	-	-	-	-	-
SL7-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL7-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL8-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Sediment - Elution Test

Station	Hexane Extract (mg/kg)	Cyanide (mg/kg)	Cr^{6+} (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Hg (mg/kg)	Alkyl-Hg (mg/kg)	Organo Phosphorous (mg/kg)	PCB (mg/kg)
PR-1	<170	<0.2	<0.1	<0.1	<0.3	0.3	1.3	0.13	<0.04	ND	ND	ND
PR-3	<170	<0.2	<0.1	<0.1	<0.3	0.3	1.5	0.07	<0.04	ND	ND	ND
PR-5	<170	<0.2	<0.1	<0.1	1.0	0.7	5.7	0.27	<0.04	ND	ND	ND
PL-2	<170	<0.2	<0.1	<0.1	1.1	0.9	6.0	0.27	<0.04	ND	ND	ND
PL-4	<170	<0.2	<0.1	<0.1	<0.3	0.3	1.5	0.13	<0.04	ND	ND	ND
PL-5	<170	<0.2	<0.1	<0.1	1.7	0.6	5.7	0.01	<0.04	ND	ND	ND
CL-1	<170	<0.2	<0.1	<0.1	<0.3	0.2	1.5	0.03	<0.04	ND	ND	ND
AP-2	<170	<0.2	<0.1	<0.1	<0.3	0.3	1.4	0.13	<0.04	ND	ND	ND
AP-5	<170	<0.2	<0.1	<0.1	<0.3	0.2	1.3	0.03	<0.04	ND	ND	ND
SL1-1	-	-	-	-	-	-	-	-	-	-	-	-
SL2-1	<170	<0.2	<0.1	<0.1	<0.3	<0.2	<0.1	<0.03	<0.04	ND	ND	ND
SL2-2	<170	<0.2	<0.1	<0.1	<0.3	<0.2	0.1	<0.03	<0.04	ND	ND	ND
SL4-1	<170	<0.2	<0.1	<0.1	<0.3	<0.2	<0.1	<0.03	<0.04	ND	ND	ND
SL4-2	-	-	-	-	-	-	-	-	-	-	-	-
SL6-1	<170	<0.2	<0.1	<0.1	<0.3	<0.2	0.1	<0.03	<0.04	ND	ND	ND
SL6-2	-	-	-	-	-	-	-	-	-	-	-	-
SL7-1	<170	<0.2	<0.1	<0.1	<0.3	0.2	<0.1	0.03	<0.04	ND	ND	ND
SL7-3	<170	<0.2	<0.1	<0.1	<0.3	<0.2	0.1	0.03	<0.04	ND	ND	ND
SL8-1	<170	<0.2	<0.1	<0.1	<0.3	<0.2	<0.1	0.03	<0.04	ND	ND	ND
PM-1	<170	<0.2	<0.1	<0.1	<0.3	<0.2	0.2	0.07	<0.04	ND	ND	ND
PM-4	<170	<0.2	<0.1	<0.3	<0.2	0.2	0.03	<0.04	ND	ND	ND	ND

Note

Sampling Dates:

March 1,1999 at PR-1, PR-3, PR -5, PL-2,PL-4, PL-5

March 2,1999 at AP-2, AP-5, CL-1

March 8,1999 at SL6-1, SL6-2, SL7-1, SL7-3, SL8-1, PM-1, PM-4

March 9,1999 at SL1-1, SL2-1, SL2-2, SL4-1

ND means "Not Detected".

Table 4.22 Summarized Results of Sediment Survey in Dry Season

Sediment-Content Test

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area (River Mouth)	Coastal Area
Particle size-75-425 μm (%)	9-13	4-11	77	28-86	24-100	28-96
Particle size-under 75 μm (%)	87-91	87-95	22	13-65	0-76	1-69
ORP (mV)	-150~-139	-118~-114	-97	-137~-132	-218~+169	+78~+110
IL (%)	14-19	14-22	7.8	6.9-13	1.5-11	1.5-1.9
COD (mg/g)	17-22	12-14	28	1.2-7.9	<0.5-15	0.5-0.8
Hexane extracts (mg/kg)	650-1400	440-970	1100	130-410	72-290	72-400
Cyanide (mg/kg)	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12
Cr (mg/kg)	25-30	25-26	5.2	14-25	<2.5-11	2.9-8.4
Cd (mg/kg)	<1	<1	<1	<1	<1	<1
Pb (mg/kg)	27-34	27-34	<10	<10-10	<10-13	<10
Cu (mg/kg)	21-26	11-22	2.9	2.7-8.8	<2.5-17	<2.5
Zn (mg/kg)	110-150	78-120	25	17-37	10-65	9.1-12
As (mg/kg)	5.8-9.0	3.4-8.4	1.2	3.2-3.7	2.0-4.3	1.7-2.3
T-Hg (mg/kg)	0.69-1.0	0.29-1.8	0.04	<0.03	<0.03-0.76	<0.03-0.04
Alkyl-mercury (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Methyl parathion (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Parathion (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Trichloroethylene (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Tetrachloroethylene (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Carbon tetrachloride (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
PCB (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
HCB (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Aldrin (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Endrin (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Dieldrin (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
DDT (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Chlordane (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D

Sediment-Elution Test

Unit:mg/kg

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area (River Mouth)	Coastal Area
Hexane extracts (mg/kg)	<170	<170	<170	<170	<170	<170
Cyanide (mg/kg)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cr^{6+} (mg/kg)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd (mg/kg)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pb (mg/kg)	<0.3-1.0	<0.3-1.7	<0.3	<0.3	<0.3	<0.3
Cu (mg/kg)	0.3-0.7	0.3-0.9	0.2	0.2-0.3	<0.2-0.2	<0.2
Zn (mg/kg)	1.3-5.7	1.5-6.0	1.5	1.3-1.4	<0.1-0.2	<0.1
As (mg/kg)	0.07-0.27	0.01-0.27	0.03	0.03-0.13	<0.03-0.07	<0.03
T-Hg (mg/kg)	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Alkyl-mercury (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Methyl parathion (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Parathion (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
PCB (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D

Note
Coastal Area(River Mouth) means the points of SL6, SL7, SL8 and PM lines.
Costal Area means the points of SL1-SL5 lines.
ND means "Not detected".

(2) Rainy Season

The results of water quality analysis in dry season are shown in Table 4.20(2) and Table 4.23. Summarized results are presented in Table 4.24.

a) Content Test

i) Basic Parameters

The concentration of each index in the sediment samples was basically affected by particle size. The more pollutant substances are supposed to accumulate in the sediment consisting of fine particles below 75 m. However, the sediment in Conejo Lagoon, including things like wooden chips, showed remarkably high values of TOC (84 mg/g), COD (160 mg/g) and ignition loss (28%), is considered as abnormal sediment. In the other water areas, excluding Conejo Lagoon, high amounts of TOC were detected at 13mg/g in Panuco River and 7-9 mg/g in Pueblo Viejo Lagoon. In the coastal area, including Altamira Industrial Port, the amount of TOC was in the range of 9-13 mg/g in muddy point and 1-3 mg/g in sandy point. The distribution of COD showed the same pattern as TOC, and a close correlation was seen with TOC. In Panuco River and at the muddy point of the river mouth, COD concentrations were 17-25 mg/g. COD concentration was low in Pueblo Viejo Lagoon, notwithstanding the high ratio of fine particles. Since a slight disparity in sampling location could result in a large difference in sediment conditions, it may be a problem to directly compare the results of both rainy and dry seasons. Normally, ORP value in Panuco River and Pueblo Viejo Lagoon fairly drops in both seasons at similar points of particle size. One reason is seasonal change; the reductional atmosphere in sediment causes rapid decomposition of organic substances with the rise in temperature.

Table 4.23 Results of Sediment Analysis in Rainy Season [Toxic Parameters]

Sediment - Content Test

Station	Hexane Extract (mg/kg)	Cyanide (mg/kg)	Cr (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Hg (mg/kg)	Alkyl-Hg (mg/kg)
PR-1	20	<0.1	58	0.57	5.1	8.9	89	21	0.82	<0.005
PR-3	23	<0.1	41	0.94	6.2	34	18	8	0.77	<0.005
PR-5	33	<0.1	15	0.07	1.6	1.7	21	6	0.14	<0.005
PL-2	16	<0.1	52	0.45	5.7	4.0	88	18	1.2	<0.005
PL-4	18	<0.1	40	1.1	4.0	18	62	17	0.74	<0.005
PL-5	6.2	<0.1	56	0.13	4.6	1.7	64	12	0.71	<0.005
AP-2	91	<0.1	57	0.27	6.4	15	67	26	0.17	<0.005
AP-5	9.3	<0.1	28	0.38	1.0	7.6	37	8	0.05	<0.005
CL-1	220	<0.1	28	0.53	3.0	24	93	14	1.0	<0.005
SL1-1	3.0	<0.1	5.1	0.01	0.68	0.4	9.5	6	0.09	<0.005
SL2-1	14	<0.1	5.9	0.02	1.1	6.5	12		0.06	<0.005
SL2-2	7.3	<0.1	7.2	0.01	0.81	3.8	13	6	<0.05	<0.005
SL4-1	5.9	<0.1	5.6	0.02	0.57	2.3	10	9	<0.05	<0.005
SL6-1	2.3	<0.1	6.1	0.01	0.39	1.9	12		<0.05	<0.005
SL6-2	14	<0.1	27	0.08	5.2	8.4	49	8	0.14	<0.005
SL7-1	15	<0.1	33	0.98	4.8	21	87	18	0.61	<0.005
SL7-3	3.7	<0.1	32	0.18	4.1	39	81	7	0.60	<0.005
SL8-1	120	<0.1	8.6	0.33	1.4	9.6	19	6	0.35	<0.005
PM-1	7.8	<0.1	2.6	0.05	0.73	0.2	6	11	0.13	<0.005
PM-4	70	<0.1	5.4	0.37	0.69	6.3	18	6	<0.05	<0.005

Sediment - Content Test

Station	Organo Phosphorous (mg/kg)	Trichloro-ethylene (mg/kg)	Tetrachloro-ethylene (mg/kg)	Carbon Tetrachlirid e	PCB (mg/kg)	HCB (mg/kg)	Aldrin (mg/kg)	Endrin (mg/kg)	Dieldrin (mg/kg)	DDT (mg/kg)	Chlordane (mg/kg)
PR-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PR-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PL-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CL-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
AP-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL1-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL2-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL2-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL4-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL4-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL6-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL6-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL7-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL7-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SL8-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PM-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Sediment - Elution Test

Station	Hexane Extract (mg/kg)	Cyanide (mg/kg)	Cr^{6+} (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Hg (mg/kg)	Alkyl-Hg (mg/kg)	Organo Phosphorous (mg/kg)	PCB (mg/kg)
PR-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	ND	ND	ND
PR-3	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
PR-5	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
PL-2	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
PL-4	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
PL-5	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
CL-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
AP-2	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
AP-5	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL1-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL2-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL2-2	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL4-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL4-2	-	-	-	-	-	-	-	-	-	-	-	-
SL6-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL6-2	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL7-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL7-3	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
SL8-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
PM-1	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND
PM-4	<170	<0.1	<0.1	<0.02	<0.03	<0.17	<0.03	<1	<0.03	<0.03	ND	ND

Note
Sampling Dates:
July 19, 1999 at SL6-1, SL6-2, SL7-1, SL7-3, SL8-1, PM-1, PM-4
July 20, 1999 at SL1-1, SL2-1, SL2-2, SL4-1
July 21, 1999 at PR-1, PR-3, PR-5, PL-2, PL-4, PL-5, AP-2, AP-5
July 22, 1999 at CL-1
ND means "Not Detected".

Table 4.24 Summarized Results of Sediment Analysis in Rainy Season

Sediment-Content Test

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area (River Mouth)	Coastal Area
Particle size-75-425 μm (%)	1-92	6-11	39	9-28	1-99	93-96
Particle size-under 75 μm (%)	8-99	85-94	57	67-91	1-99	2-5
ORP (mV)	-321~-115	-298~-231	-371	-236~-189	-227~+111	-195~+131
IL (%)	1.7-21	10-12	28	12-16	1.5-15	1.5-2.0
COD (mg/g)	1.0-25	8.7-17	160	6.8-18	0.5-20	<0.5-1.0
TOC(mg/g)	0.9-13	6.6-9.0	84	2.6-9.3	1.3-13	1.3
Hexane extracts (mg/kg)	20-33	6.2-18	217	9.3-91	2.3-120	3.0-7.3
Cyanide (mg/kg)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cr (mg/kg)	15-58	40-56	28	28-57	2.6-33	5.1-7.2
Cd (mg/kg)	0.07-0.94	0.13-1.1	0.53	0.27-0.38	0.01-0.98	0.01-0.02
Pb (mg/kg)	1.6-5.1	4.0-5.7	3.0	1.0-6.4	0.39-5.2	0.57-1.1
Cu (mg/kg)	1.7-34	1.7-18	24	7.6-15	0.2-39	0.4-6.5
Zn (mg/kg)	18-89	62-88	93	37-67	6--87	9.5-13
As (mg/kg)	6-21	12-18	14	8-26	6-18	6-9
T-Hg (mg/kg)	0.14-0.82	0.71-1.2	1.0	0.05-0.17	<0.05-0.61	<0.05-0.09
Alkyl-mercury (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Parathion (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Trichloroethylene (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Tetrachloroethylene (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Carbon tetrachloride (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
PCB (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
HCB (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Aldrin (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Endrin (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Dieldrin (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
DDT (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Chlordane (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D

Sediment-Elution Test

Unit:mg/kg

Parameter	Panuco River	Pueblo Viejo Lagoon	Conejo Lagoon	Altamira Industrial Port	Coastal Area (River Mouth)	Coastal Area
Hexane extracts (mg/kg)	<170	<170	<170	<170	<170	<170
Cyanide (mg/kg)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cr^{6+} (mg/kg)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd (mg/kg)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Pb (mg/kg)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cu (mg/kg)	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17
Zn (mg/kg)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
As (mg/kg)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
T-Hg (mg/kg)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Alkyl-mercury (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Methyl parathion (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
Parathion (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D
PCB (mg/kg)	N.D	N.D	N.D	N.D	N.D	N.D

Note

Coastal Area(River Mouth) means the points of SL6, SL7, SL8 and PM lines.
Costal Area means the points of SL1-SL5 lines.
ND means "Not detected".

ii) Toxic Parameters

The highest concentration of hexane extracts was seen in Conejo Lagoon (CL-1) at 220 mg/kg. Hexane extract concentrations were higher in fresh and brackish water areas than in the coastal area, and the average of fresh and brackish water areas were about two times of the coastal area. Distribution of heavy metals also was quite similar to that of hexane extracts. That is to say, the concentration of heavy metals is higher in fresh and brackish water areas than in the coastal area. For example, the average of mercury concentration in fresh and brackish water areas is higher by about 5 times that of the coastal area. In addition, it was clear that concentrations in Panuco River and the northern area of Pueblo Viejo Lagoon were higher than in other areas. The distribution of mercury in the coastal area is shown in Figure 4.13. Mercury concentrations in Altamira Industrial Port and the mouth of Panuco River were higher than in other areas. This trend was gleaned from the results of water quality survey.

Similar to water quality, it seems reasonable to conclude that pollutant loads in the northern area of Pueblo Viejo Lagoon, mouth of Panuco River and inside of Altamira Industrial Port, which are near urban areas, are higher than in the southern area of Pueblo Viejo Lagoon and other coastal areas.

Organic toxic compounds, (VOC, pesticides, PCB and so on) were not detected, similar to the dry season.

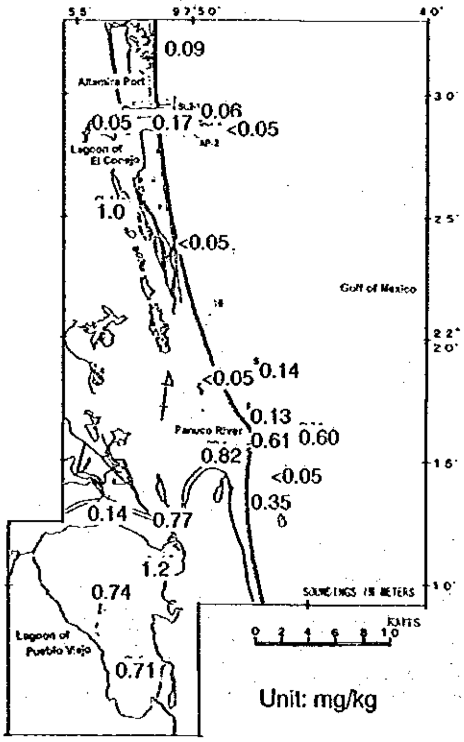


Figure 4.13 Horizontal Distribution of Mercury in Bottom Sediment (Rainy Season)

b) Elution Test

All eight parameters that had been analyzed showed concentrations of below minimum detection limit at all monitoring points.

4.5 Biological Accumulation Test

4.5.1 Method

(1) Monitoring Period

In the biological accumulation survey, fishes and shells caught in the monitoring areas on February 27 and March 3, 4, 5 and 6 were used for analysis. Gill nets were used to catch fishes while long wooden tongs were used for shells.

(2) Monitoring Samples and Monitoring Areas

Test samples of biological accumulation were chosen from 8 species of fishes and shells, or a total of 36 samples, which inhabited the monitoring areas. The species and samples used for analysis are shown in Table 4.25, and the areas where they were caught are shown in Figure 4.14.

Table 4.25 Survey Brief on Biological Accumulation Test

Sampling Area	Date of Catch	Species	Number of Samples
Coastal Area	27-Feb.	RONCO	1
	27-Feb.	TRUCHA	1
	27-Feb.	GURRUBATA	1
	27-Feb.	RPNCO	1
	27-Feb.	HAUCHINANGO	1
Pueblo Viejo Lagoon	3-Mar.	LEBRANCHA	7
	3-Mar.	GRRUBATA	1
	3-Mar.	OYSTER	5
Conejo Lagoon	5-Mar.	TILAPIA	6
	5,6-Mar.	BAGRE	2
Panuco River	6-Mar.	LEBRANCHA	5
	6-Mar.	GURRUBATA	5
Total			36

(3) Monitoring Parameters and Analytical Method

The samples were analyzed for 11 parameters; mercury, lead, cadmium, copper, zinc, PCB, HCB, aldrin, dieldrin, endrin and DDT, and the analytical methods are shown in Table 4.26. Fish represented wet, eatable muscle tissue samples, while the wet meat of oysters were used without the shell.

Incidentally, the unit of the result of content test is used weight per weight of wet sample.

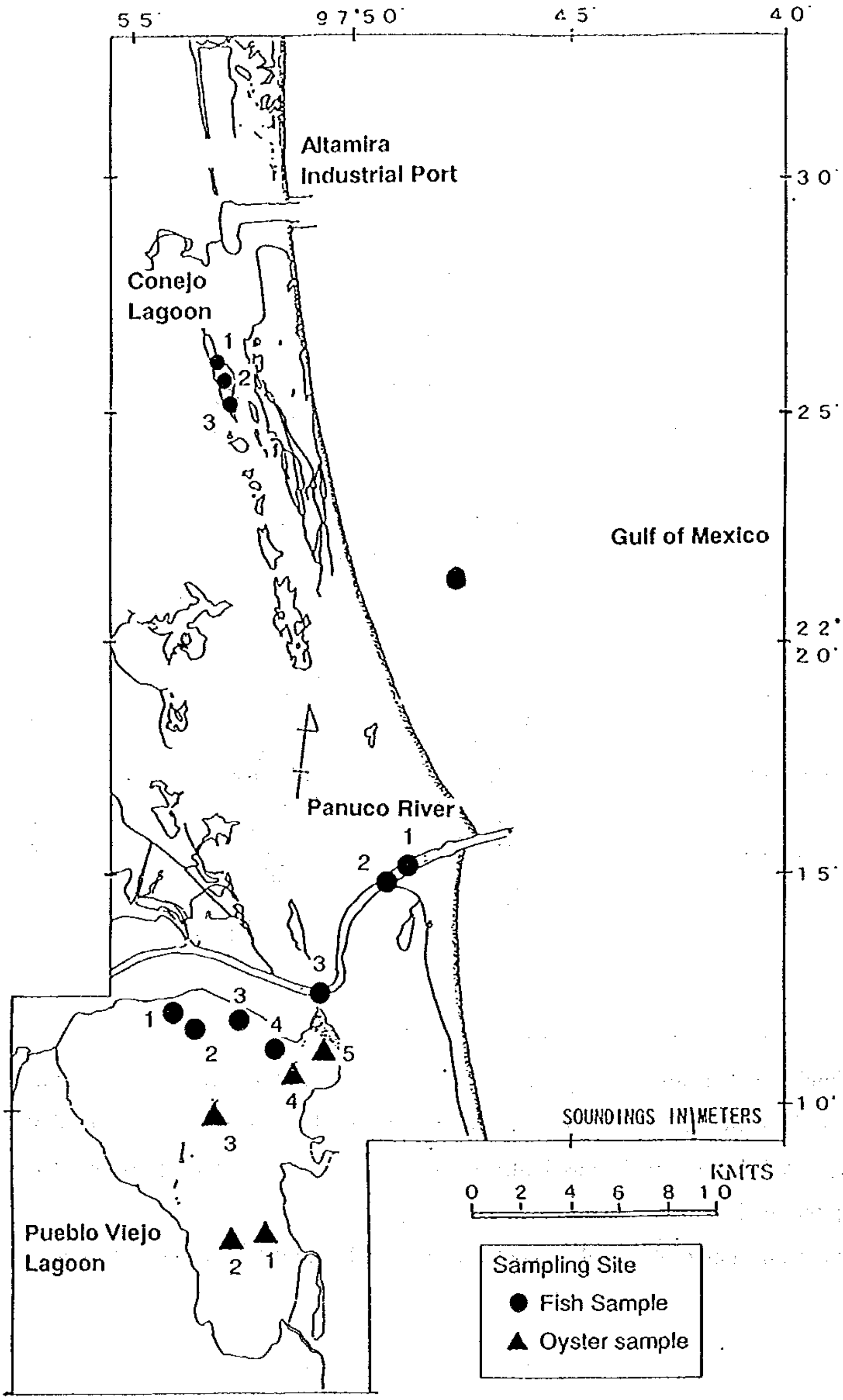


Figure 4.14 Sampling Sites for Biological Accumulation Test

Table 4.26 Analytical Method for Biological Accumulation Test

	Parameter	Method	Reference
Toxic Paramete	Cd	Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS .6, EPA 7131A
	Pb	Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS .7, EPA 7421
	Cu	Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS .8, EPA 7211
	Zn	Atomic absorption spectrometry	EPA 3050B (Digestion), HBSS .9, EPA 7951
	T-Hg	Atomic absorption spectrometry using vapor	HBSS .5, EPA 7471A
	PCB	Gas chromatography with ECD	JIS K 0093, EPA 8082, Notification No.127[2]
	HCB	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual[1]
	Aldrin	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual[1]
	Endrin	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual[2]
	Dieldrin	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual[1]
	DDT	Gas chromatography with ECD	EPA 8081A,Tentative Survey Manual[1]

Note:
JIS : Japan Industrial Standard
EPA : Environmental Protection Agency
(2) "Tentative Survey Manual of External Factor Endocrine Disturbance Chemical Substance"
(3) Notification No.127 issued by Water Quality Control Section, Water Protection Department, EPA

4.5.2 Results of the Biological Accumulation Test

The results of biological accumulation analysis are shown in Table 4.27. All of the six parameters of aldrin, dieldrin, endrin, PCB, DDT, and hexachlorobenzene are mainly utilized as agricultural chemicals; PCB was not detected, which means that aquatic life inhabiting the water area around Tampico is not affected by the aforesaid toxic parameters.

On heavy metals, zinc was detected from each sample, ranging between 1-140 mg/kg. High concentrations of zinc (100-140 mg/kg) were found in three samples: oysters in Pueblo Viejo Lagoon, Tilapia in Conejo Lagoon and Gurrubata in Panuco River. Fishes normally have zinc content of up to a hundred ppm. So the amounts found in those three samples were not regarded as high levels.

Many samples analyzed for mercury are below minimum detection limit (0.25 mg/kg). However, a few samples, Ronco in the coastal area, Gurrubata in Panuco River and Pueblo Viejo Lagoon, have high mercury content ranging from 0.9-1.7 mg/kg. The result of a monitoring survey on mercury contamination in a Japanese coast revealed that many samples contained mercury ranging from 0.005-0.05 mg/kg, and a small number with over 0.4 mg/kg.

Table 4.27 Results of Biological Accumulation Test

No.	Sample Site	Species	Cd (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Hg (mg/kg)	PCB (mg/kg)	HCB (mg/kg)	Aldrin (mg/kg)	Endrin (mg/kg)	Dieldrin (mg/kg)	DDT (mg/kg)
1	Coast South	RONCO	<0.2	<1.0	0.30	5.5	0.46	ND	ND	ND	ND	ND	ND
2	Coast South	TRUCHA	<0.2	<1.0	<0.25	6.3	0.43	ND	ND	ND	ND	ND	ND
3	Coast South	GURRUBATA	<0.2	<1.0	<0.25	9.2	0.66	ND	ND	ND	ND	ND	ND
4	Coast South	RONCO	<0.2	<1.0	0.37	3.5	0.97	ND	ND	ND	ND	ND	ND
5	Coast South	HUACHINANG	<0.2	<1.0	<0.25	2.0	<0.25	ND	ND	ND	ND	ND	ND
6	Pueblo Viejo Lagoon 1	LEBRANCHA	<0.2	<1.0	0.35	2.9	<0.25	ND	ND	ND	ND	ND	ND
7	Pueblo Viejo Lagoon	GURRUBATA	<0.2	<1.0	<0.25	8.0	1.7	ND	ND	ND	ND	ND	ND
8	Pueblo Viejo Lagoon 3	LEBRANCHA	<0.2	<1.0	0.38	11	<0.25	ND	ND	ND	ND	ND	ND
9	Pueblo Viejo Lagoon 4	LEBRANCHA	<0.2	<1.0	0.51	17	<0.25	ND	ND	ND	ND	ND	ND
10	Pueblo Viejo Lagoon 1	LEBRANCHA	<0.2	<1.0	0.38	2.0	<0.25	ND	ND	ND	ND	ND	ND
11	Pueblo Viejo Lagoon 1	LEBRANCHA	<0.2	<1.0	0.68	62	<0.25	ND	ND	ND	ND	ND	ND
12	Pueblo Viejo Lagoon 3	LEBRANCHA	<0.2	<1.0	0.56	5.2	<0.25	ND	ND	ND	ND	ND	ND
1	Pueblo Viejo Lagoon 4	LEBRANCHA	<0.2	<1.0	0.49	2.9	<0.25	ND	ND	ND	ND	ND	ND
2	Pueblo Viejo Lagoon 1	OYSTER	0.4	<1.0	9.8	55	<0.25	ND	ND	ND	ND	ND	ND
3	Pueblo Viejo Lagoon 2	OYSTER	<0.2	<1.0	3.2	17	0.26	ND	ND	ND	ND	ND	ND
4	Pueblo Viejo Lagoon 3	OYSTER	0.4	<1.0	23	140	<0.25	ND	ND	ND	ND	ND	ND
5	Pueblo Viejo Lagoon 4	OYSTER	0.2	<1.0	7.8	79	<0.25	ND	ND	ND	ND	ND	ND
6	Pueblo Viejo Lagoon 5	OYSTER	<0.2	<1.0	5.3	58	<0.25	ND	ND	ND	ND	ND	ND
7	Conejo Lagoon 1	TILAPIA	<0.2	<1.0	<0.25	4.6	<0.25	ND	ND	ND	ND	ND	ND
8	Conejo Lagoon 2	TILAPIA	<0.2	<1.0	<0.25	1.3	<0.25	ND	ND	ND	ND	ND	ND
9	Conejo Lagoon 3	TILAPIA	<0.2	<1.0	<0.25	3.6	<0.25	ND	ND	ND	ND	ND	ND
10	Conejo Lagoon 1	TILAPIA	<0.2	<1.0	<0.25	100	<0.25	ND	ND	ND	ND	ND	ND
11	Conejo Lagoon 2	TILAPIA	<0.2	<1.0	<0.25	1.3	<0.25	ND	ND	ND	ND	ND	ND
12	Conejo Lagoon 3	TILAPIA	<0.2	<1.0	<0.25	1.9	<0.25	ND	ND	ND	ND	ND	ND
1	Conejo Lagoon 2	BAGRE	<0.2	<1.0	<0.25	4.8	<0.25	ND	ND	ND	ND	ND	ND
2	Conejo Lagoon 3	BAGRE	<0.2	<1.0	<0.25	1.7	<0.25	ND	ND	ND	ND	ND	ND
3	Panuco River 1	LEBRANCHA	<0.2	<1.0	<0.25	0.90	<0.25	ND	ND	ND	ND	ND	ND
4	Panuco River 1	LEBRANCHA	<0.2	<1.0	<0.25	1.0	<0.25	ND	ND	ND	ND	ND	ND
5	Panuco River 1	LEBRANCHA	<0.2	<1.0	<0.25	0.56	<0.25	ND	ND	ND	ND	ND	ND
6	Panuco River 1	LEBRANCHA	<0.2	<1.0	<0.25	3.5	<0.25	ND	ND	ND	ND	ND	ND
7	Panuco River 2	LEBRANCHA	<0.2	<1.0	0.33	1.9	<0.25	ND	ND	ND	ND	ND	ND
8	Panuco River	GURRUBATA	<0.2	<1.0	<0.25	3.5	<0.25	ND	ND	ND	ND	ND	ND
9	Panuco River 3	GURRUBATA	<0.2	<1.0	<0.25	3.1	0.29	ND	ND	ND	ND	ND	ND
10	Panuco River 3	GURRUBATA	<0.2	<1.0	<0.25	5.2	0.90	ND	ND	ND	ND	ND	ND
11	Panuco River 3	GURRUBATA	<0.2	<1.0	<0.25	3.5	0.33	ND	ND	ND	ND	ND	ND
12	Panuco River 3	GURRUBATA	<0.2	<1.0	<0.25	100	0.39	ND	ND	ND	ND	ND	ND

Thus, it cannot really be explained why the minimum detection limit of mercury has been comparatively high in this particular survey, but the catch areas of fishes detected with a high concentration of mercury were similar areas where mercury in sediment showed high values. It is possible that parts of the fishes are affected by environmental contamination of mercury. The amount of Cd measured was over the minimum detection limit in three samples of oyster, but it was not so high. Copper was detected at 3-24 mg/kg on some oysters. This does not really pose any problem because Mollusca, which have copper protein in their blood, have exhibited high concentrations of copper, in general. All samples measured for lead had amounts below minimum detection limit (1.0 mg/kg).

4.6 Assessment of Environmental Conditions in the Tampico Area

The following results of synthesized assessment concerning the characteristics of each water area are based on two observations that have been made:

(1) Coastal Area

a) Near the Mouth of Panuco River

The area around the mouth of the river was directly affected by river water causing high turbidity and bacterial contamination in rainy season. In one part, a high concentration of mercury was found in the sediment and Gurrubata fish.

- North Area

Its condition was normal although water transparency was a little low.

- Altamira Industrial Port

There was no noteworthy phenomenon found, except for the bottom water of the inner port, which experienced oxygen deficiency in the rainy season.

(2) Panuco River

It has strong turbid condition. Contamination by bacteria and organic matter is also present. In addition, there is high mercury content in the sediment and Gurrubata fish.

(3) Pueblo Viejo Lagoon

The Panuco River has a remarkable effect on the northeast area of the lagoon. That being the case, the lagoon exhibits the same characteristics as Panuco River: high turbidity, organic and bacterial contamination, high concentration of mercury in sediment and accumulation of mercury in the Gurrubata fish.

(4) Conejo Lagoon

Among the observed water areas, Conejo Lagoon recorded the highest values for many pollutants of basic parameters. The Lagoon has remarkable eutrophication and organic contamination. However, Tilapia and Bagre, which are found in the Lagoon, did not have any abnormal accumulation of heavy metals and toxic organic compound in their system.

Chapter 5 Pollution Load Analysis and Water Quality Simulation

5.1 Pollution Load Analysis

5.1.1 Methods of Pollution Load Analysis

(1) Objectives

In general, pollution load analysis within the context of water quality monitoring is aimed at estimating the pollution loads of four parameters, i.e. COD, BOD_5, total nitrogen, and total phosphorus, in the Tampico Area for formulation of the Coastal Water Quality Monitoring Plan. Specifically, the analysis intends to accomplish the following:

- to identify existing pollution sources in the Tampico Area;
- to estimate the existing pollution loads in the Tampico Area; and
- to estimate the future pollution loads in the Tampico Area.

(2) Study Area

The Study Area for pollution load analysis includes the following five water bodies:

- Coastal Water (extending from Altamira Industrial Port to Panuco River mouth);
- Altamira Industrial Port (including Garrapatas Stream and watershed);
- Conejo Lagoon and Marismas Lagoon;
- Panuco River (from the junction with Tamesi River to the mouth of Panuco River); and
- Pueblo Viejo Lagoon (including Llave River).

(3) Calculation Flow of Pollution Load Analysis

Pollution loads have been analyzed separately for point pollution sources and for non-point pollution sources. The calculation flow of pollution load analysis is shown in Figure 5.1.

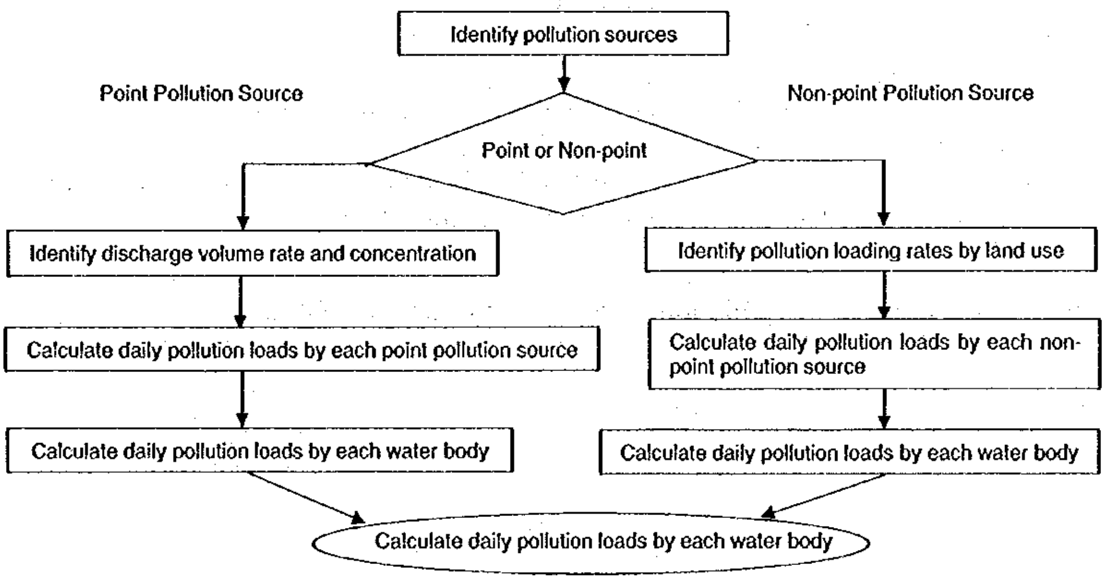


Figure 5.1 Outline of Pollution Load Analysis

5.1.2 Existing Pollution Sources

The major sources of pollutants in the Tampico Area are classified into point and non-point sources, which are itemized in Table 5.1 and briefly described as follows:

(1) Point Pollution Sources

a) Industrial Wastewater

Petrochemical and chemical industries independently discharge their wastewater into the following areas:

- Altamira Industrial Port and Garrapatas Stream (A in Table 5.1);
- Conejo Lagoon (B/1 in Table 5.1);
- Panuco River (C in Table 5.1); and
- Coast Water of Gulf of Mexico (from D to G in Table 5.1).

b) Municipal Wastewater

Untreated municipal wastewater from Tampico and Madero (C/4/1-5, C/5/1-4, and C/8/1-2 listed in Table 5.1) is discharged into Panuco River. The wastewater comes not only from domestic water use but also from industrial and commercial water uses.

(2) Non-Point Pollution Sources

Based on aerial photographs of 1995, topographical maps, and other information on Tampico Area from SAGAR, and the urban development plan of southern Panuco River Metropolitan Area, the land use of Tampico Area is categorized into the following:

i) Low density residential area;
ii) Medium density residential area;
iii) Commercial area including Tampico Commercial Port;
iv) Industrial area including Altamira Industrial Port;
v) Recreational/open lands (urban);
vi) Cropland/pasture area including open land (agriculture) and shrub land;
vii) Streams and lakes; and
viii) Wetlands (including swamp, wetland mixed hardwood forest, freshwater marshes, saltwater marshes, and non-vegetated wetlands).

The estimated areas of non-point pollution sources are indicated in Table 5.2.

Table 5.1 Inventory of Pollution Sources

Pollution Source Number*	Name	Activity	Discharge Type
	Gulf of Mexico		
A	Altamira Industrial Port		
A/1, S	Administracion Portuaria Integral del Altamira	Service	Point
A/2, I	Pittsburgh Plate Glass Industry	Inorganic Chemical Industry	Point
A/3	Garrapatas Stream		
A/3/1, I	Policyd	Polymer Synthesis Industry	Point
A/3/2, I	Comision Federal de Electricidad	Power Station	Point
A/3/3, I	Negromex (Solucion)	Petrochemical Industry	Point
A/3/4, R	Watershed of Garrapatas Stream		Non-point
B	Marismas Lagoon		
B/1	Conejo Lagoon		
B/1/1, I	BASF Mexicana	Polymer Synthesis Industry	Point
B/1/2, I	Grupo Primex	Polymer Synthesis Industry	Point
B/1/3, I	Internacional Papeles del Golfo	Pulp Industry	Point
B/1/4, I	Fibras Nacionales de Acrilico	Fiber Synthesis Industry	Point
B/1/5, I	GE Plastic (Polimar)	Polymer Synthesis Industry	Point
B/1/6	Park of Small and Medium Industry		
B/1/6(1), I	Operadora y Comercializadora Trevi Plus	Bottle Water Production	Point
B/1/6(2), I	Johns Manville	Insulant and impermeable material	Point
B/1/6(3), I	Tecno Asfalto del Golfo	Asphalt Industry	Point
B/1/6(4), I	Asfaltos y Derivados Mexicanos	Asphalt Industry	Point
B/1/6(5)-(16), I	Others		Point
B/1/7	Watershed of Conejo Lagoon		Non-point
C	Panuco River		
C/1	Panuco River Upstream		River
C/2	Tamesi River System		River
C/2/1	Costa Lagoon		Non-point
C/3	Morelos		Non-point
C/3/1, I	Sea-food Processing Industries		Point
C/4	Canal la Puntilla		
C/4/1, M	Altavista Water Supply System	Municipal Use	Point
C/4/2, M	Carcamo No 1	Municipal Wastewater Drainage	Point
C/4/3, M	Carcamo No 2	Municipal Wastewater Drainage	Point
C/4/4, M	Carcamo No 3	Municipal Wastewater Drainage	Point
C/4/5, M	Planta de Bombas No 6	Municipal Wastewater Drainage	Point
C/4/6, U	Southwestern Part of Tampico	Urban Area	Non-point
C/4/7, M	Tampico Solid Waste Landfill Site	Municipal Solid Waste	Non-point
C/5, U	Tampico		
C/5/1, M	Planta de Bombas No 1	Municipal Wastewater Drainage	Point
C/5/2, M	Planta de Bombas No 7	Municipal Wastewater Drainage	Point
C/5/3, M	Planta de Bombas No 8	Municipal Wastewater Drainage	Point
C/5/4, M	Sistema de Gravedad No 12	Municipal Wastewater Drainage	Point
C/5/5, M	Southern Part of Tampico	Urban Area	Non-point
C/6, U	Northern Part of Pueblo Viejo	Urban Area	Non-point
C/7	Pueblo Viejo Lagoon		
C/7/1, R	Watershed of Pueblo Viejo Lagoon	Pasture	Non-point
C/7/2, M	Cuauhtemoc Oxidation Pond	Municipal Wastewater Treatment	Point
C/8	Madero	Urban Area	Non-point
C/8/1, M	Sistema de Gravedad No 11	Municipal Wastewater Drainage	Point
C/8/2, M	Planta de Bombas No 9	Municipal Wastewater Drainage	Point
C/8/3, U	Southern Part of Madero	Urban Area	Non-point
C/9	Chijol Channel		Non-point
C/10, I	Refineria Madero	Petroleum Refinery	Several points
C/11, I	Quimica del Mar	Inorganic Industry	Point
D	Petrocel		
D(1), I	Petrocel	Synthesis of terephthalic acid	Point
D(2), I	Indelpro	Polymer Synthesis Industry	Point
D(3), I	Hercules	Synthetic Fiber Industry	Point
D(4), I	Tereftalatos Mexicanos	Synthesis of terephthalic acid	Point
D(5), I	Pecten Poliesters	Polymer Synthesis Industry	Point
E, I	Novaquim	Antioxidant, Antiozonant Synthesis	Point
F	Negromex		
F(1), I	Negromex	Synthetic Rubber Industry	Point
F(2), I	Nhumo	Carbon Black Production	Point
G, I	Dupont	Inorganic Color Gradient Industry	Point

* I: Industrial, S: Service, M: Municipal, R: Rural, U: Urban, Aqua: Aquaculture
** Las Marismas is not directly inter-connected with the Gulf of Mexico

Table 5.2 Non-point Pollution Source Areas by Land Use Category

unit: ha

Land Use Category	Pollution Source Number									
	A/3/4	B/1/7	C/2/1	C/3/1	C/4/6	C/4/7	C/5/5, C/8/3	C/6	C/7/1	C/9
Low density residential	50	-	60	150	-	510	1278	140	310	90
Medium density residential	-	-	-	-	-	-	267	-	-	-
Commercial	-	-	-	-	-	-	106	-	-	-
Industrial	240	80	-	-	50	-	304	120	-	-
Recreation/open	-	-	-	-	50	-	126	-	-	-
Cropland/pastureland	6550	260	4000	-	-	-	-	580	94100	2130
Lakes and streams	-	-	300	-	-	-	80	-	-	60
Wetlands	-	-	1700	-	-	-	-	25	4160	370
Total	6840	340	6060	150	100	510	2161	865	98570	2650

Source: JICA Study Team

5.1.3 Future Pollution Sources

(1) Socioeconomic Trend

a) Population projection

Although there are many unregistered inhabitants or illegal settlers especially in Pueblo Viejo or Tampico City, the JICA Study Team applied *CONAPO*'s estimation as the population projection for pollution load analysis. Table 5.3 shows the projected population in the Tampico Area from 1995 to 2010.

Table 5.3 Population Projection in the Tampico Area

Cities/Municipalities	Annual Average	Projected Population			
Year	Growth Ratio	1995	2000	2005	2010
Altamira City	4.35%	111,889	142,890	176,515	212,054
Madero City	0.94%	170,282	181,873	191,793	200,625
Tampico City	0.40%	278,364	287,176	292,503	295,622
Panuco Municipality	0.97%	95,774	101,949	106,917	110,768
Pueblo Viejo Municipality	1.40%	49,198	53,679	57,570	60,871
Tampico Alto Municipality	0.13%	14,009	14,260	14,346	14,297
Total		719,516	781,827	839,644	894,237

Source: *CONAPO*

b) Economic activities

Table 5.4 shows the projection of chemical and petrochemical production. It is projected that the production of each item will increase at an annual growth rate of 4% until 2010.

Table 5.4 Projection of Chemical-related Production

Unit: tons/year

Company Name	Products	Year 1996 Production	Year 1998 Production	Year 2010 Projection
DUPONT	Titanium Bioxide	96,000	110,000	176,114
HULES MEXICANOS	Synthetic Rubber	70,000	84,000	134,487
NHUMO	Carbon Black	106,000	120,000	192,124
PRIMEX	PVC Resins	185,000	260,000	416,268
	PVC Compound	31,000	37,200	59,558
	Pthalic Anhydride	32,000	38,400	61,480
	Dioctyl Phtalate	35,000	42,000	67,243
G.E. PLASTICS	ABS Resins	30,000	35,000	56,036
NOVAQUIM	Intermediate Rubber	9,400	7,000	11,207
PETROCEL	Dimethyl Terephtalate	390,000	468,000	749,283
	Terephtalic Acid	36,000	43,200	69,165
POLICYD	PVC Resins	105,000	113,000	180,917
NEGROMEX	Synthetic Rubber	149,000	91,000	145,694
INDELPRO	Polypropylene	135,000	183,000	292,989
FINACRIL	Acrylic Fibers	60,000	72,000	115,274
POLIOLES	Polystyrene	20,000	24,000	38,425
BASF MEXICANA	Acrylic Dispersions	25,000	33,000	52,834
	Crystal Polystyrene+	143,000	154,000	246,559
	Stirenic Copolymers++	130,000	156,000	249,761
HERCULES FIBRAS	Polypropylene Short Fiber+	15,000	18,000	28,819
P.P.G. INDUSTRIES	Precipitated Silica Gel+	30,000	11,000	17,611
TEMEX	Terephtalic Acid+	350,000	532,000	851,749
PECTEN POLIESTERS	Polyethylene Terephtalate+	200,000	70,000	112,072
QUÍMICA FLUOR	Hydrogen Fluorides	67,500	81,000	129,684
PEMEX	Oil refinery	125,000	150,000	240,155
TOTAL		2,574,900	2,932,800	4,695,507

Source: JICA Study Team

In the Tampico Area, the future industrial structure will not change mainly due to the characteristics of recent industrial trends, labor force demand, as well as the absence of any specific industrial development plan in the Area except for Altamira.

(2) Future Pollution Load Assumptions

a) Rivers

It is assumed that the discharge volume rate and pollution loads from upstream of Panuco River and from Tamesi River will remain at present levels.

b) Industrial Wastewater

The following assumptions have been made:

i) Discharge volume rate of petrochemical and chemical industrial wastewater will also increase at an annual growth rate of 4%, with increments of its industrial production.

ii) The concentration of three parameters (BOD5, total nitrogen and total phosphorus) is within 70% of maximum permissible limit of wastewater standard (NOM-001-ECOL-1996), and is expected to remain at the said level.

iii) The concentration of one parameter exceeds 70% of maximum permissible limit, and industries discharging at this level will reduce the concentration of said parameter to within 70% of the maximum permissible limit until 2010; and,

iv) The levels of other parameters and COD will also be reduced to the same proportion as above.

c) Municipal Wastewater

Municipal wastewater projection is presented in Table 5.5. It is assumed that a new wastewater treatment facility would be able to treat 1.2 m^3/s of wastewater generated by Tampico City and Madero City.

Table 5.5 Municipal Wastewater Projection in the Tampico Area between 1999 and 2010

Local Body	Population*		Daily discharge volume per capita ***		Daily BOD5 load Per capita***		Daily COD load per capita***		Daily total N load per capita***		Daily total P load per capita***	
	1999 (no. of persons)	2010 (no. of persons)	1999 (l /capita /day)	Annual growth rate(%)	1999 (g /capita /day)	Annual growth rate(%)	1999 (g /capita /day)	Annual growth rate(%)	1999 (g /capita /day)	Annual growth rate (%)	1999 (g /capita /day)	Annual growth rate (%)
Altamira Municipality	136,339	212,054	195	3	51	1.5	94	1.5	8.7	1.5	1.04	1.5
Miramar (South Part of Altamira Municipality)	60,000	70,667	195	3	51	1.5	94	1.5	8.7	1.5	1.04	1.5
Tampico City **	285,765	295,622	251	4	70	2	108	2	18.7	2	2.35	2
Madero City **	179,721	200,625	251	4	70	2	108	2	18.7	2	2.35	2
Pueblo Viejo Municipality	52,820	60,871	150	3	45	1.5	82	1.5	7.6	1.5	0.91	1.5

* Source: CONAPO except Miramar, Population of Miramar and small communities around Miramar: approximate value from 51,462 (only Miramar) in 1995

** Note: Including wastewater from commercial and industrial origin

*** Note: Estimation from data on municipal wastewater

d) Non-point Pollution Source

It is assumed that conversion of land use from pasture/cropland to low density residential area in Altamira, Pueblo Viejo, and Panuco Municipalities will increase following the growth in population.

5.1.4 Pollution Load Analysis

(1) Existing Pollution Load Analysis

a) Industrial and Municipal Wastewater

Daily discharge volume, concentrations of pollutants and daily pollution loads from industrial and municipal wastewater in the Tampico Area are shown in Table 5.6.

Table 5.6 Profile of Present Industrial and Municipal Wastewater

Pollution Source Number	Daily Discharge Volume (m^3/day)	BOD_5 Average conc. (mg/l)		COD Average Conc. (mg/l)		Total nitrogen Average conc. (mg/l)		Total phosphorus Average Conc. (mg/l)	
		Average conc. (mg/l)	Daily Load (kg/day)	Average Conc. (mg/l)	Daily Load (kg/day)	Average conc. (mg/l)	Daily Load (kg/day)	Average Conc. (mg/l)	Daily Load (kg/day)
A/1	77	28.0	2.1	118	9.1	-	-	-	-
A/2	3,010	1.2	3.6	17.0	51.2	-	-	-	-
A/3/1	1,040	17.8	18.5	39.5	41.0	2.1	2.2	0.7	0.77
A/3/2	4,770	5.2	25.0	81.0	386	0.5	2.5	1.5	7.09
A/3/3	456	14.8	6.7	41.4	18.9	0.7	0.3	2.7	1.25
B/1/1	718	34.0	24.4	153	110	21.0	15.1	0.87	0.62
B/1/2	3,590	512	1,840	959	3,440	2.9	10.4	0.46	1.64
B/1/3	296	172	52.1	400	118	-	-	-	-
B/1/4	2,390	71.2	170	138	329	19.5	46.6	3.3	7.95
B/1/5	767	8.9	6.8	46.4	35.6	-	-	-	-
B/1/6(2)	7.59	26.4	0.2	197	1.5	-	-	-	-
B/1/6(3)	0.83	125	0.1	261	0.2	-	-	-	-
B/1/6(4)	1.20	4.2	0.005	30.0	0.036	-	-	-	-
C/3/1	250	-	110	-	202	-	-	-	-
C/4/1	7,580	55.4	420	80	606	-	-	-	-
C/4/2	3,160	202	639	470	1,490	64	202	8	25
C/4/3	4,830	188	909	400	1,930	57.2	276	7.2	35
C/4/4	2,070	166	344	440	909	56	116	7	14
C/4/5	3,750	599	3,260	870	3,260	156	587	19.5	73
C/5/1	34,880	320	11,200	430	15,000	81.4	2,840	10.2	356
C/5/2	9,730	398	3,870	550	5,350	102	994	12.8	124
C/5/3	7,220	415	3,000	450	3,250	98.7	712	12.3	89
C/5/4	1,380	125	173	280	387	39	54	4.9	6.8
C/7/2	-	-	-	-	-	-	-	-	-
C/8/1	11,383	207	2,360	470	5,350	64.9	739	8.1	92
C/8/2	11,675	205	2,390	420	4,904	61.3	716	7.7	90
C/10(1)	935	43.1	40	599	560	10.5	9.8	0.81	0.75
C/10(2)	5,470	99.7	545	1,093	6,540	57	312	1.3	5.61
D	8,270	35.8	296	82.3	681	0.5	4.5	-	-
E	349	304	106	571	199	58	20.2	-	-
F(1)	2,650	63.1	167	487	1290	21.5	57	-	-
F(2)	681	51	34	100	68.1	3	2	-	-
G	5,720	21	120	-		-		-	-

Source: *CNA*

The following results are obtained:

i) Untreated municipal wastewater from the cities of Tampico and Madero (C/4/2-4, C/5/1-4, and C/8/1-2) is the main pollution source (84% of total BOD_5 load and 74% of total COD load from industrial and municipal wastewater) in the Tampico Area;

ii) *Refineria Madero* (C/10) discharges 1.8% of BOD_5 load and 12.6% of COD load from industrial and municipal wastewater; and

iii) *Grupo Primex* (B/1/2) discharges 5.7% of BOD_5 load and 6.0% of COD load from industrial and municipal wastewater.

b) Rivers and Non-point Pollution Sources

Tables 5.7 and 5.8 show the daily discharge volume, concentration of pollutants, and daily pollution loads from rivers and non-point pollution sources in the dry season and rainy season respectively. Following are the results of analysis:

i) Pollution loads are much larger in rainy season rather than in dry season;
ii) The upstream of Panuco River (C/1) discharges the largest pollution loads into Tampico Area (91% of total BOD_5 load and 95% of total COD load in dry season; 92% of total BOD_5 load and 96% of total COD load in rainy season from rivers and non-point pollution sources); and,
iii) Tamesi River (C/2) discharges the second largest pollution loads from rivers and non-point pollution sources.

Table 5.7 Profile of Present Non-Point Pollution Sources in Dry Season

Pollution Source Number	Daily Discharge Volume (m^3/day)	BOD_5		COD		Total nitrogen		Total phosphorus	
		Average Conc. (mg/l)	Pollution Load (kg/day)	Average conc. (mg/l)	Pollution Load (kg/day)	Average conc. (mg/l)	Pollution Load (kg/day)	Average Conc. (mg/l)	Pollution Load (kg/day)
A/3/4	-	-	27.1	-	68.6	-	11.7	-	1.78
B/1/7	-	-	4.36	-	8.95	-	1.07	-	0.18
C/1	16,000,000	1.81	29,000	20.7	332,000	0.788	12,600	0.090	1,440
C/2	1,200,000	1.90	2,280	15.3	18,300	0.905	967	0.075	89
C/2/1	-	-	22.5	-	67.1	-	10.9	-	1.43
C/3	-	-	1.18	-	2.24	-	0.421	-	0.054
C/4/6	-	-	1.18	-	7.61	-	1.43	-	0.18
C/4/7	-	-	2.42	-	4.59	-	0.503	-	0.078
C/5/5 C/8/3	-	-	36.5	-	69.7	-	9.13	-	1.33
C/6	-	-	7.85	-	16.5	-	2.22	-	0.35
C/7/1	-	-	134	-	400	-	74.3	-	10.8
C/9	-	-	8.06	-	23.4	-	4.18	-	0.58

Table 5.8 Profile of Present Non-point Pollution Sources in Rainy Season

Pollution Source Number	Daily Discharge Volume (m^3/day)	BOD_5 Average Conc. (mg/l)	Pollution Load (kg/day)	COD Average conc. (mg/l)	Pollution Load (kg/day)	Total nitrogen Average conc. (mg/l)	Pollution Load (kg/day)	Total phosphorus Average Conc (mg/l)	Pollution Load (kg/day)
A/3/4	-	-	141	-	357	-	60.9	-	9.3
B/1/7	-	-	22.7	-	47	-	5.59	-	0.92
C/1	66,600,000	1.02	68,000	24.7	1,645,000	1.036	17,500	0.149	9,930
C/2	3,630,000	1.18	4,260	16.4	59,300	0.62	2,250	0.073	265
C/2/1	-	-	118	-	350	-	56.9	-	7.4
C/3	-	-	6.14	-	11.7	-	2.19	-	0.28
C/4/6	-	-	20.9	-	39.7	-	7.46	-	0.96
C/4/7	-	-	12.6	-	23.9	-	2.62	-	0.41
C/5/5 C/8/3	-	-	190	-	364	-	47.6	-	6.92
C/6	-	-	43.5	-	91.6	-	12.3	-	1.9
C/7/1	-	-	743	-	2,220	-	412	-	60
C/9	-	-	44.7	-	130	-	23.1	-	3.2

c) Total Amount of Pollution Loads

Daily COD load from the Tampico Area is shown in Figure 5.2. Salient findings include the following:

i) In Altamira Industrial Port (A), contamination from industrial wastewater is not serious at present;

ii) The existing pollution loads from industrial wastewater into Conejo Lagoon is serious, because Conejo Lagoon is a small closed water body;

iii) COD level upstream of Panuco River (C/1) determines the concentration of COD in the mouth of Panuco River. On the other hand, the concentration of BOD_5, total-nitrogen, and total-phosphorus in the mouth of Panuco River is determined by the discharge volume rate and water quality of two pollution sources: upstream of Panuco River and the municipal wastewater of the cities of Tampico and Madero (C/4/2-5, C/5/1-4, and C/8/1-2); and

iv) Panuco River is the source of almost all the COD pollution load in the coastal waters of the Gulf of Mexico.

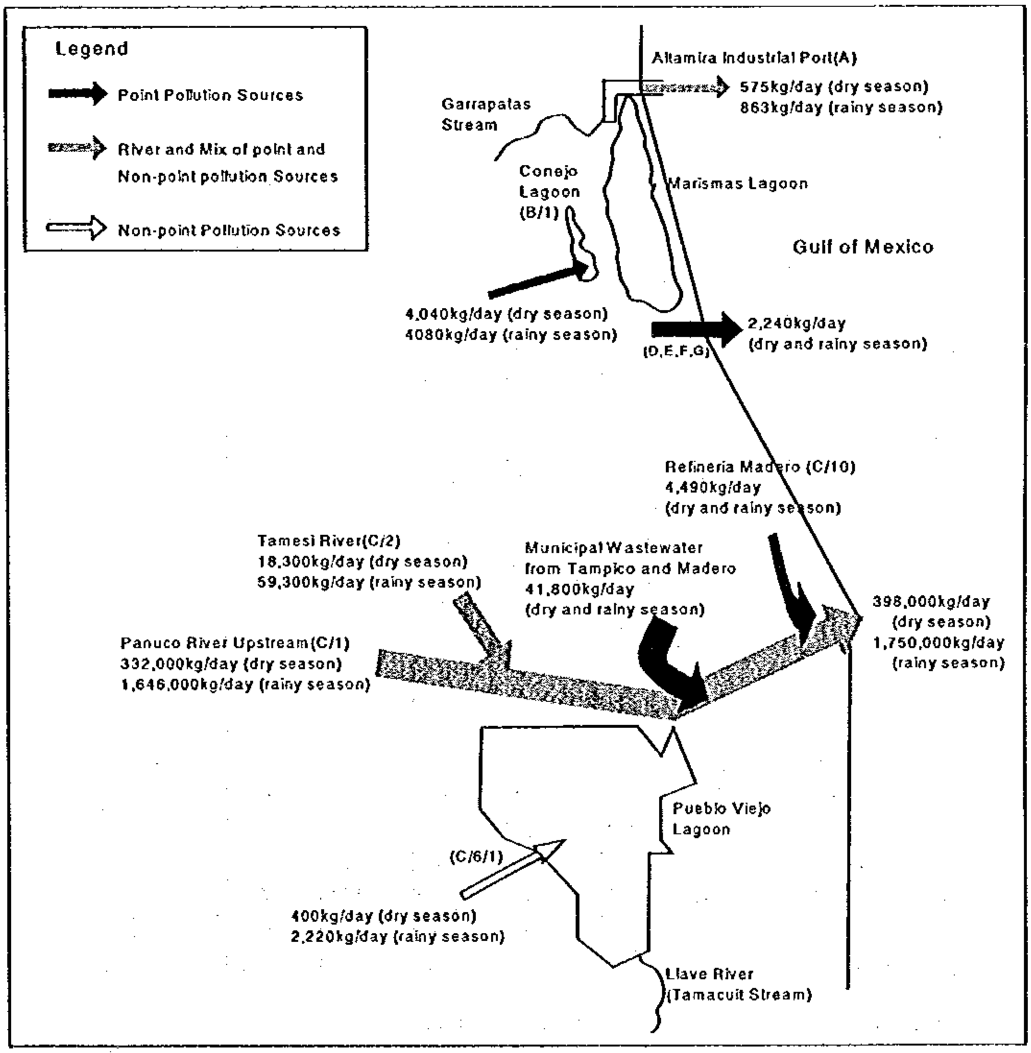


Figure 5.2 Present Pollution Load of COD in the Dry Season and Rainy Season

(2) Future Pollution Load Analysis

a) Industrial and Municipal Wastewater

The daily discharge volume, concentration of pollutants and daily pollution loads from industrial and municipal wastewater in the Tampico Area in 2010 are shown in Table 5.9. Results of analysis include the following:

i) Pollution loads from the untreated municipal wastewater of Tampico City and Madero City into Panuco River (C/4/2-5, C/5/1-4, C/8/1-2) will decrease (from 41,800 kg/day to 33,000 kg/day for COD load);

ii) In 2010, COD load will be much lesser than present levels from Grupo Primex (B/1/2) (from 3,440 to 588 kg/day), Internacional Papeles del Golfo (B/1/3) (from 118 to 60.1 kg/day), Refineria Madero (C/10) (from 7,100 to 2,760 kg/day) and Novaquim (E) (from 199 to 57 kg/day); and

iii) Pollution loads from other point pollution sources will not decrease.

Table 5.9 Projected Industrial and Municipal Wastewater by 2010

Pollution Source Number	Daily Discharge Volume (m^3/day)	BOD_5		COD		Total nitrogen		Total phosphorus	
		Average Conc. (mg/l)	Daily Load (kg/day)	Average Conc. (mg/l)	Daily load (kg/day)	Average conc. (mg/l)	Daily Load (kg/day)	Average Conc. (mg/l)	Daily Load (kg/day)
A/1	128	28.0	3.58	118	15.1	-	-	-	-
A/2	5,010	1.2	6.0	17.0	85.2	-	-	-	-
A/3/1	1,730	17.8	30.8	39.5	68.2	2.1	3.68	0.7	1.28
A/3/2	4,770	5.2	25.0	81.0	386	0.5	2.5	1.5	7.09
A/3/3	759	14.8	11.2	41.4	31.4	0.7	0.57	2.7	2.08
A/5*	4,770	5.2	25.0	81.0	386	0.5	2.5	1.5	7.09
B/1/1	1,200	34.0	40.6	153	183	21.0	25.1	0.87	1.03
B/1/2	5,975	52.5	314	98.4	588	0.3	1.79	0.047	0.28
B/1/3	493	52.5	25.9	122	60.1	-	-	-	-
B/1/4	3,973	52.5	209	102	405	14.4	57.2	1.23	4.88
B/1/5	1280	8.9	11.4	46.4	59.3	-	-	-	-
B/1/6(2)	12.6	26.4	0.332	197	2.48	-	-	-	-
B/1/6(3)	1.38	52.5	0.073	110	0.15	-	-	-	-
B/1/6(4)	2.00	4.2	0.01	30.0	0.06	-	-	-	-
C/3/1	250	-	110	-	202	-	-	-	-
C/4/1	13,000	55.4	720	80	1,040	-	-	-	-
(C/4/2-5, C/5/1-4, C/8/1-2)	95,000	-	21,400	-	33,000	-	5,730	-	704
C/10(1)	1,560	43.1	67	599	932	10.5	16.4	0.81	1.17
C/10(2)	9,100	18.4	168	201	1,830	10.5	95.6	1.73	5.61
D	13,800	35.8	494	82.3	1,136	0.5	6.9	-	-
E	580	52.5	30.5	99	57	10.0	5.8	-	-
F(1)	4,590	52.5	241	405	1,860	17.9	82.2	-	-
F(2)	1,130	51	57.6	100	113	3	3.39	-	-
G	10,700	21	224	-		-		-	-

Source:

* A/5: a new thermal power station in Altamira Industrial Port

b) Rivers and Non-point Pollution Sources

Pollution loads from rivers and non-point sources will not drastically change.

c) Total Amount of Pollution Load

The daily pollution load of COD from the Tampico Area in 2010 is shown in Figure 5.3. Results of analysis point to the following:

i) In 2010, pollution loads into Conejo Lagoon (B/1) will be reduced (from 4040 to 1310 kg/day for COD load in dry season);
ii) On the other hand, there will be an increase in pollution loads from Altamira Industrial Port (A) (from 575 kg/day to 1040 kg/day for COD load in dry season) and from the industrial zone (D, E, F, and G) into coastal waters (from 2,240 to 4,220 kg/day for COD load); and
iii) Almost all of the pollution loads of COD and other parameters (BOD_5, total nitrogen and total phosphorus) into the coastal waters of Gulf of Mexico will also be discharged from Panuco River as in the present situation.

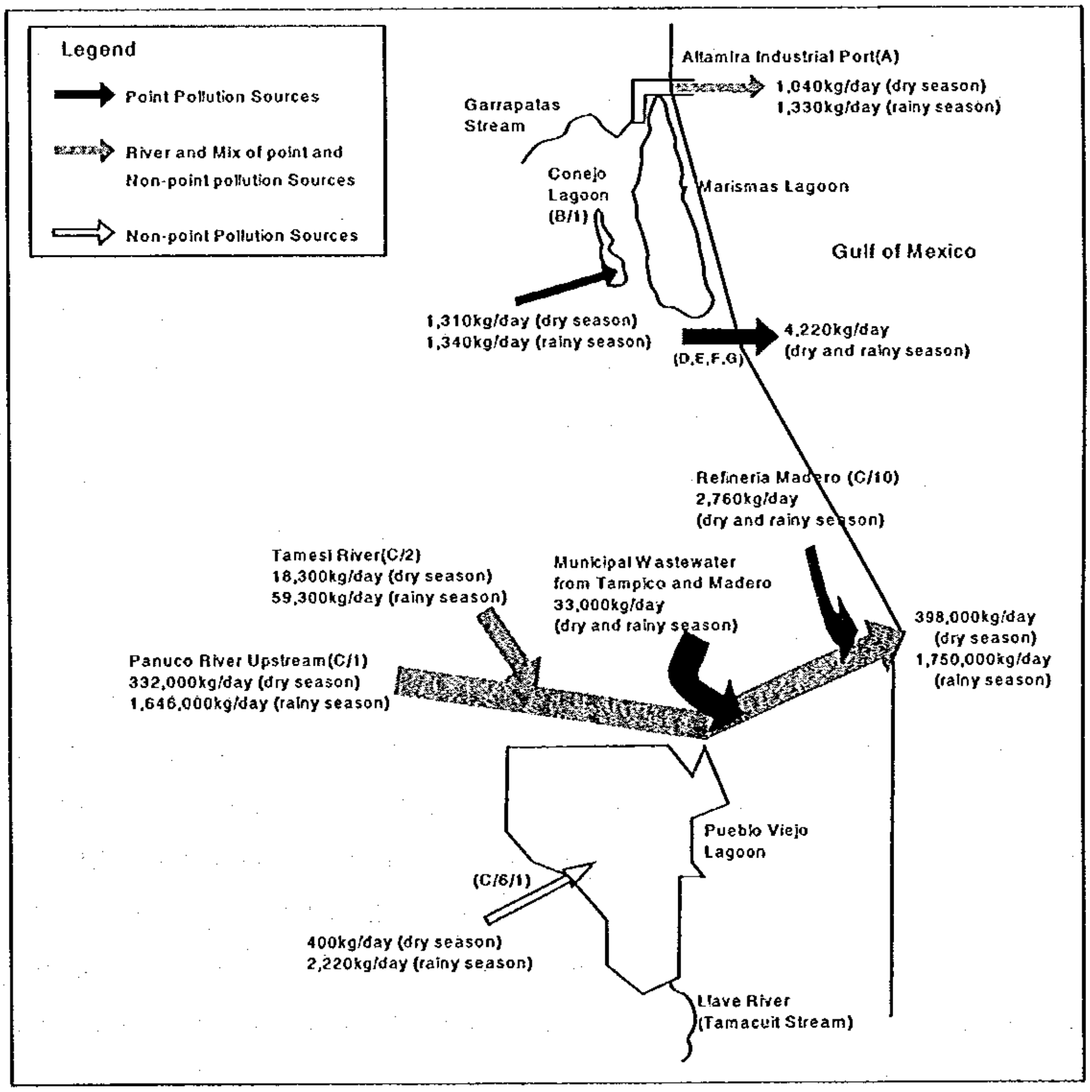


Figure 5.3 Projected Pollution Load of COD in the Dry Season and in Rainy Season by 2010

5.2 Water Quality Simulation

5.2.1 Objective

The objective of using numerical simulation models is to compute the horizontal distribution of key water quality parameters to enable appropriate selection of water quality monitoring points. The numerical simulation test can predict various changes in water quality caused by future pollution loads induced by socioeconomic conditions. As a tool for such rational environmental management planning, numerical simulation models are expected to simulate hydrodynamic characteristics and water quality of coastal and lagoon water bodies. In order to enable appropriate selection of water quality monitoring stations, the model should be, at least, two-dimensional horizontally.

5.2.2 Selection of Study Area

In this Study, water quality simulation analysis will be incorporated to seek a rational distribution of monitoring points. The water quality simulation test has been applied to two out of five water bodies in the Study Area, as follows:

- Pueblo Viejo Lagoon, and
- Coastal water, extending from the mouth of Panuco River up to Altamira industrial zone.

The above mentioned water bodies have different characters; the former is a closed water body and the latter is a sea area open to the Gulf of Mexico. The simulation model used in this Study should be applicable to other coastal and lagoon water bodies in the United Mexican States. Therefore, it is considered appropriate that two water bodies of different characteristics are selected as case studies for the water quality simulation test.

5.2.3 Model Description

The projection of water quality should be conducted using an appropriate model in accordance with the set objectives. In the projection of water quality for coastal waters, the hydrodynamic equations and/or the advection-diffusion equations are often solved numerically using the finite difference method or the finite element method. The difference between numerical simulation and analytical solution is that a lot of input data are required to execute a numerical simulation, so that much time is required to prepare data and to execute the simulation. In addition, expert skills are required to enable correct interpretation of the simulation results.

On the other hand, numerical simulations are flexible and widely applicable to any situation.

There are many types of simulation models, and some are listed below:

- One-dimensional model(horizontal)
- One-dimensional model(vertical)
- Two-dimensional model(horizontal)
- Two-dimensional model(vertical)
- Three-dimensional model

Among them, the horizontal two-dimensional model is most widely used in coastal water quality applications. This model is formulated as a depth-averaged model, which is obtained by integrating vertically the three-dimensional equations. A typical application of the two-dimensional model is the simulation of hydrodynamic characteristics and water quality of coastal and/or lagoon water bodies that are relatively shallow. This depth-averaged model is also applicable to water bodies where the water is well mixed vertically, so that the water quality is relatively uniform in the vertical. There are many applications whereby the depth-averaged two-dimensional model has been used for environmental impact assessments in Japan.

The three-dimensional model is the most comprehensive version of simulation models because it offers a three-dimensional resolution, thus there are few constraints in using it. For example, the model is capable of differentiating important factors in hydrodynamics such as tidal, wind driven and density currents. However, the model needs many input parameters, as well as expert skills, in order to use it effectively.

Taking into account the above mentioned characteristics of each numerical simulation model, it is considered that the horizontal two-dimensional model would be the appropriate model for Pueblo Viejo Lagoon and the coastal waters of Tampico. The two water bodies possess a horizontally broad area. Pueblo Viejo Lagoon is very shallow, with a depth of only 1 to 2 meters. The bed slope in the coastal section is relatively gentle; a depth contour line of 20 meters running almost parallel to the coast is located nearly 7 km offshore from the coast, and a depth contour line of 50 meters is located nearly 30 km offshore from the coast. In the shallow waters of Pueblo Viejo Lagoon and the coastal water area, which opens wide to the broad ocean, the density stratification is expected to have a minor role in determining the hydrodynamic characteristics and water quality of both water bodies. Therefore, the depth-averaged two-dimensional model is considered to be applicable.

One of the objectives of using numerical simulation is to enable the appropriate selection of water quality monitoring points. To meet this objective, it is at least necessary that horizontal distribution of water quality be one of the outputs of simulation. The depth-averaged two-dimensional model meets that requirement.

As mentioned above, the most comprehensive simulation model is the three-dimensional model, which can be applied to almost any situation. However, a high degree of technical skills is required to use a three-dimensional (3-D) model, thus it is unlikely that the use of 3-D simulation method in the context of coastal water quality monitoring program is widespread. In contrast, a computer program package of the depth-averaged two-dimensional model is relatively easy to use. Therefore, it is also recommended that the depth-averaged two-dimensional model be used until enough skills could be obtained to use 3-D simulation models.

The MIKE21 ELP software, which was developed by the Danish Hydraulics Institute (DHI), is one of the two-dimensional hydrodynamic and water-quality modeling systems. This system has been chosen as a tool to simulate the hydrodynamic characteristics and water quality of the study area owing to its worldwide use and relatively low-cost package that includes the following:

- PP : Pre- and Post-processing Module;
- HD : Hydrodynamic Module; and
- AD : Advection-Dispersion Module.

The fundamental equations used in the MIKE21 HD and AD are shown below. The following equations, with the conservation of mass and momentum integrated in the vertical, describe the flow and water level variations.

(1) Hydrodynamic Equations

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=0$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2h^2}$$

$$-\frac{1}{\rho_W}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega\, q-fVV_x+\frac{h}{\rho_W}\frac{\partial}{\partial x}(p_a)=0$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2h^2}$$

$$-\frac{1}{\rho_W}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]+\Omega\, p-fVV_y+\frac{h}{\rho_W}\frac{\partial}{\partial y}(p_a)=0$$

where:

h(x,y,t)	:	Water depth (m)
ζ (x,y,t)	:	Surface elevation (m)
p,q,(x,y,t)	:	Flux densities in x- and y- directions ($m^3/s/m$) = (uh,vh) ; (u,v) = depth averaged velocities in x- and y- directions
C(x,y)	:	Chezy resistance ($m^{0.5}/s$)
g	:	Acceleration due to gravity (m/s^2)
f(V)	:	Wind friction factor
V, V_x, V_y(x, y,t)	:	Wind speed and components in x- and y- directions (m/s)
Ω (x,y)	:	Coriolis parameter, latitude dependent (s^{-1})
P_a(x,y,t)	:	Atmospheric pressure ($kg/m/s^2$)
ρ_w	:	Density of water (kg/m^3)
x,y	:	Space coordinates (m)
t	:	Time (s)
$\tau_{xx}, \tau_{xy}, \tau_{yy}$	:	Components of effective horizontal shear stress

(2) Advection-diffusion Equations

The following equation, with the conservation of mass integrated in the vertical, describes the advection-dispersion process of substances including decay:

$$\frac{\partial}{\partial t}(hC)+\frac{\partial}{\partial x}(uhC)+\frac{\partial}{\partial y}(vhC)=\frac{\partial}{\partial x}\left(hD_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(hD_y\frac{\partial C}{\partial y}\right)-FhC+S$$

where:

C	:	Compound concentration (arbitrary units)
u,v	:	Horizontal velocity components in the x,y directions (m/s)
h	:	Water depth (m)
D_x, D_y	:	Dispersion coefficients in the x- and y- directions (m^2/s)
F	:	Linear decay coefficient (1/s)
S	:	$Q_s(C_s-C)$
Q_s	:	Source/sink discharge ($m^3/s/m^2$)
C_s	:	Concentration of compound in the source/sink discharge

(3) Limitations of the Model

There are some limitations in the model described above with respect to the capability to represent real processes that determine water quality. The horizontal two-dimensional model is applicable in a situation where current velocity and water quality is relatively uniform in vertical direction. The density stratification strongly affects current velocity field and water quality, so that the model used here may not be applicable to strongly stratified water bodies. As previously mentioned, however, the density stratification is considered to have a minor role in the two water bodies concerned. Therefore, there could be applicability of the model in this respect.

The advection-diffusion model used here is applicable to conservative or linear decaying materials. However, there are many biochemical processes that affect water quality in coastal waters and lagoons. Among these processes photosynthesis by phytoplanktons is one of the most important and the decomposition of organic material by bacteria plays a major role in the determination of water quality. These processes are particularly important in eutrophic water bodies such as lakes and semi-enclosed bays surrounded by industrial or populated areas. There have been many attempts to incorporate these processes in water quality simulation models and high quality modeling systems have been developed by some research organizations such as DELFT Hydraulics (the Netherlands), although these modeling systems are generally expensive and expertise is required to effectively use them. It is very important to recognize that biochemical processes, which are important in the determination of water quality under conditions mentioned above, are not incorporated in the advection-diffusion model used herein, so that the model can be used only for rough calculation of water quality. It could be used, however, for relative evaluation of water quality distribution under different conditions such as changed material loads.

5.2.4 Hydrodynamic Modeling

In order to establish an appropriate hydrodynamic model for the relevant water bodies, it is necessary to process the current survey data to retrieve the periodicity of the water bodies. A stepwise procedure to retrieve periodicity and to interpret/use the analysis results for establishing a simulation model is presented below:

STEP 1 Calculate the autocorrelation and power spectrum

STEP 2 Observe whether or not there are particular periodicities (spectral peaks)

1) If there is a spectral peak within a period of nearly 12 hours, a periodicity of 12 hours dominates in the coastal water area.
2) If there is a spectral peak within a period of nearly 24 hours, a periodicity of 24 hours dominates in the coastal water area.
3) If there is no spectral peak within any period, then the coastal water area has no particular periodicity and has an irregular current field.

STEP 3 Execute current simulation and calculate the diffusion coefficient

1) In the case of one in STEP 2, simulate the current for a 12-hour period using a simulation model and calculate the diffusion coefficients using the current data, which are obtained as the raw data, minus 12 hours periodic current.
2) In the case of two in STEP 2, simulate the current for a 24-hour period using a simulation model and calculate the diffusion coefficients using the current data, which are obtained as the raw data, minus 12 hours periodic current.
3) In the case of three in STEP 2, simulate the mean current during the entire period of observation using a simulation model and calculate the diffusion

coefficients using the current data, which are obtained as the raw data, minus the mean current.

STEP 4 Execute a water quality simulation using the simulated current and diffusion coefficients, which are obtained from the above steps.

Figure 5.4 shows examples of time variations of current velocity vector, which have been obtained from Pueblo Viejo Lagoon and the coastal water.

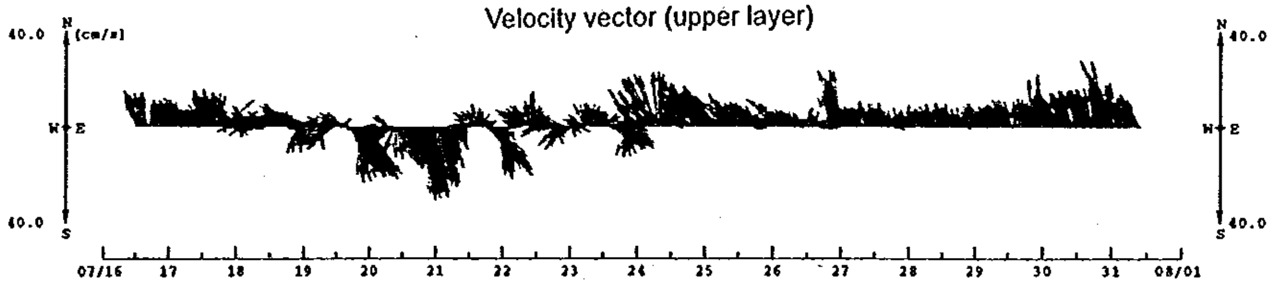


Figure 5.4 (1) Time Variation of Current Velocity Vector Obtained from the Coastal Water
Note : The observation period is 16th July to 1th August, 1999 and the location is about 10 km south from the Altamira port and 3 km offshore from the coast, with a depth of 15 m.

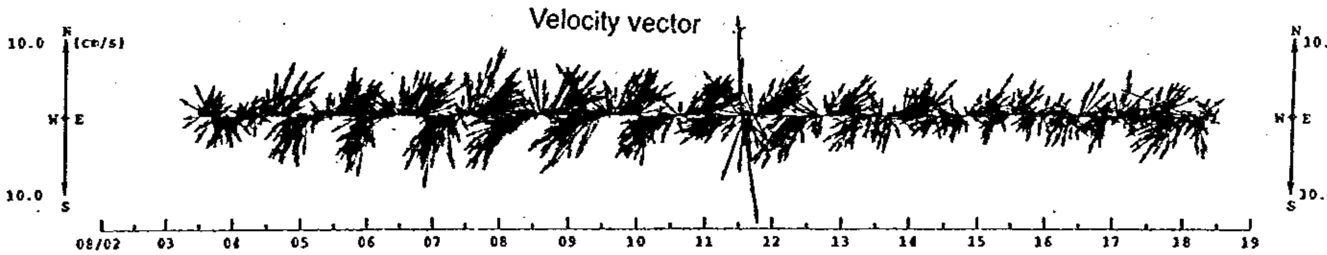


Figure 5.4 (2) Time Variation of Current Velocity Vector Obtained from Pueblo Viejo Lagoon
Note: The observation period is 3th to 18th August, 1999 and the location is about 5 km south-southwest from the exit point of Pueblo Viejo Lagoon to Panuco River, with a depth of 2 m.

Figure 5.4 (1) shows that the variability of current direction is large during July 19 to 23, which indicates the period of current variation at roughly half a day to one day. By contrast, during the period after July 24, the variability of current direction is small and the current almost constantly flows in the N-NW direction. However, even during this period the variability of current speed can be seen. In the current variation of Pueblo Viejo Lagoon

(Figure 5.1 (2)), regular variation of current direction is clearly shown, which indicates the dominant influence of diurnal tide on the current, although the absolute velocity of Pueblo Viejo Lagoon is considerably smaller than that of the coastal water area.

Figure 5.5 shows the power spectrum of current velocity components obtained from the coastal water and Pueblo Viejo Lagoon. The power spectrum of current components in the coastal water has no remarkable spectral peak within any period indicating a monotonous decrease of power with decrease of period, so that it can be seen that the coastal water area has no particular periodicity and has an irregular current field. By contrast, the power spectrum of current components in the lagoon shows a clear peak at a period of 24 hours indicating the dominance of current variation, which has been induced by diurnal tide.

Based on the above analysis, the mean current during the entire period of observation will be reproduced in the hydrodynamic model of the coastal water. Then the diffusion coefficients obtained using the current data (raw data minus the mean current) will be applied to the water quality simulation of the coastal water. On the other hand, time variation of current velocity with the period of 24 hours will be reproduced in the hydrodynamic model of Pueblo Viejo Lagoon. The diffusion coefficients in the lagoon will be obtained from the current data, which is raw data minus the 24-hour periodic current.

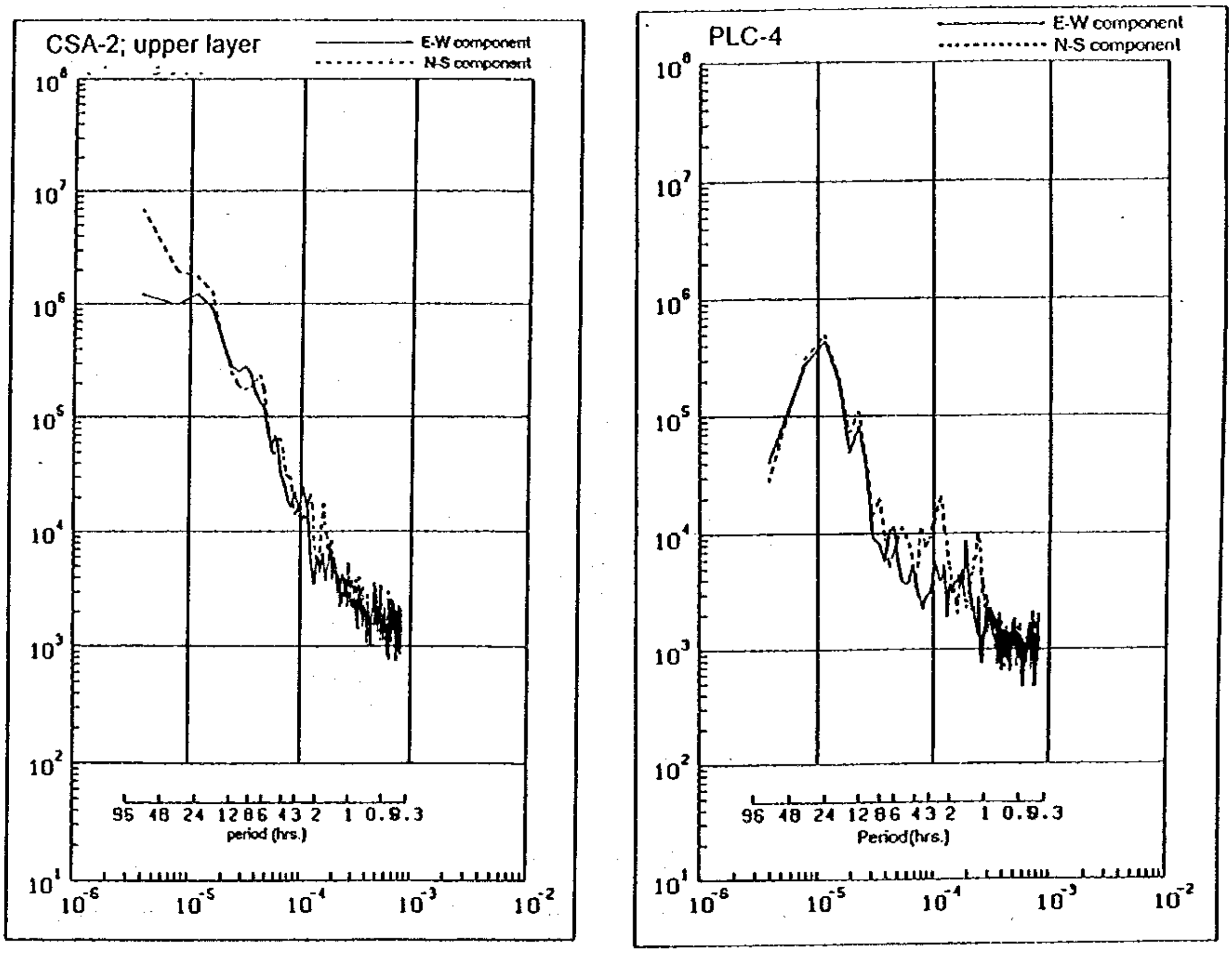
5.2.5 Setting up Simulation Conditions

Several conditions have to be set up in order to carry out the numerical simulation, such as simulation domain, grid system, water depth at each grid point, boundary conditions, parameters required in the simulation, inflows and pollution loads from river to sea and diffusion coefficients.

(1) Pueblo Viejo Lagoon

a) Model Area and Model Grid Size

Pueblo Viejo Lagoon is a closed water body, thus the entire region has been included in the rectangular computational area. The open boundary is located at the connection point of Pueblo Viejo Lagoon and Panuco River. A grid size of 300 m is used. The horizontal axis (east-west direction) of the computation area is 12 km, divided into 40 meshes. The vertical axis (north-south direction) of the computation area is 15 km, with more than 50 meshes. The grid size of 300 m is considered adequate to capture the main shoreline features and bathymetry of Pueblo Viejo Lagoon.



a. Coastal water

b. Pueblo Viejo Lagoon

Figure 5.5 Power Spectrum of Current Velocity Components

b) Boundary Conditions

The boundary conditions of the hydrodynamic model specify the driving forces of the water movement described in the model. The model requires three different boundary conditions, namely, water levels at the open boundaries, discharges from surrounding lands and wind direction and speed at the surface of water body.

The open boundary in the computational area of Pueblo Viejo Lagoon is located at the point connecting Pueblo Viejo Lagoon and Panuco River. The point is influenced by the tide of the sea, thus the water current in Pueblo Viejo Lagoon shows flood and ebb current patterns. Table 5.10 shows the harmonic constants of tides in Tampico Port, which are listed in the tide table published by the Secretary of Marine. This table shows that the diurnal tide, K_1 and O_1 constituents, dominates rather than the semi-diurnal tide, M_2 and S_2. This situation well corresponds to the dominance of current variation with a period of 24 hours in Pueblo Viejo Lagoon. From these data, water surface elevation at the open boundary of the computational area has been set. Only the diurnal tidal force, which has an amplitude of 0.26m (K_1+O_1), is specified into the model.

Table 5.10 Harmonic Constants of Tides in Tampico Port

Constituent	Amplitude Meters	Phase Degree
M_2	0.073	74.27
S_2	0.023	75.85
N_2	0.018	63.31
K_1	0.131	291.93
O_1	0.130	294.25
P_1	0.041	296.05

Source: The Secretary of Marine

c) Freshwater Discharges and Pollution Loads

Freshwater discharges and pollution loads into the lagoon come from non-point sources, as described in section 5.1. The summary is shown in Table 5.11.

Table 5.11 Freshwater Discharges and Pollution Loads into Pueblo Viejo Lagoon

No.	Name	Dry season			Rainy season		
		Discharge 1000m³/day	COD Kg/day	Total-N Kg/day	Discharge 1000m³/day	COD Kg/day	Total-N Kg/day
1	South	389.0	296.0	54.6	2,333.0.	1639.0	303.0
2	West	Negligible	62.2	12.0	Negligible	345.0	66.0
3	East	Negligible	23.8	4.5	Negligible	132.0	24.8
4	North	Negligible	18.0	3.2	Negligible	98.0	18.0
Total		389.0	400.0	74.3	2,333.0	2214.0	411.8

Source: JICA Study Team

d) Wind Conditions

Wind conditions strongly affect water currents in lagoons, particularly, shallow lagoons such as Pueblo Viejo. The vector mean of wind speed and direction during the current survey has been set as the wind conditions.

e) Diffusion Coefficient

It is important for the water quality simulation to distinguish the concepts of advection and diffusion. Advection represents the transport of material dissolved in moving fluids, the movements of which are well defined such as regular back-and-forth currents and/or steady mean currents. On the other hand, diffusion refers to the mixing of material induced by turbulence, which is considered to comprise currents with irregular variability of period less than that represented in advection.

The Study Team has modeled a water quality simulation for Pueblo Viejo Lagoon characterized by variable components with a period of 24 hours and mean current. Therefore, the diffusion coefficients in the lagoon have been obtained from the current data such that 25-hour running mean current variations are eliminated from the raw data. Table 5.12 shows the range of diffusion coefficients in Pueblo Viejo Lagoon. Based on these values of diffusion coefficients, the Study Team has set the diffusion coefficient in the simulation model as $Dx=Dy=5\times10^3$ cm^2/s.

Table 5.12 Range of Diffusion Coefficients in Pueblo Viejo Lagoon

East-west component	North-south component
$2.05\text{-}9.55\times10^3$ cm^2/s	$2.17\text{-}7.37\times10^3$ cm^2/s

Source: JICA Study Team

f) Initial and Boundary Concentrations

Initial and boundary concentrations for the water quality model have been set based on the pilot water quality monitoring data as shown in Table 5.13.

Table 5.13 Initial and Boundary Concentrations for Pueblo Viejo Lagoon

	Initial concentration		Boundary concentration	
	Dry season	Rainy season	Dry season	Rainy season
COD mg/L	2.0	3.0	3.0	4.0
Total-N mg/L	0.4	0.5	0.6	0.7

Source: JICA Study Team

(2) Coastal Water

The basic ideas of setting up the computational conditions are similar to those of the lagoon.

a) Model Area and Model Grid Size

A rectangular computational area of coastal water is taken parallel to the coastline. The side length is 40 km along the shore, from the mouth of Panuco River in the south to Altamira Port in the north. The offshore extent of the area is 20 km from the shore, so that it covers a sea area less than 30 m deep. A grid size of 500 m has been used. Because the shoreline and bathymetry of the area are relatively simple, the grid size of 500 m is considered adequate to represent the topographic features of the area. The horizontal axis (offshore direction) of the computation area is 20 km, thus the horizontal axis is divided into 40 meshes. The vertical axis (along shore direction) of the computation area is about 40 km, thus the vertical axis is divided into about 80 meshes.

b) Boundary Conditions

In the case of Pueblo Viejo Lagoon, the boundary condition is given by forcing the water surface elevation at the exit point of the lagoon to reproduce the dominant tidal current observed in the current survey. On the other hand, the time variation and power spectrum of current velocity shows that the coastal water area has no particular periodicity and it can be seen to be an irregular current field. Therefore the mean currents during the entire period of observation have been reproduced in the hydrodynamic model of the coastal water. Thus the boundary condition has been given by forcing the steady volume transport of water at all the open boundary points to reproduce the mean current pattern.

c) Freshwater Discharges and Pollution Loads

Freshwater discharges and pollution loads into the coastal water are summarized in Table 5.14.

Table 5.14 Freshwater Discharges and Pollution Loads into the Coastal Water

No.	Name	Dry season			Rainy season		
		Discharge 1000m³/day	COD Kg/day	Total-N Kg/day	Discharge 1000m³/day	COD Kg/day	Total-N Kg/day
1	Panuco River	17,300.0	398,000.0	21,200.0	70,300.00	1,750,000.0	27,400.0
2	Dupon	5.72	0.0	0.0	5.72	0.0	0.0
3	Negromex	3.33	1359.0	59.0	3.33	1359.0	59.0
4	Novaquim	0.35	199.0	20.2	0.35	199.0	20.2
5	Petrocel	8.27	681.0	4.5	8.27	681.0	4.5
6	Altamira Port	Negligible	575.0	17.1	Negligible	863.0	66.0
	Total	17,318.0	400,814.0	21,301.0	70,318.00	1,753,102.0	27,550.0

Source: JICA Study Team

d) Wind Conditions

Wind conditions are thought to strongly affect the water current in shallow lagoons, so that a wind condition has been imposed in the hydrodynamic model of Pueblo Viejo Lagoon. In the coastal water, however, winds are considered not so important in contributing to the variability of current velocity and the formation of mean current pattern, which are a result of large influence of offshore sea conditions. Therefore no wind condition is posed in the hydrodynamic model of the coastal water.

e) Diffusion Coefficient

The diffusion coefficient for the coastal water has been set based on the same concept, which has been described in the place of Pueblo Viejo Lagoon. It is thought that the coastal water is an irregular current field, so that its current is represented only by the mean current. Therefore the diffusion coefficients in the coastal water have been obtained from the current data such that only the mean current is eliminated from the raw data. Table 5.15 shows the range of diffusion coefficients in the coastal water. Based on these values of the diffusion coefficients, the Study Team has set the diffusion coefficient in the simulation model as $Dx=Dy=3\times10^5$ cm^2/s.

Table 5.15 Range of Diffusion Coefficients in the Coastal Water

Layer	East-west component	North-south component
Surface-3.5m	$1.83\text{-}9.94\times10^5$ cm^2/s	$3.97\text{-}6.01\times10^5$ cm^2/s
Surface-11.0m	$1.39\text{-}3.77\times10^5$ cm^2/s	$2.96\text{-}6.36\times10^5$ cm^2/s

Source: JICA Study Team

f) Initial and Boundary Concentrations

Initial and boundary concentrations for the water quality model have been set based on the pilot water quality monitoring data as shown in Table 5.16.

Table 5.16 Initial and Boundary Concentrations for the Coastal Water

	Initial concentration		Boundary concentration	
	Dry season	Rainy season	Dry season	Rainy season
COD mg/L	1.0	1.5	1.0	1.5
Total-N mg/L	0.15	0.20	0.15	0.20

Source: JICA Study Team