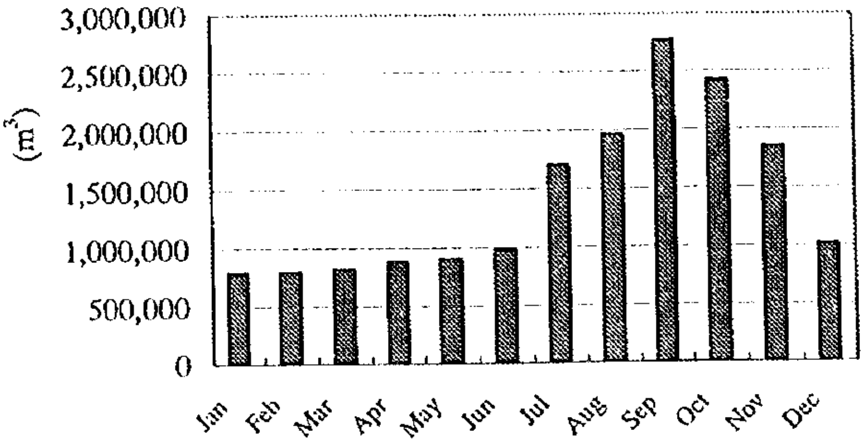
FIGURES



Source : Questionnaire Survey by DOSTE, 1998

Figure 10.1.1 Pumped Water from Coal Mine

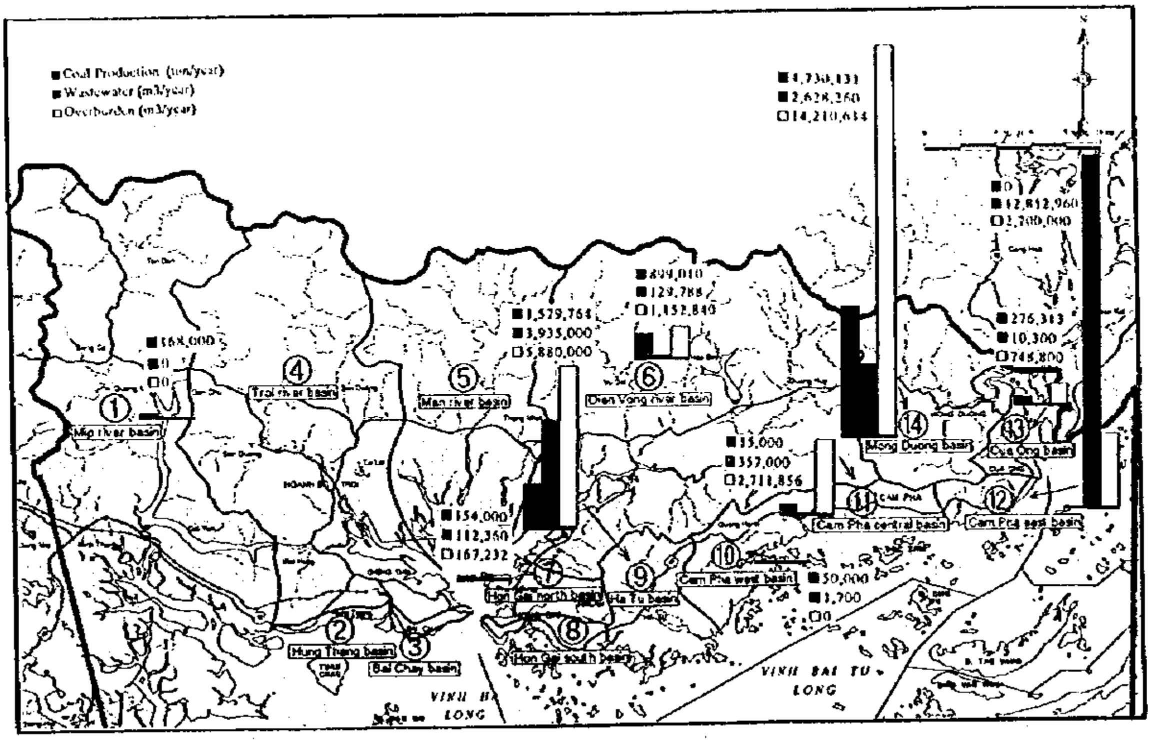
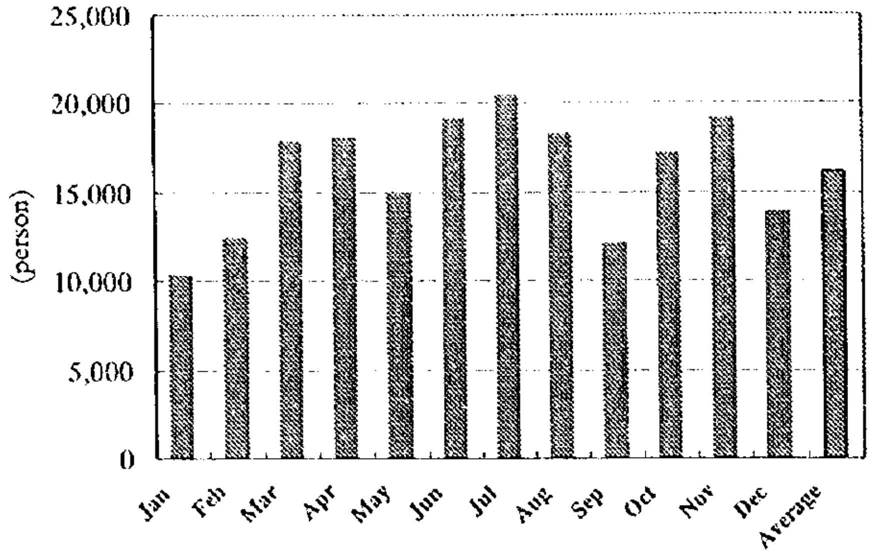


Figure 10.1.2 Coal Production, Wastewater and Overburden in the Basin



Source : Questionnaire Survey by DOSTE, 1998

Figure 10.1.3 Monthly Number of Hotels Guests

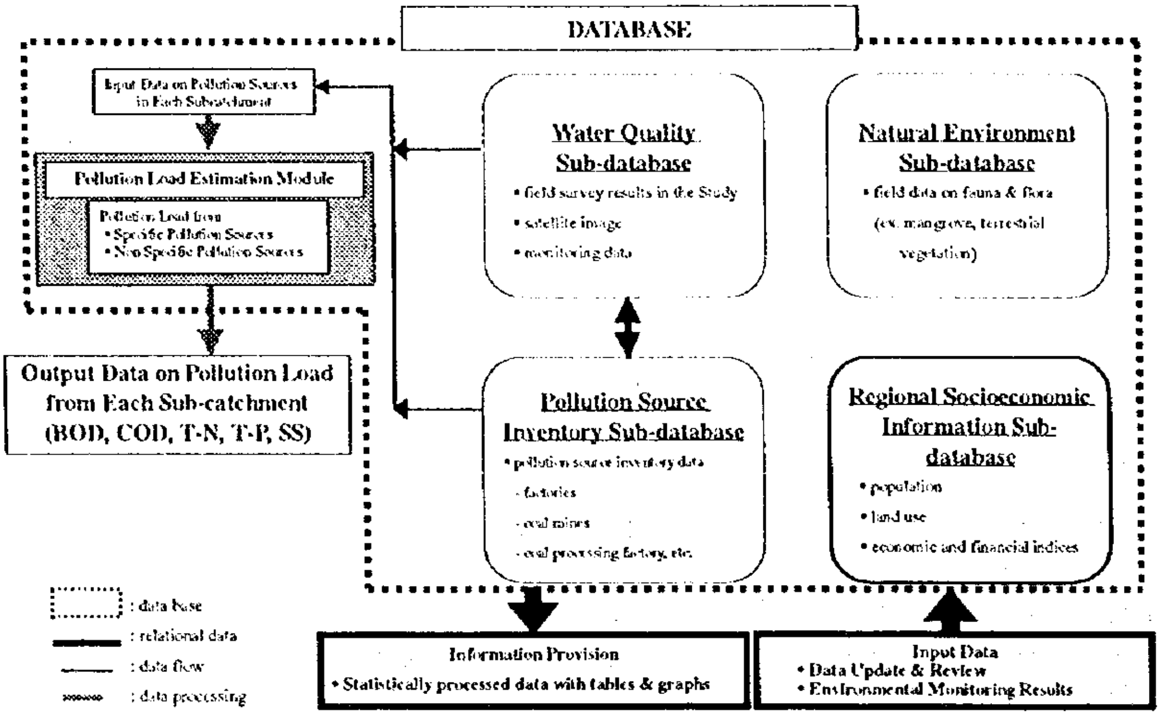


Figure 10.2.1 Components of the Database

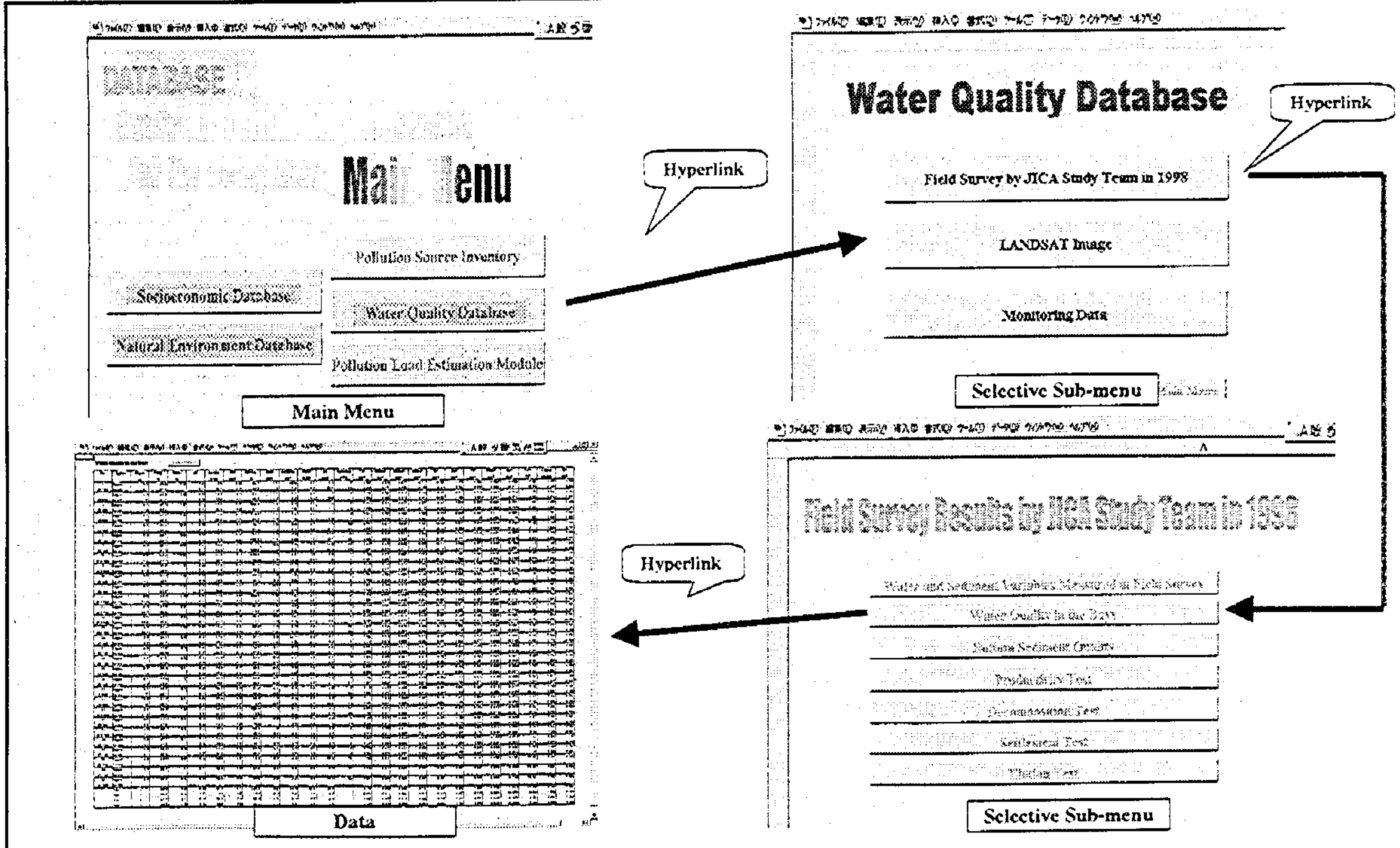


Figure 10.3.1 Selective Menu and Hyperlink of the Database

CHAPTER 11

CHAPTER 11 WATER POLLUTION MECHANISM

11.1 Setting Sub-catchment

The catchment of the bays is characterized by steep hills of weathered limestone running from east to west of 100 to 300 m high as well as rivers. The lowlands between the steep hills and the bays consist of alluvial and marine sediments, with an average elevation of 4 to 5 m.

The catchment of the bays is divided into 14 sub-catchments for pollution loads estimation and analysis. The sub-catchments accompanied with the main rivers (No.1, 4 to 6, and 14) are located in the northern part of the catchment from the east to the west. The others (No.2, 3, 8 to 13) are located on the littoral areas of the bays, whose gradient varies from 12 to 20%. With regard to islands, Cat Ba island is designed sub-catchment 15 and the other islands are grouped as sub-catchment 16 for the sake of convenience. The land use pattern of each sub-catchment, which was analyzed by satellite image and is the basis for estimating fresh water run-off and non-specific pollution generation, is shown in Table 11.1.1. The location of each sub-catchment is shown in Figure 11.1.1.

11.2 Estimation of Fresh Water Inflow into the Bays

The hydrological data taken from the gauging stations in the catchment, which were suspended about 25 years ago, are not enough to estimate the amount of freshwater inflow to the bays, because these stations were located in the upper reach of the rivers. In addition, sub-catchments located along the coastline have mountains spreading down to the bays, so that rain water quickly runs into streams/rivers discharging to the bays.

Thus, total amount of freshwater inflow into the bays is estimated based on an effective rainfall, which contributes to the surface flow, and the area of each sub-catchment. The effective rainfall is calculated by subtracting disappeared rainfall by percolation and evapo-transpiration from amount of rainfall. Runoff coefficients are used for calculation of disappeared rainfall except for evapo-transpiration, which are set based on land use patterns.

The estimated amount of freshwater inflow into the bays during the rainy season, from June to August, is shown in Table 11.2.1. The amount of freshwater flow from the Main Rivers is estimated at 806 x 10^6m^3/year, which accounts for 82% of total amount of freshwater inflow to the bays.

11.3 Specific Pollution Sources

11.3.1 Classification of Specific Pollution Sources

As discussed in Chapter 10, specific pollution sources are classified into 5 groups in the study area based on the types and/or activities as follows. In case of wastewater from coal mines, it is categorized as industrial wastewater for the sake of convenience.

- Domestic wastewater
- Industrial wastewater including coal mines'
- Commercial and institutional wastewater
- Livestock wastewater
- Leakage from solid waste disposal sites

11.3.2 Present Conditions of Specific Pollution Sources

(1) Domestic Wastewater

Ha Long city consists of Hong Gai and Bai Chay quarters, and Cam Pha town consists of Cam Binh and Cua Ong quarters. According to 1996 statistics, the population of Ha Long city and Cam Pha town was about 150,000 and 140,000, respectively. Including Yen Hung and Hoanh Bo districts, total population of the catchment is estimated at 340,000 at present. Most people are living in urban areas around the southern edge of Bai Chay bay and along route 18. There are also about 3,000 peoples living on the sea.

The pollution loads of the domestic sewage from the populated areas such as Hong Gai, Bai Chay, Cam Binh, and Cua Ong quarters are considered to be higher than those from rural areas. Since there is no area-wide sewage treatment system in these areas, the sewage is discharged directly or via a septic tank to the nearest ditch, river, or sea. According to the recent survey, "Ha Long City Water Supply and Sanitation Project, 1998", more than 50% of the households in urban area have two-compartment septic tank systems, the reminder use dry latrine holes to contain human wastes or direct discharge. In the former case, the both human and household wastes go to septic tank, and then flow out to soak away. In the latter case, the waste is subsequently used as a fertilizer for farming.

(2) Industrial Wastewater

Industrial production in the study area accounts for about 80% of total industrial and agricultural production in Quang Ninh province. Key contributors to the regional economy as the industries are coal mining, construction material like bricks and tiles, and seafood industry. Several factories have also been established in the catchment, such as brewery, ship building, and fertilizer. Industrial pollution sources are categorized into 4 groups: coal mining, construction material, food, and other industries. According to the result of questionnaire survey by the study team, most industrial wastewater has been discharged into the bays without treatment.

Although the industrial pollution is not significant in the study area except for coal mining at present, it will become the major environmental problem in the future due to the planned industrial development in the catchment.

Mainly in northeastern hinterland of the catchment, relatively large coal mines are being operated. All coal mining is performed in the lower and middle Triassic strategraphic areas. North of these regions, however, are the Ordovician layers of no coal mining activity. The wastewater from coal mining areas, which is being produced during the excavation, sometimes has low pH of 2-4 and affects the river water quality. The wastewater from coal processing plants is also one of the pollution sources.

The erosion caused by disposal of overburden, surface destruction, and deforestation should be a major pollution source. Also coal stockpiles and coal waste heaps are present in several locations along the bays. The pollution problem is worse in rainy days due to erosion from coal mining related areas. They are classified as a land runoff (deforested and bare area).

(3) Commercial and Institutional Wastewater

1) Tourism and Institutional facilities

Ha Long bay is one of the Vietnam's scenic attractions, consequently an associated tourism industry has developed in this area. There are many hotels, restaurants, and souvenir shops in Bai Chay quarter, with more under construction. The number of hotels in Bai Chay quarter is estimated at 180 including large hotels and family-run mini-hotels and about 90 hotels in Hong Gai quarter. There are about 150 restaurants in Bai Chay quarter. The number of visitors to Bai Chay bay during the rainy season (from June to August) is approximately 2,800 persons/month.

Many small boats are available for hire, taking visitors to explore islands, caves, and beaches. Trips usually range from few hours to a couple of days. According to the Ha Long Bay Management Board (HLMB), there are about 150 tourist boats in the bays, and about 1,200 visitors are received per day. The problem is that most tourist boats do not have a toilet tank, consequently, human waste and other wastewater is discharged in the sea directly.

There are also several other crucial pollution sources, namely institutional facilities, such as markets, hospitals, schools, and governmental offices where the people haunt intensively.

Kinds of pollutants of these commercial sources are the same as domestic source. Most people haunting such facilities are the local people living in the catchment. Thus, their pollution loads are involved in domestic one for the estimation.

2) Others

Shipping including freighters for coal, oil, and multi-goods, gas stations on the sea, oil port, multi-goods port are pollution sources. In particular, the sea near the ports and navigation routes receive direct impacts from a bilge water or oil leakage easily. Pollution loads from coal ports are considered to be that of coal mining.

(4) Livestock Wastewater

Livestock in the study area are being bred at livestock farms, and then brought into slaughter houses. Buffaloes are being used for farming activities at households. According to the information of the Department of Agriculture and Rural Development (DARD), numbers bred of buffalo, cattle, and pig in the study area including vicinity in 1996 is as follows:

(Unit: heads)

Livestock	Ha Long city	Cam Pha town	Hoanh Bo district	Yen Hung district	Total
Buffalo	600	1,700	850	2,800	5,950
Cattle	100	350	1,700	2,580	4,730
Pig	29,000	22,000	15,400	35,500	101,400

Note: Hoanh Bo and Yen Hung districts include outside of the study area.
Source: DARD, Statistical Year Book of QNPC, 1996

With regard to chicken, normally their wastes are used for fertilizer. Thus, pollution loads from them are regarded as one of the origin of pollution load from agricultural fields.

(5) Solid Wastes Disposal Site

About 50% of household wastes are collected and dumped in solid wastes disposal sites such as Ha Khau, northeast Bai Chay mountain, Deo Sen, north Hong Gai quarter, and C9 north Cua Ong quarter. Leakage can be found from these sites to the bays. Thus, solid waste disposal sites are considered to be a specific pollution source.

11.4 Non-specific Pollution Source

11.4.1 Classification of Non-specific Pollution Sources

Non-specific pollution sources are diffuse pollution sources which can not be identified site by site. Most loads from non-specific pollution sources are washed out on rainy days. Normally non-specific pollution sources are classified into 2 groups, land runoff and precipitation. Land runoff in the study area consists of pollution loads from forests, agricultural land, deforested bare land including denuded area by coal mining, and urban areas.

11.4.2 Present Conditions of Non-specific Pollution Sources

(1) Land Runoff

1) Forest

Forests cover mainly northern mountainous areas in the catchment. Although there have been cleared of much of their forest cover, satellite images analysis by the JICA study team revealed that more than 60% of the catchment area is still covered by forest.

2) Agricultural land

There is a relatively small portion of coastal area which is used for agricultural land. Agricultural lands are located mainly in Hoanh Bo and Yen Hung districts. The are used for rice and green crops. As the result of satellite images analysis by the JICA study team, the areas of agricultural land in the catchment is given in Chapter 2.

3) Deforested and bare land

The hill areas north of the bays, originally forested, have been cleared. The removal of forest cover has lead to erosion of the hill soils. This is likely to have increased the sediment loads being carried out into the bays. In order to clarify the magnitude of impact caused by coal mining activities, deforested areas by open-pit mining are categorized as coal mining areas, so that the estimation of pollution load can be implemented separately.

4) Urban area

The pollution loads from urban area include settled or accumulated dust on the roads, roofs, excretion of animal lives, fallen leaves, and dumped garbage. In the study area, dust is one of the non-specific pollution sources especially in Cam Binh and Cua Ong quarters. The settled dust as well as other pollutant is washed out on rainy days.

The one-month field survey of dust, from July 14 to August 13, carried out at 5 points by the JICA study team shows that the amounts of dust deposition ranged from 21 to 2,411 mg/m^2/day. Dust deposition in Cua Ong area is higher than that in Bai Chay and Hong Gai as shown in Table 11.4.1.

(2) Precipitation

Rainfall is also a source of pollution load because it contains some pollutants. The contribution of rain to the pollution loads in land area is included in the unit pollution load of land runoff. The contribution of rain to the pollution loads in the sea area was estimated separately based on reported concentrations of pollutants in rain water and the precipitation in the sea area, which is about 1.9 x 10^6 m^3/year.

11.5 Calculation Method of Pollution Load Flowing into the Bays

The method for pollution load estimation is schematically presented in Figure 11.5.1. There are mainly two pathways of pollutants into the bays, such as via rivers or drains and directly into the bays. Pollution loads via rivers are estimated by one of the two methods depending on the availability of the rivers' water quality data. Parameters required such as run-off ratios are set based on the result of the Field Survey.

For estimation of pollution loads, 4 major pollution sources such as domestic (residence) including tourism, industry including coal mining activities, livestock, and land runoff are selected. It can be said that pollution loads from solid wastes disposal sites and precipitation are negligible small compared with the above 4 major pollution sources. Selected items for the pollution load estimation are BOD, COD_{Mn}, SS, T-N, and T-P.

11.6 Estimation of Pollution Load Generation

(1) Specific Pollution Sources

1) Domestic pollution sources

a) Residence

The generated loads of domestic origin are estimated by population and pollution load units. Population multiplied by pollution load unit is generated pollution load. The per capita pollution load unit of BOD is assumed at 50 g/day based on the results of the Water Supply and Sanitation Feasibility Study, 1998. These units were quoted from "Assessment of Sources of Air, Water, and Land Pollution, WHO, 1993".

Pollution load units of COD_{Mn}, SS, T-N, and T-P are taken from "the Guideline for comprehensive basin-wide planning of sewerage systems, Japan Sewage Association, 1996 (hereinafter referred to as the Guideline)", and modified by the JICA study team. The unit of pollution load used is shown in Table 11.6.1.

The population in the study area was about 341,000 in 1996. The total generated loads of domestic origin amount to 17 tons/day of BOD, 7.5 tons/day of COD_{Mn}, 13 tons/day of SS, 3 tons/day of T-N, and 0.4 tons/day of T-P as shown in Table 11.6.2.

b) Tourism

Pollution loads generated from tourism are classified into 3 categories namely tourists in hotels, day's tourists, and tourist boats. The mean residence time of tourists in hotel is assumed to be about 19 hrs, from 15:00 to 10:00. The maximum number of tourist boats in Ha Long bay is 150 (HLMB). Assuming one boat carries 10 passengers, the maximum number of passengers on the boats a day is 1,500. It is assumed that mean cruising time of the passengers on the boats is 8 hrs.

It is considered that pollution load unit of tourist is changed in proportion to their residence time. Thus, the per capita pollution load unit of tourist in hotels is 80% and passenger on tourist boats is 30% of domestic one, respectively.

On the other hand, it is assumed that pollution loads from day's tourist are involved in those of residence.

The estimated total generated pollution loads are 0.05 tons/day of BOD, 0.02 tons/day of COD_{Mn}, 0.04 tons/day of SS, 0.01 tons/day of T-N, and 0.001 tons/day of T-P as shown in Table 11.6.3.

2) Industrial sources

The volume of wastewater being discharged from each factory is set based on the result of the questionnaire survey by the JICA study team April 1998. Since the water quality data of the industrial wastewater are not available so far, the water quality is set by the results of Field Survey by the JICA study team and a typical water quality of each type of factory taken from the Guideline. The typical water quality data used in the estimation are shown in Table 11.6.4.

As for pollution loads from coal mining industries, 41 coal mines, 2 coal processing plants, and 2 coal ports were taken into consideration. Basically, the measured quantity and quality of the wastewater by the Field Survey were used for the estimation.

For Coc6 & Deo Nai, Than Lap, Ha Lum, and Ha Tu coal mines, the following quantity and quality of the wastewater were used.

Wastewater Quantity and Quality of Coal Mines

Coal Mines	Quantity of Wastewater (m^3/s)	Water Quality (mg/ℓ)				
		BOD	COD	SS	T-N	T-P
Coc6 & Deo Nai	4.7	6.2	36.0	78	12.8	0.23
Than Lap	0.1	5.5	43.0	212	6.8	1.32
Ha Lum	0.1	6.7	42.0	354	4.7	0.61
Ha Tu	0.3	5.2	12.6	617	4.3	0.30
Average	1.3	5.9	33.4	315	7.1	0.62

Source: Field Survey by the JICA study team

Averages of the above four coal mines' wastewater quality were applied to the other coal mines.

For the coal processing plants and the coal ports, the measured quantity and quality of the wastewater were used too, except for the Cua Ong port. The quantity and quality of wastewater of the Cua Ong port was set based on that of the Vung Duc port.

The estimated pollution loads of coal mines, coal processing plants, and coal ports were shown in Table 11.6.6.

The total pollution loads generated from 30 factories and 41 coal mining industries are estimated at 0.5 tons/day of BOD, 2.1 tons/day of COD_{Mn}, 25 tons/day of SS, 0.6 tons/day of T-N, and 0.02 tons/day of T-P as shown in Table 11.6.7.

3) Livestock sources

The generated loads of livestock origin are estimated by number of livestock and pollution load units. The number of livestock is estimated by livestock population density data provided by DARD, and areas of each sub-catchment. The per head pollution load units are quoted from the Guideline as shown in Table 11.6.8. The units of buffaloes are assumed to be same as cattle's.

The total numbers of livestock in the Ha Long bay area are estimated at about 4,300 heads of buffalo and cattle, and 63,000 heads of pig. The resulting total pollution loads of livestock origin amounts to 15.3 tons/day of BOD, 10.4 tons/day of COD_{Mn}, 57 tons/day of SS, 3.8 tons/day of T-N, and 1.8 tons/day of T-P as shown in Table 11.6.9.

(2) Non-Specific Pollution Loads

The generated pollution loads of land runoff origin are estimated by area of each land use and pollution load units. The per area pollution load units of BOD, COD_{Mn}, T-N, and T-P are taken from the Guideline, that of SS is taken from "The study on the reddish soil pollution in Okinawa island in Japan, Okinawa general bureau". Regarding to SS, pollution load unit of coal mining activities is assumed to be 3,000 $kg/km^2/day$ based on the mass balance at the river mouth (see Table 11.6.10).

The areas of each land use pattern in the study area are set at 170 km^2 of agricultural fields, 680 km^2 of forest, 90 km^2 of urban, and 80 km^2 of coal mining areas (see Table 11.6.11), based on the result of satellite image analysis. Total generated loads of land runoff origin amounts to 16 tons/day of BOD, 23 tons/day of COD_{Mn}, 540 tons/day of SS, 14 tons/day of T-N, and 5 tons/day of T-P as shown in Table 11.6.12.

(3) Total Generated Pollution Loads

Total generated pollution load is tabulated in Table 11.6.13. Among the pollution sources, pollution load generated at non-specific pollution sources is largest.

11.7 Runoff Pollution Load into the Bays

11.7.1 Setting Runoff Ratios

The analysis of pollution mechanisms requires data related to type and volume of pollutants being discharged from each sub-catchment into the bays. The pollution loads flowing into the bays are calculated based on the generated pollution loads and run-off ratio. Runoff ratio is a percentage of entering pollution load into the bays to generated pollution load. Runoff ratios depend on land use, type of pollution sources, distance between location of sources and the bays, and intensity of rainfall.

In order to estimate the run-off ratios for the sub-catchments having major rivers, calibration with the water quality data taken by the Field Survey and estimated runoff pollution loads was performed. As for the small coastal sub-catchments, generated pollution loads flow into the bays directly or via short streams. Therefore, the runoff ratios are relatively high compared with that of sub-catchment having the major rivers. Estimated runoff ratios are shown in Table 11.7.1.

11.7.2 Runoff Pollution Loads

Generated pollution loads multiplied by runoff ratio is runoff pollution load. The estimated runoff pollution loads of BOD, COD_{Mn}, SS, T-N and T-P from each sub-catchment are shown in Table 11.7.2 and summarized below. It is assumed that pollution loads from tourists in hotels are discharged from sub-catchment of No.3, and from tourist boats are discharged to the shore in front of the sub-catchment of No.3. Among the inflow of pollution loads of BOD, domestic pollution loads accounts for about 50% of the total.

(Unit: tons/day)

Items	Pollution Loads Inflow into the Bays				
	Domestic	Industry	Livestock	Non-specific	Total
BOD	3.0	0.3	1.9	1.9	7.2
COD_{Mn}	4.9	1.9	2.8	12.3	21.9
SS	8.5	22.1	16.3	194.0	241.1
T-N	2.7	0.5	2.5	9.7	15.5
T-P	0.3	0.02	1.5	4.2	6.1

Notes: Domestic pollution load includes that of tourism.

11.8 Rates of Primary Production, Decomposition, Settlement, and Elution

11.8.1 Pollution Mechanism Parameters in the Bays

The pollutants that enter the bays are subjected to various physical, chemical, and biological processes. The study of physical and chemical behavior of pollutants flowing into the bays, and their material circulation are required in order to clarify a pollution mechanism in the bays. Normally, a primary production by phytoplankton is one of the key contributors of organic pollution in the stagnant water. Besides, pollutants such as COD, inorganic nitrogen (I-N) and inorganic phosphorus (I-P) are released from the cumulated pollutants in bottom sediment. On the other hand, decomposition and settlement of pollutants acts on purification of the water. The expected mechanism of water pollution in the bays is shown in Figure 11.8.1.

(1) Primary Production

The primary production by phytoplankton is one of the important contributors for organic pollution. It could be an indicator of eutrophication level in the bays. The primary production rate is used to clarify the material cycle and balance, and pollution mechanism in the bays. It depends dominantly on the change of environmental conditions surrounding the bays such as increase of the nutrients inflow.

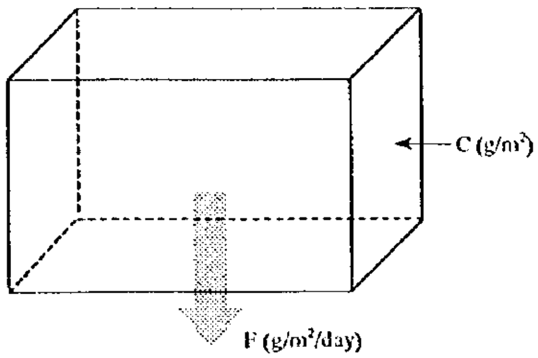
According to the calculation on the primary production and ecological effectiveness of phytoplankton at Ha Long bay in the dry season (HIO, 1997), the primary production of phytoplankton is about 67 $mgC/m^3/day$ (5.6 $mgC/m^3/h$ in the daytime). Normally, primary production of phytoplankton in eutrophic sea is more than 10 $mgC/m^3/h$. Thus, the bays' water seems to be mesotrophicated or slightly eutrophicated.

(2) Decomposition

Decomposition is one of the self-purification functions, such as biological consumption by nekton, benthos, plankton, bacteria, and fungi. Sometimes, organic matters and nutrients predated by plankton are settled as excretion or detritus, or plankton itself. Decomposition rate is expressed by daily rate like ℓ/day. In the simulation model, decomposition rates of COD_{Mn}, organic nitrogen (O-N), and organic phosphorus (O-P) are taken into consideration.

(3) Settlement

A settlement rate is calculated as the distance of particles moving downward per unit time. The amount of flux transmitting per unit area and per unit time is calculated by dividing the particle concentration by the settlement velocity. The settlement rates are obtained from following formula:



$$W = F/C \text{ (m/day)}$$

where, W : Settlement rate (m/day)

F : Flux (g/m^2/day)

C : Concentration of pollutants in the water (g/m^3)

In the simulation model, settlement rates of COD_{Mn}, organic nitrogen (O-N), and organic phosphorus (O-P) are taken into consideration.

(4) Elution

An elution is one of the key contributors for organic pollution as well as a primary production. According to the empirical data from "the Evaluation Standards of Bottom Sediments, Port Department of Tokyo Metropolitan", bottom sediment quality and release rates of COD_{Mn} and nutrients are generally correlated as shown in Figure.11.8.2. A release rate is expressed as amount of daily released matters from bottom sediment per square meter. In the simulation model, release rates of COD_{Mn}, inorganic nitrogen (I-N), and inorganic phosphorus (I-P) are involved.

11.8.2 Field Survey for the Pollution Mechanism Parameters

(1) Methods

In order to grasp the pollution mechanism parameters of the bays, the following tests consisting of productivity, decomposition, settlement, and elution tests (the Tests) were implemented in the course of the Field Survey by the JICA study team. The Tests were carried out at five points in the bays as shown in Figure 11.8.3. Items and methods of the Tests are as follows:

Items	Subjects	Methods
Productivity test	Primary production rate by phytoplankton	Light and Dark (LD) bottle method *in situ*
Decomposition test	Decomposition rate of organic matters	Dark bottle method in laboratory
Settlement test	Settling velocity/flux of organic particles	Settlement sampler method *in situ*
Elution test	Release rate from bottom sediment	Experimental water tank method in laboratory

1) Productivity test

Light and dark oxygen bottles were used for the productivity test. Light oxygen bottles were transparent ones, while dark oxygen bottles were covered by aluminum foil or the equivalent so as to shut out the light. Water samples were taken by a Van Don water sampler by two (2) layers, at 0.5 m depth and 1 m below from the Secchi disk reading depth. Three light and dark oxygen bottles were filled up with water samples from each depth, and then were submerged, hung and left at their original depths basically six hours (see Figure 11.8.4). Water temperature, pH, and DO of samples in each bottle were measured before submergence and after six hours (pulling them up).

2) Decomposition test

Dark oxygen bottles were used for the decomposition test. Dark oxygen bottles were covered by an aluminum foil or the equivalent so as to shut out the light. Water samples were taken by Van Don water sampler or the equivalent by two layers, at 0.5 m depth and at 1 m above from the bottom (at least 1 m below from the Secchi disk reading depth). Seven dark oxygen bottles including reserves were filled up with water samples from each layer, and then were brought into a laboratory and kept basically at twenty five (25) degrees Centigrade with thermostats. Water temperature, pH, DO, COD_{Mn}, T-N, NH_4-N, NO_2-N, NO_3-N, T-P, and PO_4-P of the samples were measured immediately after sampling, and after 1, 3, 7, and 15 days.

3) Settlement test

Settlement samplers were used for the settlement test. A settlement sampler was a cylindrical tube with internal diameter of 0.1 m and length of not less than 0.5 m or the equivalent. Settlement samplers were hung and left at two layers, 1 m above from the Secchi disk reading depth and 1 m above from the bottom, basically twenty-four hours (see Figure 11.8.5). Three samplers were set at each layer. One series of the test consists of five times samplings. Samples settled in the samplers were brought into a laboratory in dark and cool conditions. SS as amount of settlements, COD_{Mn}, T-N, NH_4-N, NO_2-N, NO_3-N, T-P, PO_4-P, and ignition loss of the samples were measured.

4) Elution test

An experimental water tank (the Tank) was used for the elution test. The Tank were a rectangle tank made of grass or acrylic resin with width of 0.5 m, length of 1 m, and depth of less than 1 m or the equivalent. An aeration pump was attached on the Tank (see Figure 11.8.6). Bottom sediment samples were taken by an Ekman sediment sampler or the equivalent from the sea bottom bed. Water for the elution test were also taken by a Van Don water sampler or the equivalent at 1 m from the bottom of sampling points. Bottom sediment samples were put on the bottom of the Tank gently with sediment depth of 0.1 m. The Tank was filled up with water taken at 1 m from the bottom of sampling points, and then be kept basically at 25°C with aeration in a laboratory. DO was maintained at certain value all the test time. Water temperature, pH, DO, COD_{Mn}, T-N, NH_4-N, NO_2-N, NO_3-N, T-P, and PO_4-P of the water were measured immediately after sampling, and after 1, 3, 7, and 15 days.

(2) Results of the Tests

1) Productivity rate

Net production ratio (Pn) is obtained by the light bottle test and amount of respiration (R) is from the dark bottle test. Gross production (Pg) is sum of Pn and R. Each of ratios is calculated by using following formula,

Pn = [light bottle; after (O_2mg/ℓ)-before (O_2mg/ℓ)]/installation time (h)

R = [dark bottle; before (O_2mg/ℓ)-after (O_2mg/ℓ)]/installation time (h)

Pg = Pn + R

Where, Pn : net production (O_2mg/ℓ/h)

R : respiration (O_2mg/ℓ/h)

Pg : gross production (O_2mg/ℓ/h)

Obtained data by LD bottle tests are as shown in Table 11.8.1. According to Redfield-Ketchum-Richards (RKR) model, production and decomposition processes of organic matters can be expressed by following reaction formula;

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 106O_2 \rightarrow 106CO_2 + 16NH_3 + H_3PO_4 + 106H_2O$$

This formula indicates that the proportion of C (carbon) to O_2 (oxygen) in terms of molecular weight is $C:O_2$ = 0.375:1. As ratio of C:TOD is 1:3.47 and of TOD:COD_{Mn} is 2.26:1 theoretically, 1 mg/ℓ of COD_{Mn} is equal to 0.65 mgC/ℓ. Therefore, the amount of primary production in terms of COD_{Mn} in the bays is estimated as shown below:

Location	Layer	Gross Production (O_2mg/ℓ/h)	Primary Production (mg C/m³/h)	Primary Production (COD_{Mn} mg/m³/h)
No. 2	upper	0.737	276	426
Bai Chay bay	lower	0.196	74	113
No. 6	upper	0.493	185	285
West of Ha Long bay	lower	0.134	50	78
No. 13	upper	0.112	42	65
Center of Ha Long bay	lower	0.047	18	27
No. 22	upper	0.176	66	102
Center of Bai Tu Long bay	lower	0.139	52	80
No. 25	upper	0.114	43	66
East of Bai Tu Long bay	lower	0.116	43	67

2) Decomposition rate

Observed data by the decomposition tests are shown in Table 11.8.2. Polygonal graphs are drawn by method of least squares between concentration of each item on the horizontal line and time series of test on the vertical line. Decomposition rates are gradients of graphs and summarized as shown below:

Location	Layer	COD_{Mn} (1/day)	O-N (1/day)	O-P (1/day)
No. 2	upper	0.1199	0.0154	0.0025
Bai Chay bay	lower	0.1182	0.0189	0.0025
No. 6	upper	0.0787	0.0174	0.0037
West of Ha Long bay	lower	0.0875	0.0216	0.0032
No. 13	upper	0.0841	0.0077	na
Center of Ha Long bay	lower	0.0954	0.0098	na
No. 22	upper	0.0466	0.0052	0.0014
Center of Bai Tu Long bay	lower	0.0756	0.0093	0.0024
No. 25	upper	0.1833	0.0065	0.0040
East of Bai Tu Long bay	lower	0.2706	0.0096	0.0029

Note: na means not available.

3) Settlement rate

Observed data by the settlement tests are shown in Table 11.8.3. At first, flux of settling matters per unit area was calculated. Settlement rates are summarized bellow:

Location	Layer	COD_{Mn} (m/day)	O-N (m/day)	O-P (m/day)
No. 2	upper	0.7	2.1	0.1
Bai Chay bay	lower	1.3	2.1	0.2
No. 6	upper	0.7	0.9	0.4
West of Ha Long bay	lower	0.9	0.9	0.4
No. 13	upper	1.1	1.7	1.4
Center of Ha Long bay	lower	2.9	3.1	1.7
No. 22	upper	1.9	2.2	0.4
Center of Bai Tu Long bay	lower	4.7	5.3	0.3
No. 25	upper	3.7	3.2	0.8
East of Bai Tu Long bay	lower	4.8	5.3	0.8

4) Release rate

At first, amount of released matters per square meter in the water was calculated. Amounts of dissolved matters in the water in experimental tanks were calculated by means of the following formula and the results of calculation are shown in table 11.8.4.

$$F_n = [(V - \sum_{i=1}^{n} V_i) \cdot C_n + \sum_{i=1}^{n} C_i \cdot V_i] / A \ (mg/m^2)$$

where ; F_n : amount of matters in the water in the experimental tank (mg/m^2)

n : number of sample taken

V : volume of water in the experimental tank before test (ℓ)

V_i : volume of water at ith sample taken (ℓ)

C_i : concentration of item of ith sample (mg/ℓ)

C_n : concentration of item of nth sample (mg/ℓ)

A : area of bottom sediment in the experimental tank (m^2)

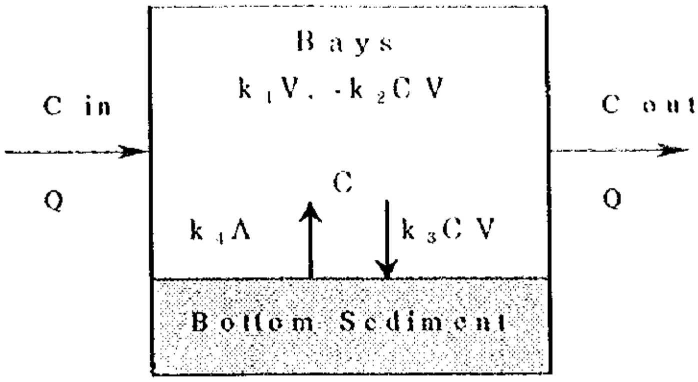
Polygonal graphs are drawn by least squares methods, plotting amount of matters in the water per area in the experimental tank on vertical line and time series of test on horizontal line. Release rates are gradient of graph, and summarized as shown below:

Location		COD_{Mn} ($mg/m^2/day$)	T-N ($mg/m^2/day$)	T-P ($mg/m^2/day$)
No. 2	Bai Chay bay	93.7	10.2	2.1
No. 6	West of Ha Long bay	56.3	13.6	1.6
No. 13	Center of Ha Long bay	49.7	10.8	2.6
No. 22	Center of Bai Tu Long bay	55.2	14.9	3.6
No. 25	East of Bai Tu Long bay	149.2	12.6	1.6

11.9 Mass Balance of Pollutants in the Bays

11.9.1 Basic Concept of Mass Balance in the Bays

A material circulation in the bays should be taken into consideration for the analysis of organic pollution mechanism in the bays. In that case, an internal production, decomposition, settlement, and release rates of organic matters and nutrients are necessary in addition to the inflow of organic matters directly and via rivers. The basic concept of mass balance for pollutants in the bays can be schematized as follows:



$$L = QCin - QCout + k_1V - k_2CV - k_3C + k_4A$$

where, C : Concentration of pollutants in the bays (kg/m^3)

Cin : Concentration of pollutants in the inflow (kg/m^3)

Cout : Concentration of pollutants in the outflow (kg/m^3)

k_1 : Primary production rate ($kg/m^3/day$)

k_2 : Decomposition rate (1/day)

k_3 : Settlement rate (m/day)

k_4 : Release rate ($kg/m^2/day$)

V : Volume of water in the bays

A : Area of bottom sediment in the bays (m^2)

Q : Flow rate (m^3/day)

L : Total pollutants in the bays (kg), given by V × C

11.9.2 Mass Balance of Pollutants

(1) Methods of Mass Balance

For the mass balance of pollution loads in the bays, 4 representative calculation areas are set such as Bai Chay bay, Bai Chay and Hong Gai, Cam Pha and Cua Ong, and Ha Long bay including Bai Tu Long bay.

The box mixing method is used for mass balance calculation. This method assumes that once pollution loads flow into each area, i.e., water column, the water and pollutants in each water column are mixed within one tidal period (assumed 24 hours), and pollution loads in the area is conveyed to the outsides with same water volume as inflow. The model calculates the balance of pollution loads in each area and seeks a concentration level where area and out flow are equal. In order to simplify the calculation, exchange of water between outside of each area is not considered.

The parameters like primary production, release, settlement, and decomposition rates are set based on the results of the Tests. BOD is used as a representative indicator of pollutants.

(2) Results of Mass Balance

The results of the mass balance calculation of BOD for the present condition (1996) of the bays are summarized below. Balance in the table means BOD left in each water column. Based on the results of this mass balance analysis, it seems reasonable to conclude that the organic pollutants represented by BOD in the bays is mainly generated by the primary production.

(Unit: BOD tons/day)

Areas	Pollution Load Inflow	Primary Production	Elution	Self-purification	Outflow	Standing Stock
Bai Chay bay	2.9	45.3	0.6	42.4	6.3	0.1
Bai Chay and Hong Gai	7.6	62.3	0.6	65.0	5.3	0.2
Cam Pha and Cua Ong	2.0	1,234.2	21.3	1,255.1	1.1	1.3
Ha Long bay	10.3	2004.2	13.5	2,009.7	10.7	7.6

Notes: 1) Self-purification includes decomposition and settlement.
2) Pollution load inflow in Bai Chay and Hong Gai area includes that from the Cua Luc strait.

11.10 Characteristics of Pollution Mechanism of the Ha Long Bay Area

Considering the results of the Field Survey and mass balance analysis, it was found that the primary production by phytoplankton in the bays is active, so that more than half of organic pollution loads is being produced in the bays in the rainy season. This is also indicated by the multiplication of phytoplankton such as green algae (*Chlorophyceae*), diatoms (*Bacillariophtcea*) found in the bays especially near coast area.

Normally, active primary production is induced by inflow of excessive nutrients such as phosphates and nitrogen which encourage growth plankton and alga. The exceeding eutrophication causes decrease in transparency, too. Thus, transparency in the bays is relatively low with 0.5-3 m.

Amounts of generated nutrients from non-specific pollution sources are relatively high compared with other pollution sources. Therefore, attention should be paid on inflow of nutrients as well as organic pollution loads.

TABLES

Table 11.1.1 Land Use at each Sub-Catchment as of 1996

No.	Sub-catchment	Items	Natural Forest	Secondary Forest	Trees on the Limestone	Scrub Land	Grass Land	Agricultural Land	Bare Land	Coal Mining	Urban Area	Water in Land	Total
1	Mip river basin	area (ha)	2,478	12,063	46	2,278	1,400	1,965	182	41	846	4,110	25,409
		ratio (%)	10	47	0	9	6	8	1	0	3	16	100
2	Hung Thang basin	area (ha)	0	10	0	680	27	24	4	0	14	48	807
		ratio (%)	0	1	0	84	3	3	1	0	2	6	100
3	Bai Chay basin	area (ha)	0	9	0	364	7	0	8	0	163	19	569
		ratio (%)	0	2	0	64	1	0	1	0	29	3	100
4	Troi river basin	area (ha)	2,245	8,988	138	3,621	1,222	1,789	285	14	380	994	19,675
		ratio (%)	11	46	1	18	6	9	1	0	2	5	100
5	Man river basin	area (ha)	3,557	3,467	698	890	1,205	987	15	0	216	933	11,967
		ratio (%)	30	29	6	7	10	8	0	0	2	8	100
6	Dien Vong river basin	area (ha)	5,351	8,882	697	4,227	1,734	1,004	82	1,709	152	1,228	25,066
		ratio (%)	21	35	3	17	7	4	0	7	1	5	100
7	Hong Gai north basin	area (ha)	0	4	0	641	115	89	32	195	191	43	1,311
		ratio (%)	0	0	0	49	9	7	2	15	15	3	100
8	Hong Gai south basin	area (ha)	0	4	49	198	50	6	18	3	381	0	709
		ratio (%)	0	1	7	28	7	1	3	0	54	0	100
9	Ha Tu basin	area (ha)	0	85	835	675	181	169	22	790	94	51	2,901
		ratio (%)	0	3	29	23	6	6	1	27	3	2	100
10	Cam Pha west basin	area (ha)	0	263	1,936	305	133	80	51	65	275	30	3,137
		ratio (%)	0	8	62	10	4	3	2	2	9	1	100
11	Cam Pha central basin	area (ha)	0	12	0	335	93	49	40	376	583	36	1,523
		ratio (%)	0	1	0	22	6	3	3	25	38	2	100
12	Cam Pha east basin	area (ha)	0	156	0	235	48	31	38	213	377	7	1,103
		ratio (%)	0	14	0	21	4	3	3	19	34	1	100
13	Cua Ong basin	area (ha)	0	195	0	381	67	0	2	138	89	4	876
		ratio (%)	0	22	0	44	8	0	0	16	10	0	100
14	Mong Duong basin	area (ha)	764	2,947	0	1,736	682	0	41	1,876	33	99	8,179
		ratio (%)	9	36	0	21	8	0	1	23	0	1	100
15	Cat Ba island	area (ha)	3	0	12,257	133	250	287	1	0	32	0	12,964
		ratio (%)	0	0	95	1	2	2	0	0	0	0	100
16	Other islands	area (ha)	2,582	768	3,108	1,143	356	182	8	0	23	0	8,171
		ratio (%)	32		38	14	4	2	0	0	0	0	100
Total (except islands;No.15&16)		area (ha)	14,396	37,084	4,398	16,566	6,965	6,193	819	5,418	3,793	7,601	103,231
		ratio (%)	13.9	35.9	4.3	16.0	6.7	6.0	0.8	5.2	3.7	7.4	100
Total (including islands)		area (ha)	16,981	37,851	19,763	17,842	7,571	6,663	828	5,418	3,848	7,601	124,366
		ratio (%)	13.7	30.4	15.9	14.3	6.1	5.4	0.7	4.4	3.1	6.1	100

Source: Satellite image analysis by JICA study team

Table 11.2.1 Estimated Freshwater Inflow into the Bay (During Rainy Season)

No.	Name of Sub-catchment	Catchment Area	Precipitation (June-Aug.)	Precipitation in Sub-catchment	Runoff Ratio	Evapo-transpiration Ratio	Discharge	
		km²	mm/month	x10⁶ m³/month	-	-	x10⁶ m³/month	m³/s
1	Mip River	289.7	320	92.7	0.72	0.08	61.0	23.6
2	Hung Thang Basin	8.5	320	2.7	0.68	0.08	1.7	0.7
3	Bai Chay Basin	10.2	320	3.2	0.69	0.08	2.1	0.8
4	Troi River	239.2	320	76.5	0.69	0.08	48.5	18.7
5	Man River	142.7	320	45.7	0.69	0.08	29.1	11.2
6	Dien Vong River	300.3	320	96.1	0.72	0.08	63.2	24.4
7	Hong Gai North Basin	19.6	320	6.3	0.72	0.08	4.1	1.6
8	Hon Hay South Basin	9.4	320	3.0	0.73	0.08	2.0	0.8
9	Ha Tu Basin	36.7	320	11.7	0.79	0.08	8.5	3.3
10	Cam Pha West Basin	34.7	370	12.8	0.71	0.08	8.4	3.2
11	Cam Pha Central Basin	18.8	370	7.0	0.82	0.08	5.3	2.0
12	Cam Pha East Basin	14.3	370	5.3	0.79	0.08	3.9	1.5
13	Cua Ong Basin	12.6	370	4.7	0.73	0.08	3.1	1.2
14	Mong Duong River	99.6	370	36.9	0.77	0.08	26.3	10.1
15	Cat Ba Island	132.6	320	42.4	0.70	0.08	27.1	10.5
	Total	1,236.3	-	404.6	-	-	267.2	103.1

Note: Rainfall and evapo-transpiration ratio are quoted from the hydro-meteorological data, Quang Ninh Province, 1996-1997.
Evapo-transpiration ratio equals the amount of evaporation/rainfall.
Runoff ratio is calculated by using land use pattern and coefficient.

Table 11.4.1 (1) Result of Dust Survey (1/2)

(Unit: mg/m²)

Points	Period	14/7	15/7	16/7	17/7	18/7	19/7	20/7	21/7	22/7	23/7	24/7	25/7	26/7	27/7	28/7	30/7	31/7
No. 1	24hr	444	417	302	403	197	318	203	na	234	322	88	80	154	67	na	65	na
Bai Chay	5 days	-	-	-	-	983	-	-	-	-	508	-	-	-	-	135	-	-
No. 2	24hr	na	21	10	53	244	na	na	na	na	na	na	na	na	na	43	na	na
Hong Gai	5 days	-	-	-	-	1,037	-	-	-	-	na	-	-	-	-	379	-	-
No. 3	24hr	233	461	221	216	117	252	230	24	27	27	na	na	na	na	na	na	na
Cam Pha	5 days	-	-	-	-	949	-	-	-	-	474	-	-	-	-	485	-	-
No. 4	24hr	2,411	1,113	1,079	1,297	1,032	717	820	579	539	1,386	1,047	21	1,256	739	570	358	181
Cua Ong	5 days	-	-	-	-	5,558	-	-	-	-	3,310	-	-	-	-	2,410	-	-
No. 5	24hr	566	388	797	969	761	625	1,760	1,274	876	1,422	525	96	297	145	346	388	na
Cua Ong Temple	5 days	-	-	-	-	2,841	-	-	-	-	5,466	-	-	-	-	1,624	-	-

Table 11.4.1 (2) Result of Dust Survey (2/2)

(Unit: mg/m²)

Points	Period	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	9/8	10/8	11/8	12/8	13/8	Average
No. 1	24hr	35	75	32	69	110	66	91	222	241	176	112	na	24	175
Bai Chay	5 days	-	-	125	-	-	-	-	311	-	-	-	-	306	395
No. 2	24hr	na	na	na	na	na	na	na	na	151	110	105	109	69	92
Hong Gai	5 days	-	-	445	-	-	-	-	134	-	-	-	-	540	507
No. 3	24hr	na	na	na	na	na	na	na	na	na	na	na	na	na	181
Cam Pha	5 days	-	-	344	-	-	-	-	396	-	-	-	-	207	476
No. 4	24hr	502	373	293	569	449	385	734	597	215	71	568	182	731	694
Cua Ong	5 days	-	-	2,010	-	-	-	-	2,262	-	-	-	-	2,948	3,083
No. 5	24hr	na	na	247	225	521	199	655	127	248	22	465	111	250	530
Cua Ong Temple	5 days	-	-	1,547	-	-	-	-	15,392	-	-	-	-	2,946	2,661

Note: na means not available

Table 11.6.1 Unit Pollution Load of Residence

(Unit: g/cap./day)

Items		Volume of wastewater (ℓ/cap./day)	BOD	COD_{Mn}	SS	T-N	T-P
Present (1996)	1.Human waste	20	19	10	21	8.0	0.9
	2.Household wastewater	80	31	12	17	1.0	0.1
	Total (1+2)	100	50	22	38	9.0	1.0
Future (2010)	1.Human waste	40	19	10	21	8.0	0.9
	2.Household wastewater	90	35	14	19	1.1	0.1
	Total (1+2)	130	54	24	40	9.1	1.0

Sources: 1. Volume of wastewater and BOD : Ha Long City Water Supply and Sanitation Project, 1998.
2. Other items: Guideline for Comprehensive basin-wide Planning of Sewerage System, Japan Sewage Association, 1997, modified by JICA study team.

Table 11.6.2 Domestic Pollution Load Generation (Present)

Items	No.	Population	Pollution Load Generation (kg/day)				
			BOD	COD_{Mn}	SS	T-N	T-P
Residents in the catchment	1	17,300	870	380	660	160	20
	2	7,500	380	170	290	70	10
	3	6,800	340	150	260	60	10
	4	45,200	2,260	990	1,720	410	50
	5	5,400	270	120	210	50	10
	6	50,000	2,500	1,100	1,900	450	50
	7	54,700	2,740	1,200	2,080	490	50
	8	33,000	1,650	730	1,250	300	30
	9	11,600	580	260	440	100	10
	10	68,200	3,410	1,500	2,590	610	70
	11	15,200	760	330	580	140	20
	12	8,000	400	180	300	70	10
	13	7,900	400	170	300	70	10
	14	7,400	370	160	280	70	10
	15	0	0	0	0	0	0
Subtotal		338,200	16,930	7,440	12,860	3,050	360
Residents on the sea	8	2,000	100	40	80	20	0
	11	1,000	50	20	40	10	0
Subtotal		3,000	150	60	120	30	0
Total		341,200	17,080	7,500	12,980	3,080	360

Table 11.6.3 Pollution Load Generated by Tourists (Present)

Items	Units (g/cap/day)					Number of Tourists (ave.)	Pollution Loads Generation (kg/day)					Remarks
	BOD	COD_{Mn}	SS	T-N	T-P	per'n/day	BOD	COD_{Mn}	SS	T-N	T-P	
Tourists in hotels	40	18	30	7	0.8	1,000	40	18	30	7	1	Discharged near sub-catchment No. 3
Tourist boats	15	7	11	3	0.3	750	11	5	9	2	0	Discharged tourist boats' routes
Total	-	-	-	-	-	-	50	23	40	10	1	

Notes: 1. Pollution load units of tourist in hotel are 80% of residence.
2. Pollution load units of tourist in boat are 30% of residence.
3. Pollution loads from day's tourists are involved in domestic pollution loads.
4. The number of tourist boasts in Ha Long Bay is 150. One boat carries 10 tourists and the rate of operation is 75%.

Table 11.6.4 Typical Water Quality of Industrial Wastewater

No.	Category No.	Type of Industries	Typical Water Quality (mg/ℓ)				
			BOD	COD_{Mn}	SS	T-N	T-P
1	1283	Cooking oil	450	168	181	5	2
2	1622	Plywood	465	650	528	13	2
3	2999	Engineering manufacture	42	4	27	24	6
4	2531	Clay and roofing tiles	137	422	3,592	2	0
5	1843	Daily paper	231	175	738	16	1
6	2546	Tile	19	73	5,834	2	0
7	1623	Wood processing for construction	110	83	103	13	2
8	2091	Explosive	313	419	72	107	6
9	3111	Car manufacture	143	123	95	16	10
10	2063	Biological medicine	118	89	119	34	8
11	3145	Ship manufacture	126	97	176	22	3
12	2931	Construction and mining machine manufacture	57	40	131	24	10
13	3099	Electric appliance manufacture	367	46	240	26	4
14	1931	Printing	197	240	147	15	2
15	2585	Mineral & debris shattering	25	14	6,708	2	0
16	1297	Grain mil	1,217	2	700	94	34
17	1422	Garment	321	452	114	13	1
18	1921	Publishing	250	300	100	10	20
19	2521	Cement	93	98	863	16	1
20	3069	Precision instrument	190	46	31	3	0
21	3431	Toy	280	161	283	32	4
22	2644-73	Steel related manufacture	57	72	845	42	4

Source: Guideline for Comprehensive B3asin-wide Planning of Sewerage System, 1996, Japan Sewerage Association

Table 11.6.5 Pollution Loads Generated by Factories (Present)

Catchment No	No.	Name of Company	Products	Land Area (m²)	Employee (people)	Water Use (m³/year)	Recycle (m³/year)	Wastewater (m³/year)	Water Quality (mg/ℓ) BOD	COD	SS	T-N	T-P	Pollution Loads Generation (kg/day) BOD	COD	SS	T-N	T-P
3	F-7	Ha Long Ship Building Factory	ship building and repairing	300,000	1,200	48,000	8,200	30,600	4.6	10.5	43	2.2	0.7	0.4	0.9	4	0.2	0.1
	Subtotal			300,000	1,200	48,000	8,200	30,600						0.4	0.9	4	0.2	0.1
4	F-1	Cailan Oils and Fats Industries Company Ltd.	vegetable oils refinery (vegetable cooking oils and shortening)	40,000	209	23,664	no	1,095	450	168	181	5	2	1.4	0.5	1	0.0	0.0
	F-2	VINAFLOWER Wheat Powder Mill	wheat powder, wheat mash	70,000	156	2,400	no	2,400	10	18	27	26.8	1.8	0.1	0.1	0	0.2	0.0
	F-21	Hoanh Bo Forestry Products Processing Workshop	handicraft (plywood)	100	12	0	-	0	465	650	528	13	2	0.0	0.0	0	0.0	0.0
	F-23	QN Engineering Factory	engineering manufacture	14,250	123	360	-	360	42	4	27	24	6	0.0	0.0	0	0.0	0.0
	F-25	Hoanh Bo Brick Factory	construction materials (air bricks)	8,000	30	3,000	no	3,000	137	422	3,592	5	0	1.1	3.5	30	0.0	0.0
	F-26	Hoanh Bo Printing & Paper Factory	printing cards, producing toilet paper	10,000	30	720	-	200	231	175	738	16	1	0.1	0.1	0	0.0	0.0
	F-9	QN Gieng Day 1 Pottery - China Factory	construction materials (baked clay, soil, brick)	16,000	443	1,900	-	1,900	19	73	5,643	2	0	0.1	0.4	30	0.0	0.0
	Subtotal			158,350	1,005	32,044	-	8,955						2.8	4.6	61	0.2	0.0
7	F-10	QN Gieng Day 3 Pottery - China Factory	brick, tile	50,000	330	5,000	-	2,300	19	73	5,643	2	0	0.1	0.5	37	0.0	0.0
	F-11	Ha Khou Brick-Tile Factory (Cam Pha Coal Company)	brick, baked clay	80,000	231	3,000	-	1,500	19	73	5,643	2	9	0.1	0.3	24	0.0	0.0
	F-12	QN Gieng Day 2 Pottery - China Factory	construction materials (brick, tile, patterned brick)	77,000	427	5,700	-	5,700	19	73	5,643	2	0	0.3	1.1	91	0.0	0.0
	F-13	QN Wood Processing & Export Goods Production	wood processing for construction and various wooden products	12,000	240	-	-	0	110	83	103	13	2	0.0	0.0	0	0.0	0.0
	F-14	QN Mining Chemical Factory	industrial explosive	500,000	400	12,000	-	1,000	313	419	72	107	6	0.9	1.1	0	0.3	0.0
	F-24	QN Car Engineering Factory	car engineering and repairing	12,000	194	120	-	120	143	123	95	16	10	0.0	0.0	0	0.0	0.0
	F-5	QN Beer Company	brewery	14,523	401	17,000	no	11,200	120	325	154	28.6	2.5	3.7	10.0	5	0.9	0.1
	Subtotal			745,523	2,223	42,820	-	21,820						5.1	13.1	157	1.2	0.1
8	F-16	Pharmaceutical & Medical Equipment Company	herb medicine	300	35	-	-	37	118	80	119	34	8	0.0	0.0	0	0.0	0.0
	F-17	QN Ferry Factory	ferry operation	-	630	-	-	3,000	126	97	176	22	3	1.0	0.8	1	0.2	0.0
	F-3	Frozen Sea Products Processing Plant (QN Fishery Export Company)	fresh frozen and dry sea products	7,000	331	30,000		30,000	66	74	362	129.5	3.1	5.4	6.1	30	10.6	0.3
	F-6	Honcai Mechanical Company	coal mine's equipment repairing and manufacturing	26,943	500	8,600	2,000	7,600	57	40	131	24	10	1.2	0.8	3	0.5	0.2
	Subtotal			34,243	1,496	38,600	2,000	40,637						7.2	7.7	34	11.3	0.5
10	F-27	Engineering Factory 3	manufacturing spare parts for drilling, exploring, repairing facilities	20,000	105	200	150	50	57	40	131	24	10	0.0	0.0	0	0.0	0.0
	F-28	Factory of Electric Appliance Manufacturing in Cam Pha	electric appliance, construction of the power station & electric line	14,664	429	4,660	468	936	367	46	240	26	4	0.9	0.1	1	0.1	0.0
	F-33	Cam Pha Centre Mechanical Company	coal mine's equipment repairing and manufacturing	220,000	1,973	54,633	65,735	20,000	6.0	12	12	2.9	0.94	0.3	0.7	1	0.2	0.1
	F-41	Quang Hanh Mineral Water Plant	beverage producing (mineral water with gas)	3,500	150	360,000	no	50,000	5.5	43	116	6.8	1.32	0.8	5.9	16	0.9	0.2
	Subtotal			258,164	2,657	419,513	66,353	70,986						2.0	6.7	17	1.2	0.2
11	F-30	Brewery, Soft Drink Factory	brewery	3,484	190	31,685	-	29,000	275	550	245	20.8	5.0	21.8	43.7	19	1.7	0.4
	F-31	Cam Pha Engineering Factory	repairing big ram, truck and diesel engine	19,560	520	-	-	2,500	143	123	95	16	10	1.0	0.8	1	0.1	0.1
	F-36	Engineering - Power Machinery Assembly Factory	engineering processing, power machinery assembly	10,000	144	500	-	500	42	4	27	24	6	0.1	0.0	0	0.0	0.0
	F-40	Hoa Hop (Harmony) Printing Factory	print (binding books, lining paper)	192	22	-	-	4	197	240	147	15	2	0.0	0.0	0	0.0	0.0
	Subtotal			33,236	876	32,185	-	32,004						22.9	44.5	20	1.8	0.5
12	F-37	QN Ship Building & Repairing Factory	ship building and repairing	26,070	61	-	-	200	126	97	176	22	3	0.1	0.1	0	0.0	0.0
	F-43	Factory of Construction No.7	civil and industrial construction (private & public house, office and workshop)	2,072	150	800	-	800	110	63	103	13	2	0.2	0.2	0	0.0	0.0
	LS-1	Cam Pha Stone Exploitation and Constructive Production Company	construction materials	63,700	174	561,600	-	561,600	25	14	6,708	2	0	38.5	21.5	10,321	3.1	0.0
	Subtotal			91,842	385	562,400	-	562,600						38.8	21.8	10,321	3.1	0.0
	Total			1,621,338	9,842	1,175,562	76,553	767,802						80	99	10,614	19	1

Note: - not available

Table 11.6.6 (1) Pollution Load Generated by Coal Mines (Present, 1/2)

Sub-Catchment No.	No.	Name of Coal Mine (Company)	Annual Production Amount in 1997	Land Area	Employee	Water Use	Wastewater	Pollution Loads Generation (kg/day)				
			(ton)	(m²)	(Person)	(m³/year)	(m³/year)	BOD	COD	SS	T-N	T-P
1	M-17	Hoanh Bo Coal Factory (QN Coal Company)	168,000	-	642	68,880	68,880	1.1	6.3	59	1.3	0.1
		Subtotal	168,000	0	642	68,880	68,880	1.1	6.3	59	1.3	0.1
6	M-1	917 Factory (Hong Gai Coal Company)	59,000	300,000	320	30,945	30,945	0.5	2.8	27	0.6	0.1
	M-3	Cao Thang mine (Hong Gai Coal Company)	122,700	787,498	1,074	122,250	122,250	2.0	11.2	106	2.4	0.2
	M-7	Suoi Lai Mine (VINACOAL)	65,415	1,180,000	317	26,820	468	0.0	0.0	0	0.0	0.0
	M-13	Cai Da (Hong Gai Coal Company)	51,000	172,100	442	2,630	78,000	1.3	7.1	67	1.5	0.1
	M-16	916 Company (Geography and Mineral Resources Exploitation Company)	72,113	2,892,000	380	450	450	0.0	0.0	0	0.0	0.0
	M-18	Factory for exploitation & survey (Geography and Mineral Resources Exploitation Company)	7,000	4,640,000	60	36,000	43,200	0.7	4.0	37	0.8	0.1
	M-21	Khe Tam Mine (QN Coal Company)	89,000	2,761,850	578	16,000	7,000	0.1	0.6	6	0.1	0.0
	M-23	Harang Mine (QN Coal Company)	56,200	2,800,000	380	14,670	14,670	0.2	1.3	13	0.3	0.0
	M-34	Nam Khe Tam Mine (Dong Bac Company)	118,582	40,066	532	2,800	0	0.0	0.0	0	0.0	0.0
	M-35	KTT 148 Factory (Dong Bac Company)	80,000	400,000	250	6,000	0	0.0	0.0	0	0.0	0.0
	M-36	Coal Exploitation Factory 35 (Cong Ty Dong Bac)	106,000	600,000	266	2,496	0	0.0	0.0	0	0.0	0.0
	M-40	Tay Bai Nga Hai	72,000	200,000	300	2,000	1,120	0.0	0.1	1	0.0	0.0
	M-58*	Dong Khe Sim (Dong Bac Company)	(see basin no.11)	(see basin no.11)	(see basin no.11)	(see basin no.11)	-	-	-	-	-	-
		Subtotal	899,010	16,773,514	4,899	263,061	298,103	4.8	27.3	257	5.8	0.5
7	M-2	Binh Minh Construction Site -	20,000	160,000	120	31,200	2,170	0.0	0.2	2	0.0	0.0
	M-4	Ha Lum Mine (VINACOAL)	467,000	1,680,000	3,392	35,000	72,000	1.3	8.3	70	0.9	0.1
	M-11	Binh Minh Coal Factory (QN Coal Company)	54,000	13,000	-	3,000	9,360	0.2	0.9	8	0.2	0.0
	M-12	Thanh Cong Mine (QN Coal Company)	30,000	3,500,000	350	6,000	25,000	0.4	2.3	22	0.5	0.0
	M-15	Cao Xanh Coal Mine Factory (VINACOAL)	70,000	3,200,000	376	1,900	78,000	1.3	7.1	67	1.5	0.1
		Subtotal	154,000	6,713,000	726	10,900	112,360	3.2	18.8	169	3.2	0.3
9	M-5	Ha Tu Mine (VINACOAL)	830,000	7,500,000	2,920	200,000	2,500,000	35.6	86.3	4,226	29.2	2.1
	M-6	Nui Beo Mine (VINACOAL)	279,498	2,330,000	842	120,000	1,200,000	19.4	109.8	1,036	23.3	2.0
	M-8	Tan Lap Coal Mine (Hong Gai Coal Company)	470,266	6,800,000	2,074	71,543	235,000	3.5	27.7	136	4.4	0.8
		Subtotal	1,579,764	16,630,000	5,836	391,543	3,935,000	58.6	223.8	5,398	56.9	4.9
10	M-33	Khe Sim Factory (Dong Bac Company)	50,000	17,200	310	45,000	1,700	0.0	0.2	1	0.0	0.0
		Subtotal	50,000	17,200	310	45,000	1,700	0.0	0.2	1	0.0	0.0
11	M-27*	Deo Nai (VINACOAL)	(see basin no.14)	(see basin no.14)	(see basin no.14)	(see basin no.14)	(see basin no.12)	-	-	-	-	-
	M-31	Thong Nhat	332,000	300,000	1,858	15,000	15,000	0.2	1.4	13	0.3	0.0
	M-58*	Dong Khe Sim (Dong Bac Company)	25,000	3,800	400	360,000	360,000	5.8	32.9	311	7.0	0.6
		Subtotal	357,000	303,800	2,258	375,000	375,000	6.1	34.3	324	7.3	0.6
12	M-26*	Coc 6 Mine (VINACOAL)	(see basin no.14)	(see basin no.14)	(see basin no.14)	(see basin no.14)	7,500,000	127.4	739.7	1,603	263.4	4.7
	M-27*	Deo Nai (VINACOAL)	(see basin no.14)	(see basin no.14)	(see basin no.14)	(see basin no.14)	5,312,960	90.2	524.0	1,135	186.6	3.3
	M-49	Xi Nghup Than Cau 20 (Bai Tu Long)	-	-	200	0	0	0.0	0.0	0	0.0	0.0
		Subtotal	0	0	200	0	12,812,960	217.6	1,263.7	2,738	450.0	8.1

Table 11.6.6 (2) Pollution Load Generated by Coal Mines (Present, 2/2)

Sub-catchment No.	No.	Name of Coal Mine (Company)	Annual Production Amount in 1997	Land Area	Employee	Water Use	Wastewater	Pollution Loads Generation (kg/day)				
			(ton)	(m^2)	(Person)	(m^3/year)	(m^3/year)	BOD	COD	SS	T-N	T-P
13	M-32	Quang Loi Coal Expolitation Factory (Dong Bac Company)	160,100	39,000	139	10,800	0	0.0	0.0	0	0.0	0.0
	M-45	Via 9 Quyet Thang Khu Bac Quang Loi (Dong Bac Company)	116,213	375,000	400	1,500	10,300	0.2	0.9	9	0.2	0.0
	Subtotal		276,313	414,000	539	12,300	10,300	0.2	0.9	9	0.2	0.0
14	M-25	Cao Son Mine (VINACOAL)	1,027,910	4,500,000	3,865	113,150	687,000	11.1	62.9	593	13.4	1.2
	M-26*	Coc 6 Mine (VINACOAL)	1,455,000	7,340,487	5,164	150,000	(see basin no.12)	-	-	-	-	-
	M-27*	Deo Nai (VINACOAL)	1,100,763	922,834	3,367	693,400	(see basin no.12)	-	-	-	-	-
	M-29	Khe Cham Mine (VINACOAL)	352,000	3,490,000	2,043	64,800	376,560	6.1	34.5	325	7.3	0.6
	M-30	Mong Duong Coal Mine (VINACOAL)	328,458	5,100,000	1,862	80,000	1,530,700	24.7	140.1	1,321	29.8	2.6
	M-37	Thang Long (Dong Bac Company)	50,000	11,000	120	30,000	24,000	0.4	2.2	21	0.5	0.0
	M-39	397 Factory (Dong Bac Company)	115,000	300,000	135	4,560	4,800	0.1	0.4	4	0.1	0.0
	M-44	Mong Duong Dong Bac (Geographical Mineral Exploitation Company)	124,000	11,000	557	3,000	3,000	0.0	0.3	3	0.1	0.0
	M-50	Cam Pha Coal Factory (QN Coal Company)	137,000	960,000	210	6,600	6,600	0.1	0.6	6	0.1	0.0
	M-57	Tay Bac Da Mai (QN Coal Company)	40,000	30,000	100	18,000	5,200	0.1	0.5	4	0.1	0.0
	Subtotal		4,730,131	22,665,321	17,423	1,163,510	2,637,860	42.6	241.4	2,277	51.3	4.5
Total			8,214,000	63,516,335	32,833	2,330,194	20,252,163	334	1,817	11,232	576	19

Note: - : not available
M-26 : Coc 6 (wastewater => No.12, production & overburden =>No.14)
M-27 : Deo Nai (wastewater => No.12, overburden =>No.11:50%&No.12:50%), Production = No.14)
M-58 : Dong Khe Sim (production => No.11, Wastewater =>No.6:50%&No.11:50%, overburden => No.6)

Table 11.6.6 (3) Pollution Load Generated by Coal Processing Plants (Present)

Sub-catchment No.	No.	Name of Coal Processing Pants	Annual Production Amount in 1997	Land Area	Employee	Water Use	Wastewater	Pollution Load Generation (kg/day)				
			(ton)	(m^2)	(person)	(m^3/year)	(m^3/year)	BOD	COD_{Mn}	SS	T-N	T-P
8	CP-1	Nam Cau Trang Coal Processing Plant	1,000,000	-	2,194	150,000	50,000	1.0	3.3	3	0.5	0.2
12	CP-2	Cua Ong Coal Processing Plant	3,007,000	-	4,668	2,100,000	150,000	81.0	151.2	2,799	6.4	0.5
Total			4,007,000	-	6,862	2,250,000	200,000	82	155	2,802	6.9	0.7

Note: - not available
water quality Nam Cau Trang BOD=7.1mg/ℓ, COD=24.3mg/ℓ, SS=22mg/ℓ, T-N=3.8mg/ℓ, T-P=1.58mg/ℓ (Field Survey)
Cua Ong BOD=197mg/ℓ, COD=368mg/ℓ, SS=6,812mg/ℓ, T-N=15.5mg/ℓ, T-P=1.20mg/ℓ (Field Survey)

Table 11.6.6 (4) Pollution Load Generated by Coal Ports (Present)

Sub-catchment No.	No.	Name of Ports	Annual Shipping Amount in 1997	Land Area	Employee	Water Use	Wastewater	Pollution Load Generation (kg/day)				
			(ton)	(m^2)	(person)	(m^3/year)	(m^3/year)	BOD	COD_{Mn}	SS	T-N	T-P
11	CSP-3	Vung Duc Port (Thong Nhat coal mine)	140,000	2,500	17	20	20	trace	0.001	0.004	trace	trace
13	CSP-6	Cua Ong Port (Cam Pha Port)	2,489,000	160,000	372	356	356	0.002	0.006	0.064	0.006	0.001
Total			2,629,000	162,500	389	376	376	0.002	0.007	0.068	0.006	0.001

Note: water quality Vung Duc BOD=2.2mg/ℓ, COD=6.5mg/ℓ, SS=66mg/ℓ, T-N=5.5mg/ℓ, T-P=1.04mg/ℓ (Field Survey)
Cam Phu BOD=2.2mg/ℓ, COD=6.5mg/ℓ, SS=66mg/ℓ, T-N=5.5mg/ℓ, T-P=1.04mg/ℓ (Set same as Vung Duc)

Table 11.6.7 Total Pollution Load Generated by Industries (Present)

No.	Factories	Coal Mining	Pollution Loads Generation (kg/day)				
			BOD	COD_{Mn}	SS	T-N	T-P
1	0	1	1	6	59	1.3	0.1
2	0	0	0	0	0	0.0	0.0
3	1	0	0	1	4	0.2	0.1
4	7	0	3	5	61	0.2	0.0
5	0	0	0	0	0	0.0	0.0
6	0	12	5	27	257	5.8	0.5
7	7	5	8	32	326	4.4	0.4
8	4	1	9	11	37	11.8	0.7
9	0	3	59	224	5,398	56.9	4.9
10	4	1	2	7	18	1.2	0.2
11	4	3	29	79	344	9.1	1.1
12	3	4	338	1,437	15,865	459.5	8.6
13	0	3	0	1	9	0.2	0.0
14	0	8	43	241	2,277	51.3	4.5
15	0	0	0	0	0	0.0	0.0
Total	30	41	496	2,071	24,655	601.9	21.1

Notes: 1. Number of Industries means industries which answered the questioner prepared by JICA study team.
2. Pollution load from coal mining does not include SS runoff caused by coal mining areas.

Table 11.6.8 Unit Pollution Loads of Livestock

Items	Unit	Cattle & Buffalo	Pig
Wastewater Discharge	ℓ/head/day	90	14
BOD	g/head/day	640	200
COD_{Mn}	g/head/day	530	130
SS	g/head/day	3,000	700
T-N	g/head/day	290	40
T-P	g/head/day	50	25

Source: Guideline for Comprehensive Basin-wide Planning of Sewerage System, Japan Sewage Association, 1997

Table 11.6.9 Pollution Load Generated by Livestock (Present)

No.	Heads		Pollution Load Generation (kg/day)				
	Cattle & Buffalo	Pig	BOD	COD_{Mn}	SS	T-N	T-P
1	1,020	12,700	3,190	2,190	11,950	810	370
2	50	1,860	400	270	1,450	80	50
3	30	1,310	280	190	1,010	60	30
4	790	9,840	2,480	1,700	9,260	620	290
5	480	5,980	1,510	1,030	5,630	380	170
6	1,000	12,530	3,150	2,160	11,770	790	360
7	80	3,020	650	430	2,350	140	80
8	40	1,630	360	230	1,260	80	40
9	170	6,670	1,440	960	5,180	320	180
10	130	1,570	390	270	1,490	100	50
11	60	760	190	130	710	50	20
12	40	550	140	90	510	30	10
13	40	440	120	80	430	30	10
14	330	4,090	1,030	700	3,850	260	120
Total	4,260	62,950	15,330	10,430	56,850	3,750	1,780

Note: Heads of livestock are calculated by JICA study team based on data of DARD.

Table 11.6.10 Pollution Load Units of Non-specific Pollution Sources

(Unit: kg/km²/day)

Items	Forest & Grass Land	Agricultural Land	Bare Land	Coal Mining Area	Urban Area
BOD	14	18	16	16	38
COD_{Mn}	20	28	26	26	42
SS	200	2,500	2,500	3,000	200
T-N	10	36	32	32	20
T-P	4	8	6	6	12

Note: Estimated by JICA study team based on the Field Survey

Table 11.6.11 Land Use by Sub-catchments (Present)

No.	Area (ha)						
	Total	Forest & Grass Land	Agricultural Land	Bare Land	(Coal)	Urban Area	Water Area in Land
1	25,409	18,265	1,965	223	(41)	846	4,110
2	807	717	24	4	(0)	14	48
3	569	380	0	8	(0)	163	19
4	19,675	16,213	1,789	299	(14)	380	994
5	11,967	9,816	987	15	(0)	216	933
6	25,066	20,892	1,004	1,791	(1,709)	152	1,228
7	1,311	761	89	227	(195)	191	43
8	709	301	6	21	(3)	381	0
9	2,901	1,776	169	811	(790)	94	51
10	3,137	2,637	80	116	(65)	275	30
11	1,523	440	49	416	(376)	583	36
12	1,103	438	31	251	(213)	377	7
13	876	643	0	140	(138)	89	4
14	8,179	6,130	0	1,917	(1,876)	33	99
15	12,964	12,643	287	1	(0)	32	0
Total	116,195	92,050	6,481	6,238	(5,418)	3,825	7,601
	100%	79%	6%	5%	(5%)	3%	7%

Note: Numbers in parenthesis (coal) are included in bare land.

Table 11.6.12 Pollution Load Generated by Non-specific Sources (Present)

No.	Forest & Grass Land (kg/day)					Agricultural Land (kg/day)					Bare Land (kg/day)					Urban Area (kg/day)					Total (kg/day)					SS by Coal Mining	
	BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P	BOD	COD	SS	T-N	T-P	kg/day	%
1	2,557	3,653	36,529	1,826	731	354	550	49,120	707	157	36	58	4,552	71	13	322	356	1,693	169	102	3,268	4,616	93,109	2,774	1,003	1,215	1
2	100	143	1,434	72	29	4	7	594	9	2	1	1	111	1	0	5	6	28	3	2	111	157	2,167	84	33	0	0
3	53	76	760	38	15	0	0	0	0	0	1	2	192	2	0	62	68	325	33	20	116	146	1,277	73	35	0	0
4	2,270	3,243	32,426	1,621	649	322	501	44,717	644	143	48	78	7,125	96	18	145	160	761	76	46	2,784	3,981	85,442	2,437	855	413	0
5	1,374	1,963	19,632	982	393	178	276	24,672	355	79	2	4	369	5	1	82	93	431	43	26	1,636	2,334	45,104	1,385	498	0	0
6	2,925	4,178	41,783	2,089	836	181	281	25,105	362	80	287	466	2,047	573	107	58	64	303	30	18	3,450	4,989	120,506	3,054	1,042	51,268	43
7	106	152	1,521	76	30	16	25	2,230	32	7	36	59	798	73	14	73	80	382	38	23	232	316	10,791	219	74	5,859	54
8	42	60	602	30	12	1	2	158	2	1	3	5	450	7	1	145	160	762	76	46	191	227	2,049	115	60	77	4
9	249	355	3,552	178	71	30	47	4,225	61	14	130	211	542	260	49	36	39	188	19	11	444	653	32,192	517	144	23,685	74
10	369	527	5,274	264	105	14	22	2,008	29	6	18	30	1,263	37	7	104	115	550	55	33	507	695	11,046	385	152	1,952	18
11	62	88	880	44	18	9	14	1,225	18	4	67	108	998	133	25	221	245	1,166	117	70	358	455	15,545	311	116	11,276	73
12	61	88	876	44	18	6	9	778	11	2	40	65	941	80	15	143	158	753	75	45	250	320	9,742	211	80	6,394	66
13	90	129	1,287	64	26	0	0	0	0	0	22	36	50	45	8	34	37	178	18	11	146	202	5,639	127	45	4,125	73
14	858	1,226	12,260	613	245	0	0	0	0	0	307	498	1,031	613	115	13	14	67	7	4	1,178	1,738	69,626	1,233	364	56,269	81
15	1,770	2,529	25,286	1,264	506	52	80	7,184	103	23	0	0	34	0	0	12	13	64	6	4	1,834	2,623	32,569	1,375	533	0	0
Total	12,887	18,410	184,101	9,205	3,682	1,167	1,815	162,016	2,333	518	998	1,622	20,503	1,996	374	1,454	1,607	7,650	765	459	16,505	23,453	536,802	14,299	5,034	162,533	30

Table 11.6.13 Total Pollution Load Generated (Present)

No.	BOD (kg/day)					COD (kg/day)					SS (kg/day)					T-N (kg/day)					T-P (kg/day)				
	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total
1	870	1	3,190	3,268	7,330	380	6	2,190	4,616	7,190	660	59	11,950	93,109	105,800	160	1	810	2,774	3,750	20	0	370	1,003	1,390
2	380	0	400	111	890	170	0	270	157	600	290	0	1,450	2,167	3,900	70	0	80	84	230	10	0	50	33	90
3	390	0	280	116	790	173	1	190	146	510	300	4	1,010	1,277	2,600	70	0	60	73	200	11	0	30	35	80
4	2,260	3	2,480	2,784	7,530	990	5	1,700	3,981	6,680	1,720	61	9,260	85,442	96,500	410	0	620	2,437	3,470	50	0	290	855	1,200
5	270	0	1,510	1,636	3,420	120	0	1,030	2,334	3,480	210	0	5,630	45,104	50,900	50	0	380	1,385	1,810	10	0	170	498	680
6	2,500	5	3,150	3,450	9,100	1,100	27	2,160	4,989	8,280	1,900	257	11,770	120,506	134,400	450	6	790	3,054	4,300	50	1	360	1,042	1,450
7	2,740	8	650	232	3,630	1,200	32	430	316	1,980	2,080	326	2,350	10,791	15,500	490	4	140	219	850	50	0	80	74	200
8	1,650	9	360	191	2,210	730	11	230	227	1,200	1,250	37	1,260	2,049	4,600	300	12	80	115	510	30	1	40	60	130
9	580	59	1,440	444	2,520	260	224	960	653	2,100	440	5,398	5,180	32,192	43,200	100	57	320	517	990	10	5	180	144	340
10	3,410	2	390	507	4,310	1,500	7	270	695	2,470	2,590	18	1,490	11,046	15,100	610	1	100	385	1,100	70	0	50	152	270
11	760	29	190	358	1,340	330	79	130	455	990	580	344	710	15,545	17,200	140	9	50	311	510	20	1	20	116	160
12	400	338	140	250	1,130	180	1,437	90	320	2,030	300	15,865	510	9,742	26,400	70	460	30	211	770	10	9	10	80	110
13	400	0	120	146	670	170	1	80	202	450	300	9	430	5,639	6,400	70	0	30	127	230	10	0	10	45	60
14	370	43	1,030	1,178	2,620	160	241	700	1,738	2,840	280	2,277	3,850	69,626	76,000	70	51	260	1,233	1,610	10	5	120	364	500
15	0	0	0	1,834	1,830	0	0	0	2,623	2,620	0	0	0	32,569	32,600	0	0	0	1,375	1,370	0	0	0	533	530
Total	16,980	496	15,330	16,505	49,320	7,463	2,071	10,430	23,453	43,420	12,900	24,655	56,850	536,802	631,100	3,060	602	3,750	14,299	21,700	361	21	1,780	5,034	7,190
%	34.4	1.0	31.1	33.5	100	17.2	4.8	24.0	54.0	100	2.0	3.9	9.0	85.0	100	14.1	2.8	17.3	65.9	100	5.0	0.3	24.7	70.0	100

Table 11.7.1 Run-off Ratios of Pollution Loads

No.	BOD				COD				SS				T-N				T-P			
	Dom.	Ind.	Live.	Non-S.	Dom.	Ind.	Live.	Non-S.	Dom.	Ind.	Live.	Non-S.	Dom.	Ind.	Live.	Non-S.	Dom.	Ind.	Live.	Non-S.
1	0.1	0.5	0.1	0.1	0.5	0.7	0.2	0.5	0.5	0.7	0.3	0.3	0.8	0.8	0.6	0.6	0.9	0.9	0.8	0.8
2	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
3	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
4	0.2	0.7	0.1	0.1	0.7	0.9	0.2	0.5	0.7	0.9	0.2	0.3	0.9	0.9	0.7	0.7	1.0	1.0	0.8	0.8
5	0.1	0.6	0.1	0.1	0.5	0.8	0.2	0.5	0.5	0.8	0.2	0.3	0.8	0.8	0.6	0.6	0.9	0.9	0.8	0.8
6	0.1	0.5	0.1	0.1	0.5	0.7	0.2	0.5	0.5	0.7	0.2	0.3	0.8	0.8	0.6	0.6	0.9	0.9	0.8	0.8
7	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
8	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
9	0.2	0.7	0.2	0.2	0.7	0.9	0.4	0.6	0.7	0.9	0.4	0.6	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
10	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
11	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
12	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
13	0.2	0.7	0.2	0.2	0.7	0.9	0.5	0.7	0.7	0.9	0.5	0.7	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
14	0.2	0.7	0.1	0.1	0.7	0.9	0.2	0.5	0.7	0.9	0.2	0.3	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9
15	0.2	0.7	0.1	0.1	0.7	0.9	0.2	0.5	0.7	0.9	0.2	0.3	0.9	0.9	0.8	0.8	1.0	1.0	0.9	0.9

Table 11.7.2 Run-off Pollution Loads into the Bays (Present)

No.	BOD (kg/day)					COD (kg/day)					SS (kg/day)					T-N (kg/day)					T-P (kg/day)				
	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total	Dom.	Ind.	Live.	Non-S.	Total
1	87	1	319	327	730	190	4	438	2,308	2,940	330	41	3,585	27,933	31,900	128	1	486	1,665	2,280	18	0	296	802	1,120
2	76	0	80	22	180	119	0	135	110	360	203	0	725	1,517	2,400	63	0	64	68	190	10	0	45	29	80
3	78	0	56	23	160	121	1	95	102	320	210	4	505	894	1,600	63	0	48	58	170	11	0	27	32	70
4	452	2	248	278	980	693	4	340	1,990	3,030	1,204	55	1,852	25,632	28,700	369	0	434	1,706	2,510	50	0	232	684	970
5	27	0	151	164	340	60	0	206	1,167	1,430	105	0	1,126	13,531	14,800	40	0	228	831	1,100	9	0	136	399	540
6	250	2	315	345	910	550	19	432	2,494	3,500	950	180	2,354	36,152	39,600	360	5	474	1,832	2,670	45	0	288	833	1,170
7	548	6	130	46	730	840	29	215	222	1,310	1,456	293	1,175	7,554	10,500	441	4	112	175	730	50	0	72	67	190
8	330	6	72	38	450	511	10	115	159	800	875	33	630	1,434	3,000	270	11	64	92	440	30	1	36	54	120
9	116	41	288	89	530	182	201	384	392	1,160	308	4,858	2,072	19,315	26,600	90	51	256	413	810	10	5	162	130	310
10	682	1	78	101	860	1,050	6	135	487	1,680	1,813	16	745	7,732	10,300	549	1	80	308	940	70	0	45	137	250
11	152	20	38	72	280	231	71	65	318	690	406	310	355	10,881	12,000	126	8	40	249	420	20	1	18	105	140
12	80	236	28	50	390	126	1,293	45	224	1,690	210	14,279	255	6,819	21,600	63	414	24	168	670	10	9	9	72	100
13	80	0	24	29	130	119	1	40	142	300	210	8	215	3,948	4,400	63	0	24	101	190	10	0	9	40	60
14	74	30	103	118	320	112	217	140	869	1,340	196	2,049	770	20,888	23,900	63	46	208	986	1,300	10	5	108	328	450
15	0	0	0	183	180	0	0	0	1,311	1,310	0	0	0	9,771	9,800	0	0	0	1,100	1,100	0	0	0	479	480
Total	3,032	346	1,930	1,886	7,170	4,904	1,857	2,765	12,296	21,860	8,476	22,126	16,364	194,000	241,100	2,688	541	2,542	9,753	15,520	353	21	1,483	4,191	6,050
%	42	5	27	26	100	22	9	13	56	100	4	9	7	81	100	17	3	16	63	100	6	0	25	69	100

Table 11.8.1 Result of Productivity Test

No. 2: Bai Chay Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Average
Upper	Light bottle	(before)	O_2 mg/ℓ	6.89	6.89	6.89	6.89
		(after)		9.22	9.20	9.24	9.22
	Dark bottle	(before)	O_2 mg/ℓ	6.98	6.98	6.98	6.98
		(after)		6.41	6.43	6.42	6.42
	Installation time		hr	3.92	3.92	3.92	3.92
	Pn		O_2 mg/ℓ/h	0.594	0.589	0.599	0.594
	R		O_2 mg/ℓ/h	0.145	0.140	0.143	0.143
	Pg		O_2 mg/ℓ/h	0.740	0.730	0.742	0.737
Lower	Light bottle	(before)	O_2 mg/ℓ	5.89	5.89	5.89	5.89
		(after)		6.22	6.24	6.23	6.23
	Dark bottle	(before)	O_2 mg/ℓ	5.89	5.89	5.89	5.89
		(after)		5.48	5.45	5.44	5.46
	Installation time		hr	3.92	3.92	3.92	3.92
	Pn		O_2 mg/ℓ/h	0.084	0.089	0.087	0.087
	R		O_2 mg/ℓ/h	0.105	0.110	0.115	0.110
	Pg		O_2 mg/ℓ/h	0.189	0.199	0.202	0.196

No. 6: West of Ha Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Average
Upper	Light bottle	(before)	O_2 mg/ℓ	7.27	7.27	7.27	7.27
		(after)		10.11	10.13	10.12	10.12
	Dark bottle	(before)	O_2 mg/ℓ	7.27	7.27	7.27	7.27
		(after)		6.41	6.43	6.42	6.42
	Installation time		hr	7.50	7.50	7.50	7.50
	Pn		O_2 mg/ℓ/h	0.379	0.381	0.380	0.380
	R		O_2 mg/ℓ/h	0.115	0.112	0.113	0.113
	Pg		O_2 mg/ℓ/h	0.493	0.493	0.493	0.493
Lower	Light bottle	(before)	O_2 mg/ℓ	6.27	6.27	6.27	6.27
		(after)		6.77	6.85	6.84	6.82
	Dark bottle	(before)	O_2 mg/ℓ	6.27	6.27	6.27	6.27
		(after)		5.81	5.78	5.85	5.81
	Installation time		hr	7.50	7.50	7.50	7.50
	Pn		O_2 mg/ℓ/h	0.067	0.077	0.076	0.073
	R		O_2 mg/ℓ/h	0.061	0.065	0.056	0.061
	Pg		O_2 mg/ℓ/h	0.128	0.143	0.132	0.134

No. 13: Centre of Ha Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Average
Upper	Light bottle	(before)	O_2 mg/ℓ	6.24	6.24	6.24	6.24
		(after)		6.70	6.80	6.83	6.78
	Dark bottle	(before)	O_2 mg/ℓ	6.24	6.24	6.24	6.24
		(after)		6.12	6.14	6.11	6.12
	Installation time		hr	5.83	5.83	5.83	5.83
	Pn		O_2 mg/ℓ/h	0.079	0.096	0.101	0.092
	R		O_2 mg/ℓ/h	0.021	0.017	0.022	0.020
	Pg		O_2 mg/ℓ/h	0.099	0.113	0.123	0.112
Lower	Light bottle	(before)	O_2 mg/ℓ	6.26	6.26	6.26	6.26
		(after)		6.48	6.53	6.47	6.49
	Dark bottle	(before)	O_2 mg/ℓ	6.26	6.26	6.26	6.26
		(after)		6.22	6.23	6.20	6.22
	Installation time		hr	5.83	5.83	5.83	5.83
	Pn		O_2 mg/ℓ/h	0.038	0.045	0.036	0.040
	R		O_2 mg/ℓ/h	0.007	0.005	0.010	0.007
	Pg		O_2 mg/ℓ/h	0.045	0.051	0.046	0.047

No. 22: Centre of Bai Tu Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Average
Upper	Light bottle	(before)	O_2 mg/ℓ	5.77	5.77	5.77	5.77
		(after)		6.48	6.38	6.44	6.43
	Dark bottle	(before)	O_2 mg/ℓ	5.77	5.77	5.77	5.77
		(after)		5.64	5.62	5.66	5.64
	Installation time		hr	4.50	4.50	4.50	4.50
	Pn		O_2 mg/ℓ/h	0.158	0.136	0.149	0.147
	R		O_2 mg/ℓ/h	0.029	0.033	0.024	0.029
	Pg		O_2 mg/ℓ/h	0.187	0.169	0.173	0.176
Lower	Light bottle	(before)	O_2 mg/ℓ	5.68	5.68	5.68	5.68
		(after)		6.23	6.27	6.30	6.27
	Dark bottle	(before)	O_2 mg/ℓ	5.68	5.68	5.68	5.68
		(after)		5.66	5.62	5.64	5.64
	Installation time		hr	4.50	4.50	4.50	4.50
	Pn		O_2 mg/ℓ/h	0.122	0.131	0.138	0.130
	R		O_2 mg/ℓ/h	0.004	0.013	0.009	0.009
	Pg		O_2 mg/ℓ/h	0.127	0.144	0.147	0.139

No. 25: East of Bai Tu Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Average
Upper	Light bottle	(before)	O_2 mg/ℓ	5.75	5.75	5.75	5.75
		(after)		6.48	6.47	6.49	6.48
	Dark bottle	(before)	O_2 mg/ℓ	5.75	5.75	5.75	5.75
		(after)		5.61	5.63	5.60	5.61
	Installation time		hr	7.58	7.58	7.58	7.58
	Pn		O_2 mg/ℓ/h	0.096	0.095	0.098	0.096
	R		O_2 mg/ℓ/h	0.018	0.016	0.020	0.018
	Pg		O_2 mg/ℓ/h	0.115	0.111	0.117	0.114
Lower	Light bottle	(before)	O_2 mg/ℓ	5.58	5.58	5.58	5.58
		(after)		6.40	6.42	6.41	6.41
	Dark bottle	(before)	O_2 mg/ℓ	5.58	5.58	5.58	5.58
		(after)		5.53	5.53	5.54	5.53
	Installation time		hr	7.58	7.58	7.58	7.58
	Pn		O_2 mg/ℓ/h	0.108	0.111	0.109	0.109
	R		O_2 mg/ℓ/h	0.007	0.007	0.005	0.006
	Pg		O_2 mg/ℓ/h	0.115	0.117	0.115	0.116

Note: Pn: Net production, R: Respiration, Pg: Gross production

Table 11.8.2 Result of Decomposition Test

No. 2: Bai Chay

Layer	Days	DO	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Upper	0	4.2	7.67	1.68	0.11	0.020	0.07	0.20	1.48	0.56	0.018	0.54
	1	4.7	7.45	1.61	0.13	0.021	0.08	0.23	1.38	0.56	0.028	0.53
	5	4.5	6.74	1.64	0.15	0.029	0.09	0.27	1.37	0.57	0.031	0.54
	10	3.9	6.09	1.63	0.19	0.139	0.13	0.46	1.17	0.58	0.075	0.51
	20	3.2	5.25	1.62	0.19	0.141	0.13	0.46	1.16	0.60	0.110	0.49
Lower	0	5.5	7.82	1.69	0.13	0.022	0.06	0.21	1.48	0.61	0.022	0.59
	1	4.8	7.48	1.70	0.16	0.023	0.08	0.26	1.44	0.60	0.025	0.58
	5	4.6	6.82	1.67	0.18	0.026	0.10	0.31	1.36	0.63	0.026	0.60
	10	3.9	5.81	1.71	0.20	0.147	0.17	0.52	1.19	0.63	0.061	0.57
	20	3.1	5.46	1.66	0.23	0.152	0.17	0.55	1.11	0.63	0.087	0.54

No. 6: West of Ha Long Bay

Layer	Days	DO	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Upper	0	7.0	5.52	1.32	0.03	0.024	0.06	0.11	1.21	0.59	0.024	0.57
	1	4.7	5.14	1.36	0.10	0.026	0.08	0.21	1.15	0.58	0.028	0.55
	5	4.0	4.58	1.31	0.13	0.035	0.09	0.26	1.06	0.60	0.034	0.57
	10	3.5	4.12	1.34	0.15	0.092	0.11	0.35	0.99	0.60	0.062	0.54
	20	3.3	3.84	1.30	0.19	0.141	0.13	0.46	0.84	0.60	0.110	0.49
Lower	0	6.7	5.20	1.56	0.05	0.010	0.08	0.14	1.42	0.62	0.024	0.60
	1	4.7	5.08	1.60	0.19	0.013	0.09	0.29	1.31	0.64	0.027	0.61
	5	4.1	4.47	1.58	0.23	0.040	0.10	0.37	1.21	0.65	0.038	0.61
	10	3.5	3.98	1.62	0.26	0.049	0.16	0.47	1.15	0.67	0.074	0.60
	20	3.3	3.46	1.55	0.28	0.152	0.17	0.61	0.94	0.63	0.087	0.54

No. 13: Centre of Ha Long Bay

Layer	Days	DO	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Upper	0	5.8	4.58	1.91	0.07	0.015	0.08	0.17	1.75	0.12	0.018	0.10
	1	4.5	4.23	1.85	0.08	0.017	0.09	0.19	1.66	0.15	0.025	0.13
	5	4.2	3.87	1.78	0.10	0.036	0.09	0.22	1.56	0.19	0.027	0.16
	10	4.1	3.23	2.81	0.12	0.050	0.10	0.27	2.54	0.20	0.060	0.14
	20	3.9	2.83	1.84	0.13	0.052	0.10	0.28	1.56	0.20	0.071	0.13
Lower	0	3.9	4.15	2.27	0.08	0.029	0.05	0.16	2.11	0.21	0.030	0.18
	1	4.4	3.88	2.19	0.09	0.038	0.06	0.19	2.00	0.27	0.034	0.24
	5	4.1	3.56	2.22	0.20	0.046	0.10	0.35	1.87	0.31	0.038	0.27
	10	4.0	2.82	2.27	0.25	0.057	0.12	0.43	1.84	0.35	0.064	0.29
	20	3.9	2.22	2.31	0.26	0.065	0.12	0.45	1.87	0.37	0.082	0.29

No. 22: Centre of Bai Tu Long Bay

Layer	Days	DO	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Upper	0	6.4	3.63	1.76	0.08	0.006	0.04	0.13	1.63	0.34	0.026	0.31
	1	4.8	3.41	1.74	0.09	0.008	0.07	0.17	1.57	0.35	0.028	0.32
	5	4.5	3.10	1.78	0.10	0.016	0.08	0.20	1.58	0.34	0.035	0.30
	10	4.4	2.90	1.80	0.11	0.030	0.10	0.24	1.56	0.37	0.040	0.33
	20	4.1	2.62	1.75	0.11	0.039	0.10	0.25	1.50	0.36	0.083	0.28
Lower	0	5.7	4.43	1.96	0.07	0.021	0.03	0.12	1.84	0.54	0.015	0.53
	1	4.7	4.08	2.01	0.10	0.023	0.07	0.19	1.82	0.55	0.019	0.53
	5	4.5	3.58	1.97	0.12	0.026	0.08	0.23	1.74	0.57	0.027	0.54
	10	4.3	3.10	1.94	0.15	0.037	0.10	0.29	1.65	0.59	0.054	0.54
	20	4.0	2.83	1.99	0.17	0.049	0.11	0.33	1.66	0.59	0.114	0.48

No. 25: East of Bai Tu Long Bay

Layer	Days	DO	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
Upper	0	5.2	7.26	1.69	0.07	0.006	0.03	0.11	1.58	0.35	0.025	0.33
	1	5.0	6.98	1.72	0.08	0.007	0.04	0.13	1.59	0.37	0.028	0.34
	5	4.5	6.46	1.73	0.09	0.016	0.06	0.17	1.56	0.36	0.044	0.32
	10	4.3	4.23	1.68	0.09	0.028	0.09	0.21	1.47	0.34	0.062	0.28
	20	4.1	3.83	1.74	0.11	0.046	0.11	0.27	1.47	0.36	0.096	0.26
Lower	0	5.2	8.47	1.48	0.09	0.004	0.03	0.12	1.36	0.80	0.019	0.78
	1	4.9	7.58	1.54	0.09	0.004	0.03	0.12	1.42	0.80	0.029	0.77
	5	4.5	6.07	1.51	0.10	0.007	0.06	0.17	1.34	0.80	0.045	0.76
	10	4.5	4.61	1.47	0.11	0.028	0.08	0.22	1.25	0.80	0.057	0.74
	20	4.2	2.83	1.46	0.12	0.044	0.09	0.25	1.21	0.81	0.090	0.72

Table 11.8.3 Result of Settlement Test (1/4)

No. 2: Bai Chay Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	SS	before	g	0.046	0.041	0.040	0.041	0.035	0.041
		after	g	1.168	0.778	0.409	0.277	0.198	0.566
		net	g	1.122	0.738	0.368	0.236	0.163	0.525
	COD	before	g	0.024	0.028	0.024	0.028	0.013	0.023
		after	g	0.069	0.058	0.045	0.052	0.044	0.054
		net	g	0.046	0.031	0.021	0.023	0.031	0.030
	T-N	before	g	0.005	0.005	0.005	0.005	0.004	0.005
		after	g	0.014	0.014	0.016	0.015	0.013	0.014
		net	g	0.009	0.009	0.011	0.010	0.009	0.010
	T-P	before	g	0.001	0.001	0.001	0.001	0.001	0.001
		after	g	0.002	0.002	0.002	0.001	0.013	0.004
		net	g	0.000	0.001	0.000	0.000	0.012	0.003
	Sampling time		hr	28.0	21.0	23.5	23.8	22.5	23.8
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	123.3	108.1	48.2	30.5	22.3	68.0
		COD		5.0	4.5	2.7	3.0	4.3	3.9
		T-N		1.0	1.3	1.4	1.3	1.2	1.2
		T-P		0.0	0.1	0.1	0.0	1.7	0.4
	W	SS	m/day	10.6	10.4	4.7	2.9	2.5	6.6
		COD		0.8	0.6	0.5	0.4	1.3	0.7
		T-N		0.8	1.0	1.1	1.1	1.2	1.0
		T-P		0.1	0.3	0.1	0.1	5.7	1.1
Lower	SS	before	g	0.077	0.234	0.056	0.048	0.037	0.090
		after	g	2.602	2.273	1.037	0.910	0.563	1.477
		net	g	2.524	2.040	0.980	0.861	0.526	1.386
	COD	before	g	0.020	0.021	0.022	0.028	0.013	0.021
		after	g	0.107	0.088	0.063	0.076	0.014	0.076
		net	g	0.086	0.067	0.041	0.048	0.031	0.055
	T-N	before	g	0.005	0.007	0.006	0.005	0.004	0.005
		after	g	0.021	0.023	0.026	0.023	0.022	0.023
		net	g	0.016	0.017	0.020	0.018	0.018	0.018
	T-P	before	g	0.001	0.002	0.001	0.001	0.001	0.002
		after	g	0.002	0.002	0.002	0.002	0.002	0.002
		net	g	0.000	0.000	0.001	0.001	0.001	0.001
	Sampling time		hr	28.0	21.0	23.5	23.8	22.5	23.8
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	277.4	298.9	128.4	111.3	72.0	179.5
		COD		9.5	9.8	5.3	6.2	4.3	7.1
		T-N		1.8	2.5	2.7	2.3	2.5	2.3
		T-P		0.0	0.0	0.1	0.1	0.1	0.1
	W	SS	m/day	14.1	5.0	9.0	9.1	7.7	7.8
		COD		1.8	1.8	0.9	0.9	1.3	1.3
		T-N		3.5	1.5	1.9	1.9	2.2	1.8
		T-P		0.1	0.0	0.3	0.2	0.2	0.2

No. 6: West of Ha Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	SS	before	g	0.036	0.056	0.066	0.054	0.049	0.052
		after	g	0.510	0.586	0.853	1.277	0.888	0.823
		net	g	0.473	0.530	0.788	1.223	0.839	0.771
	COD	before	g	0.025	0.030	0.021	0.016	0.016	0.022
		after	g	0.051	0.059	0.052	0.051	0.043	0.051
		net	g	0.025	0.029	0.031	0.035	0.027	0.029
	T-N	before	g	0.007	0.008	0.008	0.008	0.007	0.008
		after	g	0.022	0.020	0.021	0.023	0.019	0.021
		net	g	0.015	0.012	0.012	0.015	0.012	0.013
	T-P	before	g	0.003	0.002	0.002	0.003	0.003	0.003
		after	g	0.003	0.004	0.005	0.005	0.005	0.005
		net	g	0.001	0.002	0.003	0.002	0.002	0.002
	Sampling time		hr	20.8	23.5	23.0	22.8	23.0	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	70.2	69.4	105.4	165.4	112.3	104.9
		COD		3.8	3.8	4.1	4.7	3.6	4.0
		T-N		2.2	1.5	1.7	2.0	1.6	1.8
		T-P		0.1	0.3	0.4	0.3	0.3	0.3
	W	SS	m/day	7.6	4.9	6.3	12.1	9.0	7.9
		COD		0.6	0.5	0.8	1.1	0.9	0.7
		T-N		1.2	0.7	0.8	1.0	0.9	0.9
		T-P		0.1	0.4	0.6	0.5	0.4	0.4
Lower	SS	before	g	0.062	0.057	0.066	0.080	0.057	0.064
		after	g	1.389	1.296	1.458	1.185	1.206	1.307
		net	g	1.328	1.239	1.392	1.105	1.149	1.243
	COD	before	g	0.027	0.027	0.031	0.013	0.014	0.022
		after	g	0.082	0.090	0.073	0.055	0.063	0.073
		net	g	0.055	0.063	0.042	0.042	0.049	0.050
	T-N	before	g	0.009	0.011	0.010	0.009	0.008	0.009
		after	g	0.026	0.024	0.026	0.022	0.024	0.025
		net	g	0.017	0.013	0.016	0.014	0.016	0.015
	T-P	before	g	0.003	0.003	0.003	0.003	0.003	0.003
		after	g	0.004	0.006	0.006	0.005	0.005	0.005
		net	g	0.001	0.003	0.003	0.002	0.002	0.002
	Sampling time		hr	20.8	23.5	23.0	22.8	23.0	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	196.9	162.2	186.2	149.4	153.7	169.2
		COD		8.2	8.3	5.7	5.6	6.5	6.8
		T-N		2.6	1.7	2.2	1.9	2.1	2.1
		T-P		0.2	0.5	0.4	0.2	0.3	0.3
	W	SS	m/day	12.5	11.2	11.1	7.3	10.5	10.3
		COD		1.2	1.2	0.7	1.7	1.8	1.2
		T-N		1.2	0.6	0.9	0.9	1.0	0.9
		T-P		0.3	0.5	0.5	0.3	0.4	0.4

Table 11.8.3 Result of Settlement Test (2/4)

No. 13: Centre of Ha Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	SS	before	g	0.032	0.028	0.026	0.044	0.039	0.034
		after	g	3.085	1.983	1.901	1.742	1.222	1.987
		net	g	3.053	1.954	1.875	1.698	1.182	1.953
	COD	before	g	0.022	0.022	0.016	0.022	0.020	0.020
		after	g	0.064	0.073	0.069	0.055	0.051	0.062
		net	g	0.042	0.051	0.053	0.033	0.031	0.042
	T-N	before	g	0.007	0.007	0.005	0.006	0.005	0.006
		after	g	0.028	0.027	0.024	0.022	0.019	0.024
		net	g	0.022	0.020	0.019	0.016	0.014	0.018
	T-P	before	g	0.001	0.001	0.001	0.001	0.001	0.001
		after	g	0.002	0.003	0.002	0.003	0.002	0.002
		net	g	0.001	0.002	0.002	0.002	0.002	0.002
	Sampling time		hr	22.3	22.8	22.8	23.4	23.8	23.0
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	421.3	264.3	253.7	223.3	153.2	261.4
		COD		5.7	6.8	7.2	4.4	4.0	5.6
		T-N		3.0	2.7	2.5	2.1	1.8	2.4
		T-P		0.2	0.2	0.2	0.2	0.2	0.2
	W	SS	m/day	52.0	36.7	39.0	19.9	15.3	30.4
		COD		1.0	1.2	1.8	0.8	0.8	1.1
		T-N		1.7	1.5	2.0	1.3	1.4	1.6
		T-P		1.5	1.1	1.5	1.4	1.4	1.3
Lower	SS	before	g	0.076	0.066	0.127	0.152	0.122	0.108
		after	g	6.967	18.435	15.691	10.740	7.475	11.862
		net	g	6.891	18.370	15.564	10.588	7.353	11.753
	COD	before	g	0.022	0.019	0.017	0.025	0.024	0.021
		after	g	0.126	0.211	0.176	0.170	0.115	0.160
		net	g	0.104	0.193	0.159	0.145	0.091	0.138
	T-N	before	g	0.008	0.008	0.008	0.008	0.007	0.008
		after	g	0.040	0.069	0.062	0.040	0.045	0.051
		net	g	0.031	0.061	0.054	0.031	0.037	0.043
	T-P	before	g	0.001	0.001	0.001	0.001	0.001	0.001
		after	g	0.003	0.004	0.004	0.003	0.002	0.003
		net	g	0.003	0.003	0.003	0.002	0.002	0.003
	Sampling time		hr	22.3	22.8	22.8	23.4	23.8	23.0
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	950.9	2,484.5	2,105.0	1,392.3	952.6	1,573.0
		COD		14.3	26.0	21.6	19.0	11.8	18.5
		T-N		4.3	8.3	7.3	4.1	4.8	5.8
		T-P		0.4	0.4	0.4	0.3	0.2	0.3
	W	SS	m/day	49.3	148.8	65.2	36.0	30.6	57.0
		COD		2.6	5.4	5.1	3.0	2.0	3.4
		T-N		2.0	4.2	3.7	1.9	2.6	2.9
		T-P		2.5	1.9	1.4	1.5	1.1	1.6

No. 22: Centre of Bai Tu Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	SS	before	g	0.051	0.051	0.069	0.058	0.037	0.053
		after	g	1.307	3.327	3.888	3.155	2.449	2.825
		net	g	1.257	3.276	3.819	3.098	2.412	2.772
	COD	before	g	0.012	0.016	0.018	0.014	0.013	0.015
		after	g	0.083	0.092	0.108	0.099	0.091	0.095
		net	g	0.071	0.076	0.089	0.085	0.079	0.080
	T-N	before	g	0.007	0.006	0.007	0.007	0.006	0.007
		after	g	0.024	0.030	0.038	0.033	0.030	0.031
		net	g	0.017	0.023	0.030	0.026	0.024	0.024
	T-P	before	g	0.001	0.001	0.001	0.002	0.002	0.001
		after	g	0.002	0.002	0.003	0.002	0.003	0.003
		net	g	0.001	0.001	0.001	0.001	0.001	0.001
	Sampling time		hr	22.8	24.8	21.5	23.0	21.1	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	169.6	407.2	547.9	414.4	351.7	377.1
		COD		9.5	9.4	12.8	11.4	11.5	10.9
		T-N		2.3	2.9	4.4	3.5	3.5	3.3
		T-P		0.1	0.1	0.2	0.1	0.2	0.1
	W	SS	m/day	13.1	31.1	31.1	28.2	37.0	27.8
		COD		3.1	2.3	2.7	3.1	3.5	2.9
		T-N		1.3	1.8	2.4	1.9	2.4	1.9
		T-P		0.4	0.4	0.5	0.2	0.4	0.4
Lower	SS	before	g	0.118	0.066	0.205	0.200	0.268	0.171
		after	g	8.741	26.846	38.487	17.945	14.751	21.354
		net	g	8.623	26.780	38.282	17.745	14.483	21.183
	COD	before	g	0.014	0.018	0.017	0.013	0.015	0.016
		after	g	0.179	0.337	0.329	0.243	0.223	0.262
		net	g	0.164	0.319	0.311	0.231	0.208	0.247
	T-N	before	g	0.008	0.007	0.010	0.009	0.009	0.008
		after	g	0.053	0.091	0.115	0.077	0.071	0.081
		net	g	0.045	0.084	0.106	0.068	0.062	0.073
	T-P	before	g	0.001	0.002	0.002	0.002	0.002	0.002
		after	g	0.003	0.003	0.003	0.003	0.002	0.003
		net	g	0.001	0.001	0.001	0.001	0.001	0.001
	Sampling time		hr	22.8	24.8	21.5	23.0	21.1	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	1,163.7	3,329.3	5,491.5	2,374.0	2,112.0	2,881.4
		COD		22.2	39.6	44.7	30.9	30.3	33.5
		T-N		6.1	10.4	15.1	9.1	9.0	9.9
		T-P		0.2	0.2	0.2	0.1	0.1	0.2
	W	SS	m/day	38.8	198.2	105.2	45.6	30.9	66.0
		COD		6.1	8.6	10.1	9.6	7.9	8.5
		T-N		3.1	6.1	6.2	4.2	3.9	4.7
		T-P		0.6	0.4	0.5	0.3	0.2	0.4

Table 11.8.3 Result of Settlement Test (3/4)

No. 25: East of Bai Tu Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	SS	before	g	0.063	0.054	0.070	0.065	0.039	0.058
		after	g	10.176	7.638	5.644	4.287	1.945	5.938
		net	g	10.113	7.585	5.574	4.221	1.906	5.880
	COD	before	g	0.020	0.018	0.019	0.022	0.023	0.020
		after	g	0.193	0.216	0.136	0.158	0.110	0.163
		net	g	0.173	0.198	0.117	0.136	0.087	0.142
	T-N	before	g	0.007	0.007	0.007	0.007	0.007	0.007
		after	g	0.073	0.063	0.049	0.028	0.018	0.046
		net	g	0.066	0.056	0.042	0.021	0.011	0.039
	T-P	before	g	0.001	0.001	0.001	0.001	0.002	0.001
		after	g	0.003	0.004	0.002	0.003	0.003	0.003
		net	g	0.001	0.003	0.001	0.002	0.001	0.002
	Sampling time		hr	21.8	24.0	24.5	24.0	20.3	22.9
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	1,430.7	972.4	700.0	541.2	288.9	789.7
		COD		24.5	25.3	14.7	17.4	13.2	19.1
		T-N		9.4	7.2	5.2	2.7	1.7	5.3
		T-P		0.2	0.4	0.2	0.3	0.2	0.2
	W	SS	m/day	88.9	71.0	39.1	32.4	28.9	53.1
		COD		4.8	5.4	3.1	3.1	2.2	3.7
		T-N		5.0	4.3	2.8	1.5	1.0	3.0
		T-P		0.6	1.6	0.6	0.9	0.4	0.7
Lower	SS	before	g	0.117	0.332	0.106	0.065	0.048	0.134
		after	g	46.686	22.126	27.216	12.797	6.810	23.127
		net	g	46.569	21.794	27.110	12.732	6.762	22.993
	COD	before	g	0.020	0.027	0.028	0.030	0.027	0.026
		after	g	0.321	0.291	0.265	0.225	0.212	0.263
		net	g	0.301	0.264	0.236	0.195	0.185	0.236
	T-N	before	g	0.010	0.010	0.008	0.007	0.007	0.008
		after	g	0.118	0.096	0.110	0.059	0.045	0.086
		net	g	0.108	0.085	0.102	0.051	0.039	0.077
	T-P	before	g	0.002	0.001	0.003	0.002	0.002	0.002
		after	g	0.007	0.006	0.005	0.004	0.002	0.005
		net	g	0.005	0.005	0.002	0.002	0.000	0.003
	Sampling time		hr	21.8	24.0	24.5	24.0	20.3	22.9
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	SS	$g/m^2 \cdot day$	6,588.0	2,794.0	3,404.7	1,632.3	1,024.9	3,088.1
		COD		42.6	33.9	29.7	25.0	28.0	31.7
		T-N		15.3	10.9	12.8	6.6	5.8	10.3
		T-P		0.6	0.6	0.3	0.3	-0.0	0.4
	W	SS	m/day	220.3	33.0	125.6	98.9	83.3	90.6
		COD		8.3	5.0	4.1	3.3	4.1	4.7
		T-N		6.0	4.2	6.0	3.6	3.5	4.8
		T-P		1.2	2.8	0.4	0.8	-0.0	0.8

No. 2: Bai Chay Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	O-N	before	g	0.004	0.104	0.004	0.004	0.003	0.004
		after	g	0.012	0.013	0.015	0.013	0.012	0.013
		net	g	0.008	0.009	0.011	0.010	0.009	0.009
	O-P	before	g	0.001	0.001	0.001	0.001	0.001	0.001
		after	g	0.002	0.002	0.002	0.001	0.001	0.002
		net	g	0.000	0.001	0.000	0.000	0.000	0.000
	Sampling time		hr	28.0	21.0	23.5	23.8	22.5	23.8
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O-N	$g/m^2 \cdot day$	0.8	1.3	1.4	1.2	1.2	1.2
		O-P		0.0	0.1	0.0	0.0	0.0	0.0
	W	O-N	m/day	0.8	1.2	1.4	1.2	1.6	1.2
		O-P		0.1	0.3	0.1	0.1	0.1	0.1
Lower	O-N	before	g	0.003	0.005	0.005	0.004	0.003	0.004
		after	g	0.018	0.022	0.025	0.021	0.021	0.021
		net	g	0.015	0.016	0.020	0.017	0.018	0.017
	O-P	before	g	0.001	0.002	0.001	0.001	0.001	0.001
		after	g	0.002	0.002	0.002	0.002	0.002	0.002
		net	g	0.000	0.000	0.001	0.001	0.000	0.001
	Sampling time		hr	28.0	21.0	23.5	23.8	22.5	23.8
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O-N	$g/m^2 \cdot day$	1.6	2.4	2.6	2.2	2.4	2.2
		O-P		0.0	0.0	0.1	0.1	0.1	0.1
	W	O-N	m/day	1.8	1.7	2.2	2.2	2.9	2.1
		O-P		0.1	0.0	0.3	0.3	0.2	0.2

No. 6: West of Ha Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	O-N	before	g	0.006	0.008	0.008	0.007	0.007	0.007
		after	g	0.019	0.019	0.020	0.022	0.019	0.020
		net	g	0.013	0.011	0.012	0.015	0.012	0.013
	O-P	before	g	0.003	0.002	0.002	0.003	0.003	0.002
		after	g	0.003	0.004	0.005	0.005	0.005	0.004
		net	g	0.001	0.002	0.003	0.002	0.002	0.002
	Sampling time		hr	20.8	23.5	23.0	22.8	23.0	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O-N	$g/m^2 \cdot day$	1.9	1.5	1.7	2.0	1.6	1.7
		O-P		0.1	0.3	0.4	0.3	0.3	0.3
	W	O-N	m/day	1.2	0.8	0.9	1.0	0.9	0.9
		O-P		0.1	0.4	0.6	0.5	0.4	0.4
Lower	O-N	before	g	0.008	0.010	0.009	0.007	0.008	0.009
		after	g	0.026	0.023	0.025	0.021	0.023	0.024
		net	g	0.018	0.012	0.016	0.013	0.015	0.015
	O-P	before	g	0.003	0.003	0.003	0.003	0.003	0.003
		after	g	0.004	0.005	0.006	0.005	0.005	0.005
		net	g	0.001	0.003	0.003	0.002	0.002	0.002
	Sampling time		hr	20.8	23.5	23.0	22.8	23.0	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O-N	$g/m^2 \cdot day$	2.7	1.6	2.1	1.8	2.0	2.1
		O-P		0.2	0.3	0.4	0.2	0.3	0.3
	W	O-N	m/day	1.3	0.6	0.9	1.0	1.0	0.9
		O-P		0.3	0.5	0.5	0.3	0.4	0.4

Table 11.8.3 Result of Settlement Test (4/4)

No. 13: Centre of Ha Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	O N	before	g	0.007	0.007	0.004	0.006	0.004	0.005
		after	g	0.029	0.026	0.022	0.021	0.017	0.023
		net	g	0.022	0.019	0.018	0.015	0.013	0.018
	O P	before	g	0.000	0.001	0.001	0.001	0.001	0.001
		after	g	0.002	0.002	0.002	0.002	0.002	0.002
		net	g	0.001	0.002	0.002	0.002	0.002	0.002
	Sampling time		hr	22.3	22.8	22.8	23.4	23.8	23.0
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O N	g/m^2·day	3.1	2.6	2.5	2.0	1.7	2.4
		O P		0.2	0.2	0.2	0.2	0.2	0.2
	W	O N	m/day	1.9	1.6	2.5	1.4	1.5	1.7
		O P		1.6	1.1	1.5	1.4	1.5	1.4
Lower	O N	before	g	0.008	0.007	0.007	0.008	0.006	0.007
		after	g	0.039	0.067	0.060	0.038	0.043	0.049
		net	g	0.032	0.060	0.053	0.030	0.036	0.042
	O P	before	g	0.001	0.001	0.001	0.001	0.001	0.001
		after	g	0.003	0.004	0.004	0.003	0.002	0.003
		net	g	0.003	0.003	0.003	0.002	0.002	0.002
	Sampling time		hr	22.3	22.8	22.8	23.4	23.8	23.0
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O N	g/m^2·day	4.3	8.1	7.2	3.9	4.7	5.6
		O P		0.4	0.4	0.4	0.3	0.2	0.3
	W	O N	m/day	2.2	4.4	4.0	2.0	2.9	3.1
		O P		2.6	2.0	1.4	1.5	1.1	1.7

No. 22: Centre of Bai Tu Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	O N	before	g	0.006	0.006	0.006	0.006	0.004	0.006
		after	g	0.023	0.029	0.036	0.032	0.028	0.029
		net	g	0.017	0.023	0.030	0.026	0.024	0.024
	O P	before	g	0.001	0.001	0.001	0.002	0.002	0.001
		after	g	0.002	0.002	0.003	0.002	0.003	0.002
		net	g	0.001	0.001	0.001	0.001	0.001	0.001
	Sampling time		hr	22.8	24.8	21.5	23.0	21.1	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O N	g/m^2·day	2.2	2.8	4.3	3.4	3.5	3.2
		O P		0.1	0.1	0.2	0.1	0.2	0.1
	W	O N	m/day	1.5	1.9	2.8	2.2	3.1	2.2
		O P		0.4	0.4	0.5	0.2	0.4	0.4
Lower	O N	before	g	0.007	0.006	0.008	0.007	0.008	0.007
		after	g	0.050	0.089	0.113	0.075	0.069	0.079
		net	g	0.043	0.083	0.105	0.068	0.061	0.072
	O P	before	g	0.001	0.001	0.002	0.002	0.002	0.002
		after	g	0.003	0.003	0.003	0.003	0.002	0.003
		net	g	0.001	0.001	0.001	0.001	0.000	0.001
	Sampling time		hr	22.8	24.8	21.5	23.0	21.1	22.6
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O N	g/m^2·day	5.8	10.4	15.0	9.1	8.9	9.8
		O P		0.2	0.1	0.2	0.1	0.1	0.1
	W	O N	m/day	3.3	7.1	7.1	4.8	4.3	5.3
		O P		0.6	0.4	0.4	0.3	0.2	0.3

No. 25: East of Bai Tu Long Bay

Layer	Items		Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Upper	O N	before	g	0.007	0.006	0.007	0.006	0.006	0.006
		after	g	0.072	0.062	0.048	0.027	0.017	0.045
		net	g	0.066	0.056	0.042	0.021	0.011	0.039
	O P	before	g	0.001	0.001	0.001	0.001	0.002	0.001
		after	g	0.003	0.004	0.002	0.003	0.003	0.003
		net	g	0.001	0.003	0.001	0.002	0.001	0.002
	Sampling time		hr	21.8	24.0	24.5	24.0	20.3	22.9
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O N	g/m^2·day	9.3	7.2	5.2	2.6	1.7	5.2
		O P		0.2	0.4	0.2	0.3	0.2	0.2
	W	O N	m/day	5.4	4.7	3.1	1.6	1.1	3.2
		O P		0.6	1.8	0.7	0.9	0.4	0.8
Lower	O N	before	g	0.009	0.010	0.008	0.006	0.006	0.008
		after	g	0.121	0.095	0.109	0.057	0.044	0.085
		net	g	0.112	0.085	0.101	0.051	0.038	0.077
	O P	before	g	0.002	0.001	0.003	0.001	0.002	0.002
		after	g	0.007	0.006	0.005	0.004	0.002	0.005
		net	g	0.005	0.005	0.002	0.002	0.000	0.003
	Sampling time		hr	21.8	24.0	24.5	24.0	20.3	22.9
	Area of sampler		m^2	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
	F	O N	g/m^2·day	15.8	10.9	12.7	6.5	5.8	10.4
		O P		0.6	0.6	0.3	0.3	-0.0	0.4
	W	O N	m/day	6.5	4.4	6.3	4.2	4.1	5.3
		O P		1.3	3.1	0.4	0.8	-0.0	0.8

Table 11.8.4 Result of Elution Test

No. 2: Bai Chay

Layer	Days	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
Bottom	0	2.03	0.90	0.06	0.01	0.03	0.11	0.79	0.27	0.01	0.26
	1	3.27	0.97	0.12	0.01	0.04	0.18	0.79	0.31	0.01	0.30
	5	3.57	1.52	0.18	0.01	0.06	0.26	1.25	0.58	0.04	0.54
	10	4.09	2.01	0.21	0.02	0.08	0.32	1.68	0.60	0.04	0.55
	20	4.43	2.11	0.22	0.02	0.08	0.34	1.76	0.85	0.04	0.80

No. 6: West of Ha Long Bay

Layer	Days	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
Bottom	0	2.73	0.85	0.02	0.01	0.04	0.07	0.78	0.25	0.01	0.24
	1	3.03	1.10	0.10	0.01	0.06	0.17	0.93	0.31	0.01	0.29
	5	3.21	1.49	0.15	0.01	0.08	0.25	1.23	0.53	0.03	0.50
	10	3.47	1.78	0.20	0.02	0.09	0.32	1.45	0.80	0.04	0.76
	20	3.99	1.86	0.25	0.02	0.09	0.38	1.47	0.92	0.04	0.88

No. 13: Centre of Ha Long Bay

Layer	Days	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
Bottom	0	2.41	1.00	0.04	0.01	0.03	0.08	0.92	0.07	0.01	0.05
	1	2.92	1.06	0.11	0.01	0.03	0.16	0.90	0.12	0.01	0.10
	5	3.00	1.39	0.13	0.01	0.11	0.26	1.13	0.72	0.04	0.68
	10	3.40	1.56	0.16	0.02	0.09	0.28	1.27	0.75	0.05	0.69
	20	3.59	1.66	0.19	0.02	0.09	0.32	1.33	0.80	0.05	0.74

No. 22: Centre of Bai Tu Long Bay

Layer	Days	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
Bottom	0	1.91	0.96	0.04	0.01	0.02	0.06	0.89	0.22	0.01	0.21
	1	2.30	1.10	0.09	0.00	0.04	0.14	0.96	0.73	0.01	0.71
	5	2.17	1.48	0.19	0.01	0.07	0.29	1.19	0.93	0.03	0.89
	10	2.89	1.74	0.26	0.01	0.08	0.36	1.37	1.00	0.05	0.95
	20	3.09	1.79	0.26	0.02	0.09	0.38	1.40	1.03	0.07	0.94

No. 25: East of Bai Tu Long Bay

Layer	Days	COD_{Mn}	T-N	NH_4-N	NO_2-N	NO_3-N	I-N	O-N	T-P	PO_4-P	O-P
		g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
Bottom	0	1.14	0.81	0.04	0.00	0.02	0.06	0.75	0.21	0.01	0.20
	1	1.95	0.93	0.07	0.00	0.04	0.12	0.80	0.39	0.01	0.38
	5	2.57	1.18	0.16	0.01	0.08	0.26	0.92	0.82	0.03	0.79
	10	3.28	1.50	0.21	0.01	0.08	0.32	1.18	0.82	0.03	0.78
	20	4.43	1.54	0.21	0.02	0.08	0.33	1.20	0.84	0.03	0.80

FIGURES

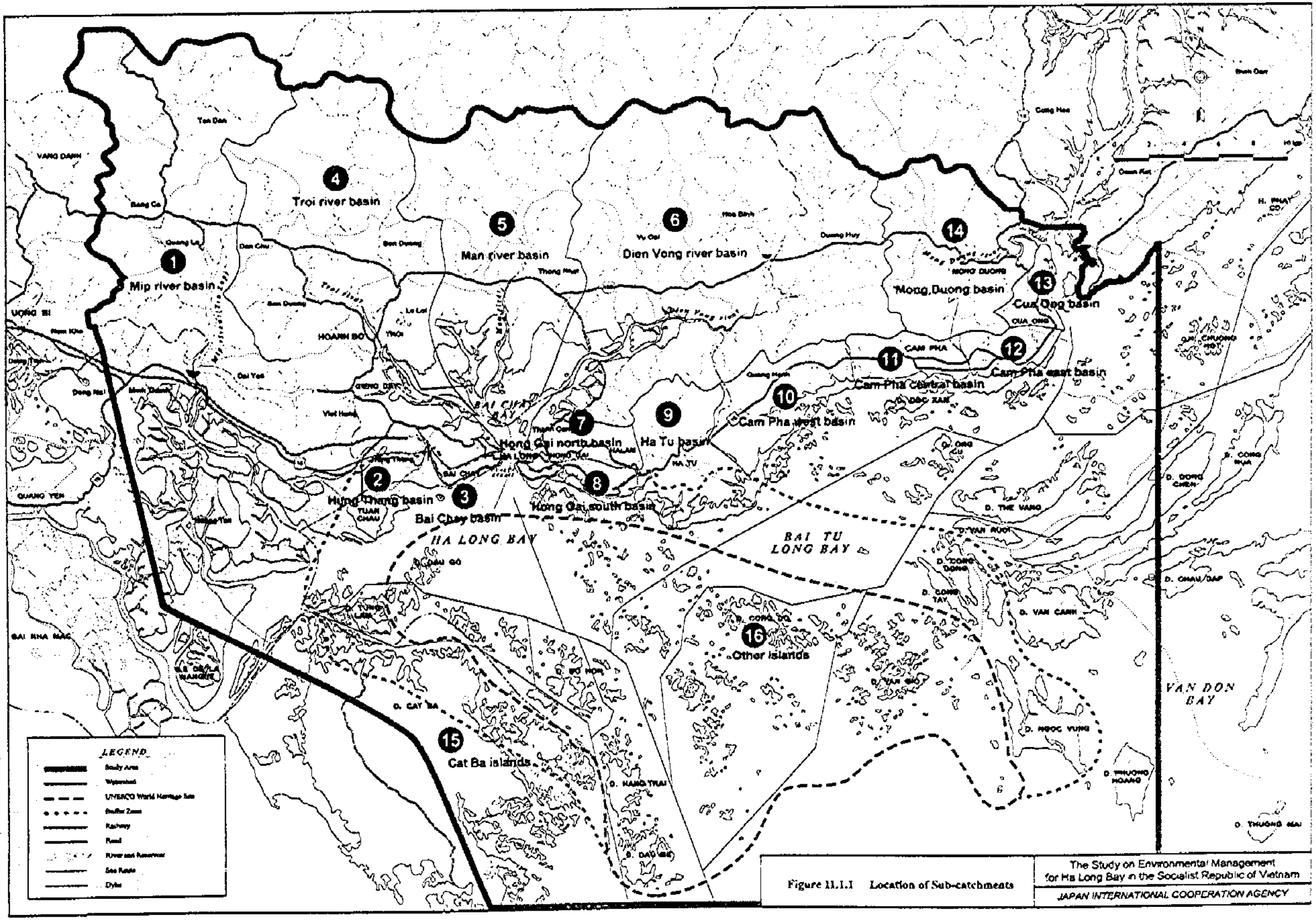


Figure 11.1.1 Location of Sub-catchments

The Study on Environmental Management for Ha Long Bay in the Socialist Republic of Vietnam

JAPAN INTERNATIONAL COOPERATION AGENCY

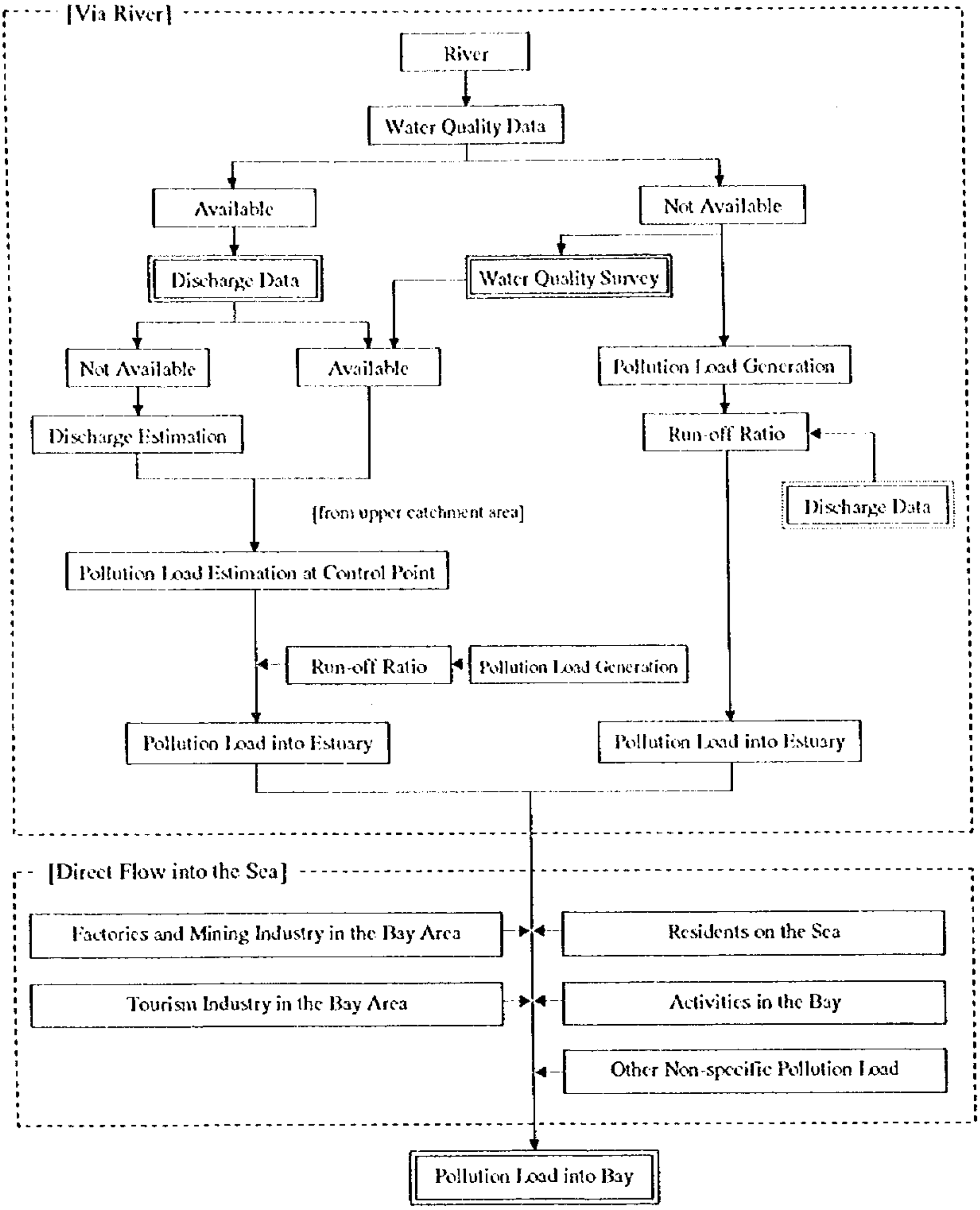
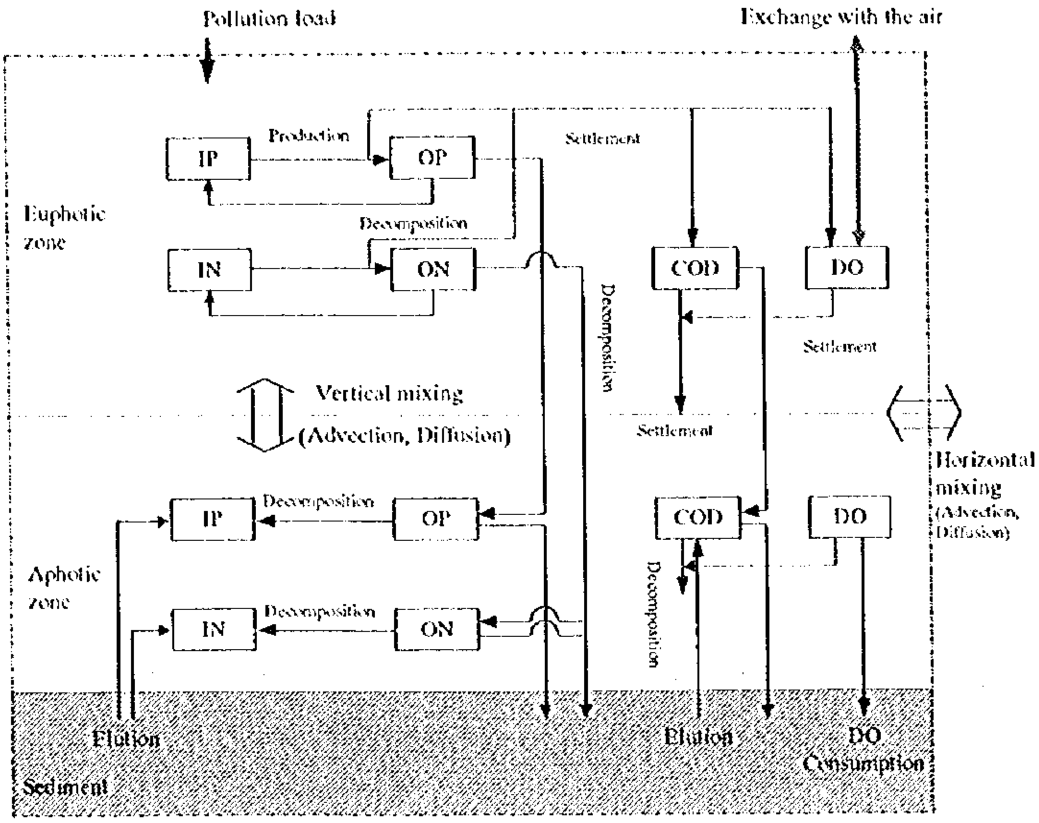


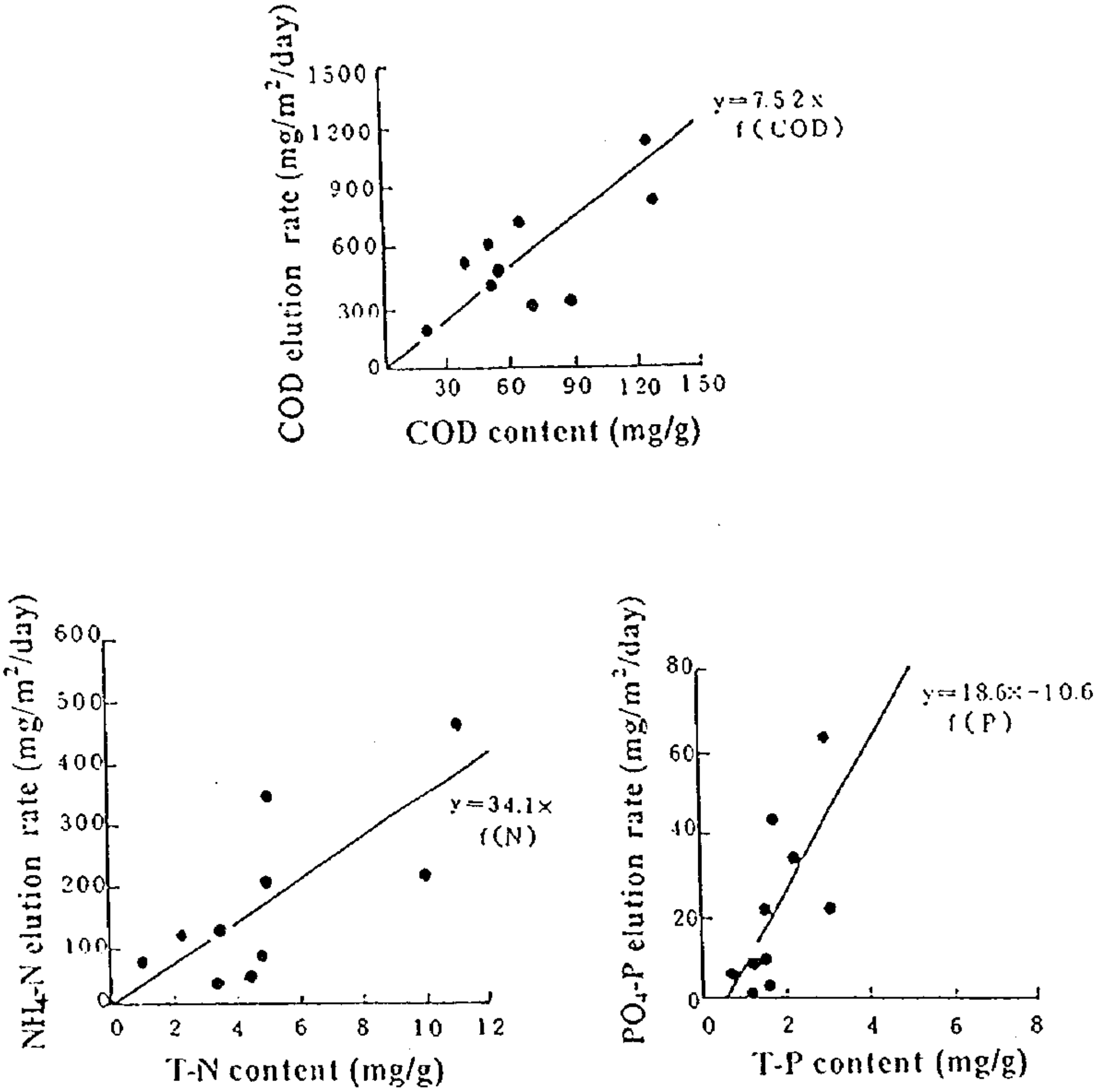
Figure 11.5.1 Method of Pollution Load Analysis



Note: IP: Inorganic phosphorus OP: Organic phosphorus
IN: Inorganic nitrogen ON: Organic nitrogen

Concept of water pollution mechanism in the Ha Long bay

Figure 11.8.1 Expected Mechanism of Water Pollution in the Bays



Source: The Evaluation Standards of Bottom Sediments, Port Department of Tokyo Metropolitan

Figure 11.8.2 Correlation between Bottom Sediment Quality and Release Rates of COD and Nutrients

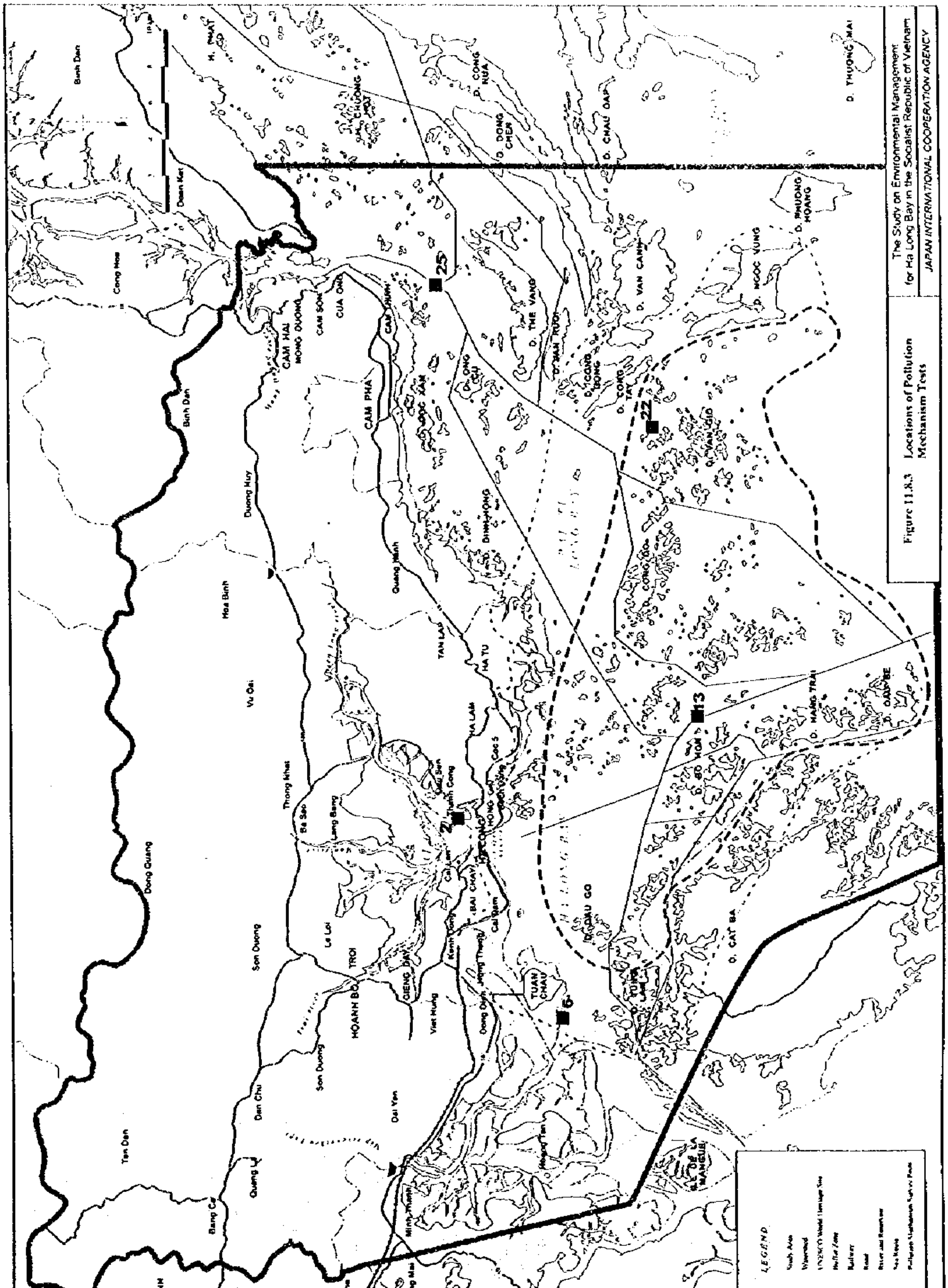


Figure 11.8.3 Locations of Pollution Mechanism Tests

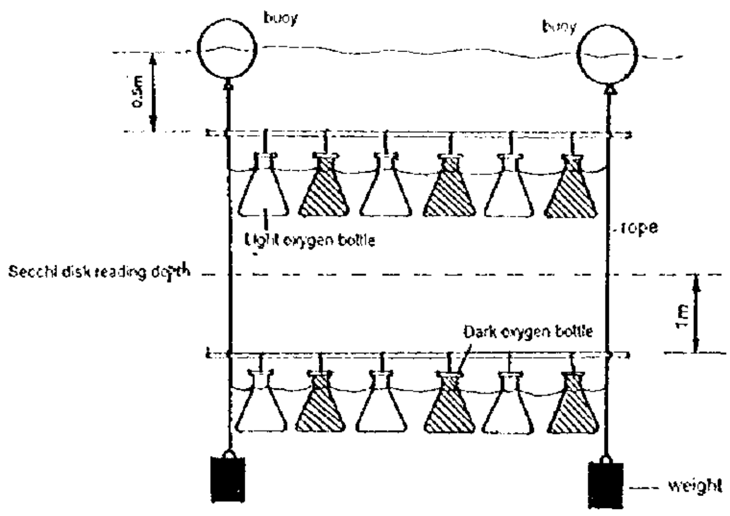


Figure 11.8.4 Productivity Test

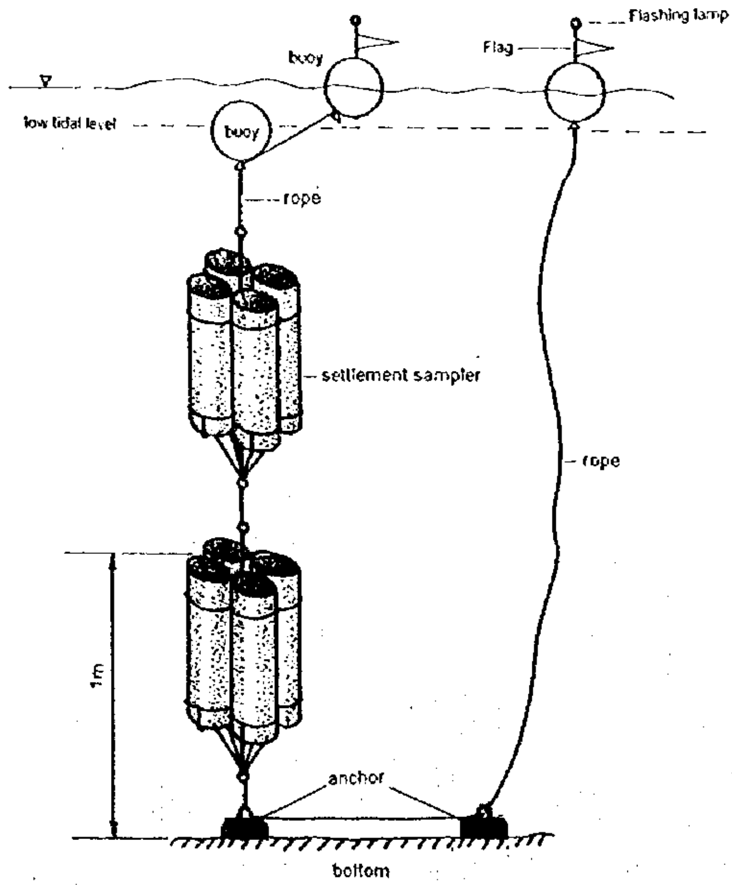


Figure 11.8.5 Settlement Test

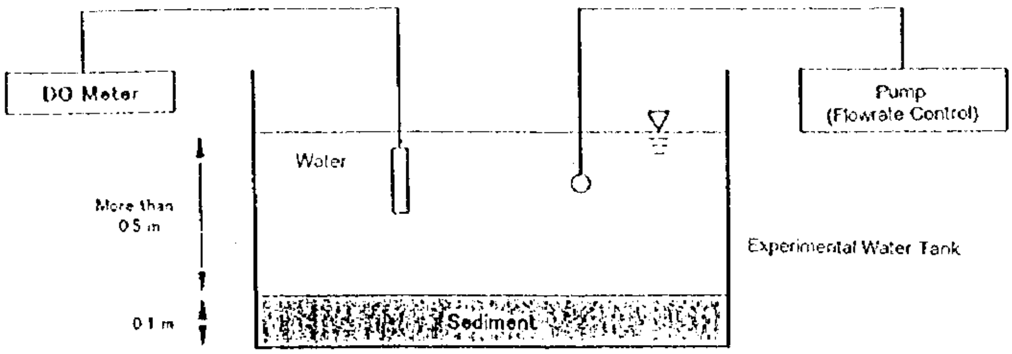


Figure 11.8.6 Elution Test

CHAPTER 12

CHAPTER 12 NUMERICAL SIMULATION MODEL

12.1 Structure of the Model

12.1.1 Objective

The objective of the numerical simulation model of the Study is to estimate changes in key water quality parameters based on pollution loads calculated for the different environmental scenarios derived from the socioeconomic frame considered in the Study. As a tool for such rational environmental management planning, the numerical simulation model is expected to simulate the hydrodynamics and water quality in the study area by integrating topographic conditions and estimated pollution loads.

12.1.2 Methodology

The model simulates three processes such as hydrodynamics, diffusion, and nutrient cycling in two levels so that it is applicable to the conditions of physical and chemical stratification. The model was developed based on the data of the Field Survey of the Study and the existing data.

The hydrodynamic model simulated time-varying circulation patterns together with the distribution of density in the bays by solving equations of continuity and equations of motion as described in Table 12.1.1. The results were used as input data for the diffusion model and the nutrient cycling model.

The diffusion model simulated advection and diffusion of SS based on the hydrodynamics and estimated loads. Advection and diffusion of conservative substances such as SS follows the equations were shown in Table 12.1.2.

The nutrient cycling model treated non-conservative processes such as production, decomposition, settlement, elution, re-aeration, and consumption in addition to the simple conservative processes of advection and diffusion. The model simulated those processes for COD, DO, and nutrients (O-N, I-N, O-P, and I-P) based on the hydrodynamics and estimated loads by the equations as shown in Table 12.1.3.

12.1.3 Existing Water Quality Simulation Model of Ha Long Bay

In the course of the Ha Long Bay Environmental Pollution Study, February 1998, a hydrodynamic and water quality model was developed. The developed model is a depth averaged one-layer model, which is simpler than that of the Study. Parameters treated in the model were SS, BOD, DO, and coliform bacteria.

The differences of methodology of that model and the model of the Study are described below.

(1) One-layer Model

The model is a depth averaged one-layer model. Vertical shear of the horizontal velocity, which exists in the bay, is not described in the hydrodynamic model. Wind effects to the currents are not included. Stratification of water quality parameters is not treated in the water quality model.

(2) Model Area

The model mainly focuses on Bai Chay area covered by the uniform grid size of 125 m. The area does not include Cam Pha and Cua Ong areas and the coastal area of eastern part of the Cat Ba island.

(3) Density Distribution

Density distribution caused by freshwater from rivers is not built in the hydrodynamics.

(4) Biochemical Reaction Terms

BOD and DO are not linked to nutrients. The primary production of phytoplankton under the condition of eutrophication is not considered.

12.1.4 Model Area

The model area of the Study was set up as shown in Figure 12.1.1 corresponding to the study area. The area extends 50 km in north and south direction and 60 km in east and west direction. This model area also covers the western edge of the Ha Long bay area where is planned to be integrated into Ha Long city by the Ha Long

City Master Plan. The edge is located about 10 km west of the Ha Long city boundary as of 1998.

12.1.5 Grid Size

Three different grid sizes that is 1,000 m, 333 m, and 111 m were proposed to provide the necessary topographic resolution for the Study as shown in Figure 12.1.1. The minimum grid size, 111 m, was chosen to provide at least three grids across the Cua Luc strait, the mouth of Bai Chay bay so that the horizontal shear of the velocity could be simulated properly in the strait. Other grid sizes were decided by the model scheme which requires those ratio of 1:3 among connected domains. Bai Chay area and Cua Ong area were covered by the 333 m grid for the in-depth study required in the Scope of Work (S/W) so that the environmental scenarios could be evaluated by this resolution.

The Mieu channel extending from the mouth of Bai Chay bay toward southeast and the La Saone channel extending from Cam Pha toward southwest were also covered by 333 m grid. The model area as a result contained four areas with 333 m grid as shown in Figure 12.1.1.

The rest of the model area was covered by the 1,000 m grid to keep the computing time within a realistic amount of time such as several hours by unix workstations.

12.1.6 Shoreline and Bathymetry

For the mapping of present shoreline and bathymetry, the map provided by CP/T, photographs of helicopter survey, marine charts and topographic maps were used.

The shoreline of Bai Chay area was digitized from "The Map of the Distribution of Tidal Wetland Types in the Bai Chay Embayment" as of 1997 provided by DOSTE. This map is the latest and the most detailed map of Bai Chay area collected in the Study. Photographs taken in the field reconnaissance by a helicopter of the Study in March 28, 1998 were used to help confirm the latest condition of the dyke in the area.

The shoreline of the other area and the bathymetry were digitized from marine charts No. 93626 (9th Ed., June 15, 1996) and No.93629 (7th Ed., March 15, 1997). The topographic map of No. 6450 IV surveyed in 1960 was used to assist with the digitizing of bathymetry.

The digitized bathymetry data were numerically interpolated and mapped into the three different grid sizes shown in Figure 12.1.1. The shoreline and bathymetry used in the model were shown in Figure 12.1.2.

12.1.7 Depth of the Layer Boundary

Sharp gradients of the vertical profiles of salinity near the surface in Field Survey data suggested the stratification of density in many places of the model area. To describe the condition of the stratification even in the shallow area, the depth of the layer boundary was defined as 2 m below mean sea level.

12.1.8 Target Season

The Field Survey results and dry season survey data provided by DOSTE revealed that the water quality in the bays during the rainy season was worsen than that of during the dry season (see Chapter 9). Viewed in this light, if the water quality of the rainy season attain the conservation criteria, that of the dry season is expected to attain the criteria. Thus, it can be said that the rainy season analysis is enough to examine whether the simulated water quality meet the conservation criteria or not. Therefore, the rainy season was selected as a target season of the numerical simulation model analysis in the Study.

12.2 Hydrodynamic Model

12.2.1 Boundary Conditions

The boundary conditions of the hydrodynamic model are the driving forces of the seawater movement described in the model. The model requires four different boundary conditions as below.

- Water level on the open boundaries,
- River discharge for tributaries,
- Wind direction and speed at the surface of the sea, and
- Densities on the open boundaries

The water levels on the open boundaries shown in Figure 12.2.1 were induced by diurnal and semi-diurnal oscillations. The amplitudes and phases of the constituents at numbered points in Figure 12.2.1 were set as below based on the existing harmonic constants (ESSA and CMESRC, 1997) obtained near the points. The amplitudes and phases for other boundary points were interpolated from these values.

Point	K_1		O_1		M_2		S_2	
	Amp. cm	Phase degree	Amp. cm	Phase Degree	Amp. cm	Phase degree	Amp. cm	Phase degree
1	74.0	102.6	80.0	17.0	4.0	118.0	3.0	152.4
2	74.0	102.6	80.0	17.0	4.0	118.0	3.0	152.4
3	73.0	87.6	79.0	2.0	4.0	88.0	3.0	122.4
4	72.0	87.6	78.0	2.0	4.0	88.0	3.0	122.4
5	72.0	87.6	78.0	2.0	4.0	88.0	3.0	122.4
6	79.0	97.6	86.0	12.0	15.0	108.0	3.0	142.4

The river discharges were set up as below based on the estimation of the average freshwater inflow during the rainy season for the sub-catchment areas in Section 11.2. Locations of the river discharges are shown in Figure 12.2.2.

The wind direction and speed at the surface of the sea were set as 345° and 3.4 m/s, respectively. These values were the average of the Field Survey data described in Section 8.3.3.

The densities on the open boundaries shown in Figure 12.2.1 were set as below based on the Field Survey data. Values for other boundary points were interpolated from these values.

No.	Name of Sub-catchment	Discharge (m^3/s)
1	Mip River	23.6
2	Hung Thang Basin	0.7
3	Bai Chay Basin	0.8
4	Troi River	18.7
5	Man River	11.2
6	Dieng Vong River	24.4
7	Hong Gai North Basin	1.6
8	Hon Hay South Basin	0.8
9	Ha Tu Basin	3.3
10	Cam Pha West Basin	3.2
11	Cam Pha Central Basin	2.0
12	Cam Pha East Basin	1.5
13	Cua Ong Basin	1.2
14	Cam Pha West Basin	10.1
15-1	Cat Ba Island	3.5
15-2	Cat Ba Island	3.5
15-3	Cat Ba Island	3.5
Total		113.6

Point	Density (g/cm³)	
	Upper Layer	Lower Layer
1	0.998	1.000
2	0.998	1.000
3	1.012	1.019
4	1.009	1.012
5	1.009	1.020
6	1.012	1.013

12.2.2 Effect of Small Islands

Although small islands must influence the water quality through affecting the circulation patterns especially in the World Natural Heritage site, the existence of the islands can not be expressed in the model if their sizes are smaller than the resolution limit, a half of the grid size. This is a common limitation of the modeling and a possible conventional solution is to adjust the cross section and/or bottom friction of the local grids so that the circulation patterns of the model results properly simulate those of the Field Survey.

However, the adjustment technique was not used in the Study because the simulated results met with the Field Survey data without using this technique as will be described in Section 12.5.

12.2.3 Initial Conditions

Horizontal and vertical velocities were set as zero at the beginning of the model run. Initial densities were set as the averages of the boundary values mentioned above in Boundary Conditions in each layer.

12.2.4 Period of the Model Run

The hydrodynamic model was run for the period from 1 July 1998 to 30 July 1998. The first half of the period was necessary to obtain the realistic periodicity free from the initial conditions. The second half, which corresponded to the Field Survey period, was necessary to obtain one whole cycle of the four major constituents of the tides. The results of the second half were stored and used as time-varying current conditions for the diffusion model and the nutrient cycling model.

12.2.5 Coefficients

Coefficients used in Table 12.1.1 were set up as below based on the Field Survey data in Section 8.3.3 and the existing study (Horie, 1980).

Coefficient	Value	Unit
Ah	1x105	cm^2/s
$f=2\omega\sin\varphi$ ω	$2\pi/(24\times3600)$	rad/s
φ	21.9	degree
γa^2	0.0016	–
γi^2	0.0001	–
γb^2	0.0026	–
Kx, Ky	1x105	cm^2/s
Kz	0.1	cm^2/s

12.3 Diffusion Model

12.3.1 Pollutant Variables

Pollutant variables of the diffusion model were SS in the Study. The grain size distribution was not considered in the model because the information was not available during the Study.

12.3.2 Loads of SS

Loads of SS were set up as below based on the estimation in Section 11.5. Locations of the load points were the same as those of the fresh water discharges set up for the hydrodynamic model shown in Figure 12.2.2.

No.	Name of Sub-catchment	Loads (kg/day)
1	Mip River	31,900
2	Hung Thang Basin	2,400
3	Bai Chay Basin	1,600
4	Troi River	28,700
5	Man River	14,800
6	Dieng Vong River	39,600
7	Hong Gai North Basin	10,500
8	Hon Hay South Basin	3,000
9	Ha Tu Basin	26,600
10	Cam Pha West Basin	10,300
11	Cam Pha Central Basin	12,000
12	Cam Pha East Basin	21,600
13	Cua Ong Basin	4,400
14	Cam Pha West Basin	23,900
15-1	Cat Ba Island	3,300
15-2	Cat Ba Island	3,300
15-3	Cat Ba Island	3,300
Total		241,100

12.3.3 Initial Values and Boundary Conditions

Initial values and boundary conditions should reflect the level of background concentration in the model area. Therefore, observed data of the offshore stations were referenced to decide these values.

The initial values used in the model were 1 mg/ℓ for both the upper and the lower layer based on the lowest value in the Field Survey data. The boundary conditions at numbered points in Figure 12.2.1 were fixed as constant values shown below based on the Field Survey data of the stations near the points. The values for other boundary points were interpolated from these values.

Point	Upper Layer (mg/ℓ)	Lower Layer (mg/ℓ)
1	10	19
2	10	19
3	3	10
4	4	7
5	4	7
6	2	3

12.3.4 Advection

Advection terms were simulated based on the time-varying circulation patterns obtained by the hydrodynamic model as the input data. Not only the horizontal advection but also the vertical advection was considered in the diffusion model as described in the equations in Table 12.1.2.

12.3.5 Diffusion

The effects of diffusion terms depend on the eddy diffusivity. Based on field studies, 10,000 cm^2/s for horizontal eddy diffusivity and 0.1 cm^2/s for vertical diffusivity were used.

12.3.6 Period of the Run

The diffusion model was run for the period from 1 July 1998 to 30 July 1998 corresponding to the Field Survey period. The first half of the period was necessary to obtain the realistic periodicity free from the initial conditions. The second half was necessary to obtain one whole cycle of the change of the concentrations caused by four major constituents of the tides. The results of the second half were stored and the averages of the concentrations for the period were used as the results of the diffusion model.

12.4 Nutrient Cycling Model

12.4.1 Pollutant Variables

Pollutant variables addressed by the model were:

a) COD_1 (External)

b) COD_2 (Internal)

c) I-N (Inorganic Nitrogen = Ammonia + Nitrate + Nitrite)

d) O-N (Organic Nitrogen)

e) I-P (Inorganic Phosphorus = PO_4-P)

f) O-P (Organic Phosphorus)

g) DO (Dissolved Oxygen)

The final outputs of the model were the distribution of the same pollutant variables mentioned above.

12.4.2 Loads

Loads for the nutrient cycling model were set up as below based on the estimation in Section 11.5. Locations of the load points were the same as those of the river discharges set up for the hydrodynamic model shown in Figure 12.2.2. The ratio of I-N/T-N and I-P/T-P were used as below based on the Field Survey data with some calibration estimating inorganic part and organic part in the loads separately.

No.	Name of Sub-catchment	COD (kg/day)	T-N (kg/day)	T-P (kg/day)	I-N/T-N	I-P/T-P
1	Mip River	2,940	2,280	1,120	0.17	0.035
2	Hung Thang Basin	360	190	80	0.15	0.049
3	Bai Chay Basin	340	180	70	0.50	0.049
4	Troi River	3,030	2,510	970	0.50	0.066
5	Man River	1,430	1,100	540	0.50	0.053
6	Dieng Vong River	3,500	2,670	1,170	0.50	0.062
7	Hong Gai North Basin	1,310	730	190	0.50	0.016
8	Hon Hay South Basin	800	440	120	0.50	0.016
9	Ha Tu Basin	1,160	810	310	0.20	0.040
10	Cam Pha West Basin	1,680	940	250	0.12	0.029
11	Cam Pha Central Basin	690	420	140	0.23	0.036
12	Cam Pha East Basin	1,690	670	100	0.05	0.035
13	Cua Ong Basin	300	190	60	0.20	0.042
14	Mong Duong River	1,340	1,300	450	0.20	0.042
15-1	Cat Ba Island	440	370	160	0.15	0.049
15-2	Cat Ba Island	440	370	160	0.15	0.049
15-3	Cat Ba Island	430	360	160	0.15	0.049
	Total	21,800	15,530	6,050	-	-

12.4.3 Initial Values and Boundary Conditions

Initial values and boundary conditions reflect the levels of background concentrations in the model area. Therefore, observed data of the offshore stations were referenced to decide these values.

The initial values and the boundary conditions used in the model were set up as below based on the Field Survey data.

Variables	Initial values and boundary conditions	
	Upper Layer (mg/ℓ)	Lower Layer (mg/ℓ)
COD_1	3.10	4.60
COD_2	3.10	4.60
I-N	0.11	0.11
O-N	1.54	1.15
I-P	0.03	0.03
O-P	0.69	0.86
DO	4.79	5.23

12.4.4 Advection

Advection terms were simulated based on the time-varying circulation patterns obtained by the hydrodynamic model as the input data. Not only the horizontal advection but also the vertical advection was considered in the diffusion model as described in the equations in Table 12.1.3.

12.4.5 Diffusion

The effects of diffusion terms depend on the eddy diffusivity. Based on field studies, 10,000 cm^2/s for horizontal eddy diffusivity and 0.1 cm^2/s for vertical diffusivity were used.

12.4.6 Reactions

Reaction terms were simulated based on the rates of bio-chemical processes. Constants for the rates used in Table 12.1.3 were set up as below based on the results of pollution mechanism study in the Section 11.7, other study results (Jorgensen et al., 1991), and the calibration.

Constant	Value	Unit
μmax	3.0	1/day
KIP	0.003	mg/ℓ
KIN	0.040	mg/ℓ
DP(I)	0.003	1/day
DN(I)	0.012	1/day
DCOD(I)	0.050	1/day
SP(I)	0.65*	m/day
SN(I)	0.65*	m/day
SCOD(I)	0.70*	m/day
YP	2.3	$mg/m^2/day$
YN	12.4	$mg/m^2/day$
YCOD	80.8	$mg/m^2/day$
DOSH	0.000	$mg/m^2/day$
Kex	0.300	1/day
DOS	7.680	mg/ℓ
C1	65.40	-
C2	7.200	-
C3	142.5	-

Note: * SP(I), SN(I), and SCOD(I) were set as 0 m/day for the domain of 111 m grid and the next domain of 333 m grid in Bai Chay area based on the calibration.

12.4.7 Period of the Run

The nutrient cycling model was run for the period from 1 July 1998 to 30 July 1998 corresponding to the Field Survey period. The first half of the period was necessary to obtain the realistic periodicity free from the initial conditions. The second half was necessary to obtain one whole cycle of the change of the concentrations caused by four major constituents of the tides. The results of the second half were stored and the averages of the concentrations for the period were used as the results of the nutrient cycling model.

12.5 Examination of Verification of the Model

12.5.1 Hydrodynamic Model

To verify the validity of the model, the simulated results were compared to the measured data obtained by the Field Survey and the Ha Long Bay Environmental Pollution Study (February 1998) at the station shown in Figure 12.5.1.

(1) Tidal Currents

The tidal current ellipses extracted from the simulated results were plotted in Figures 12.5.2 to 12.5.4 with the measured data. The results were summarized for diurnal currents and semi-diurnal currents as below. The examples of simulated circulation patterns of the ebb tide and the rising tide during spring tide were shown in Figures 12.5.5 and 12.5.6 for the reference.

1) Diurnal constituents

The diurnal constituents dominated in the area as reported in the Section 8.3.3. The diurnal tidal current ellipses of the simulated results for K_1+O_1 were drawn with those of the Field Survey as shown in Figure 12.5.2. The major directions and the maximum velocities of the simulated results met with the measured data except the lower layer at Cua Luc.

The tidal current ellipses of the simulated results were also drawn with the measured data by the Ha Long Bay Environmental Pollution Study, February 1998, as shown in Figure 12.5.3. The measured data of Dau Go were plotted with the simulated results for both upper and lower layer for the reference because the measured data were obtained only for the "bottom layer" of unknown depth at the shallow site of 5 m depth. Most major directions and the maximum velocities of the simulated results rather met with the measured data.

2) Semi-diurnal constituents

The semi-diurnal constituents dominated secondarily in the area as reported in the section 8.3.3. The semi-diurnal tidal current ellipses of the simulated results for M_2+S_2 were drawn with those of the Field Survey as shown in Figure 12.5.4. The simulated results met with the high velocities such as measured velocities at Cam Pha - Cua Ong.

(2) Averaged Currents

The averages of the simulated currents were shown in Figure 12.5.7. To highlight the comparison of the measured and simulated average currents, the currents around Cua Luc, Cam Pha - Cua Ong, and Cua Dua were separately shown in Figures 12.5.8, 12.5.9, and 12.5.10 with vectors at the measured point circled.

1) Cua Luc

The simulated currents in Figure 12.5.8 rather met with the measured data for both upper and lower layer. The currents of the upper layer in Figure 12.5.8(1) showed clear outgoing currents from Bai Chay bay while those in the lower layer in Figure 12.5.8(2) showed rather weak or even reverse currents. These suggested that the freshwater from rivers to Bai Chay bay are transported mainly in the upper layer.

2) Cam Pha – Cua Ong

The simulated currents of the upper layer in Figure 12.5.9(1) showed southward shift compared to the measured data. However, this is within the actual variations of the daily averaged current directions shown by the running mean in Figure 8.3.9. The simulated currents in the lower layer in Figure 12.5.9(2) rather met with the measured data.

3) Cua Dua

The simulated currents in Figure 12.5.10 showed eastward shift compared to the measured data. The southward direction of the measured currents was the reverse of the wind direction during the current measurement and hence difficult to be simulated. The possible reasons of the shift were: i) the currents were not largely affected by the wind because the measuring depth was deeper than other stations; and ii) the measuring location was at the downstream of the small island, which was not effectively expressed in the model.

12.5.2 Diffusion Model

(1) Levels of the Concentrations

To validate results of the diffusion model, the simulated results were compared to the Field Survey data. Locations of the sampling stations for the water quality survey are shown in Figure 12.5.11.

The simulated concentrations of SS were plotted with the measured concentrations of SS in Figure 12.5.12. Most of the simulated results met with the measured data at offshore stations while some results at near shore stations showed lower concentrations than the measured data.

The high concentrations measured at near shore stations such as No. 5, 6, 7, 28, 29, and 30 could be the effects of re-suspension from the bottom sediment because of the relatively shallow depths compared to other stations. The depths of these stations measured during sampling were 3.4, 4.1, 2.3, 0.8, 1.1, and 1.2 m respectively.

Another possible reason of the high concentrations at the station 5, 6, and 7 was the effect of loads caused by the construction of the causeway to Tuan Chau island as of 1998 which was not included in the loads estimated for the model. More discussion on the results would be necessary to validate the model.

(2) Distributions of the Concentrations

The results of the diffusion model were shown in Figure 12.5.13 as the distributions of concentrations. The high concentrations were found near the load points shown in Figure 12.2.2. The concentrations decreased from the load points to offshore and then increased toward the model boundaries of southern and southeastern ends especially in the lower layer. The Field Survey data showed such trend during the rainy season as shown in the concentrations of the station 13, 14, 15, 22, and 23 in Figure 12.5.12. The simulated water quality reflected this trend and suggested that the bays' water could be influenced by the water body with relatively high concentration of SS originating from outside of the study area.

12.5.3 Nutrient Cycling Model

(1) Levels of the Concentrations

To validate results of the nutrient cycling model, the simulated results were compared to the Field Survey data. Locations of the sampling stations for the water quality survey were shown in Figure 12.5.11.

The simulated concentrations of COD (= COD_1 + COD_2), T-N (= O-N + I-N), T-P (= O-P + I-P) and DO were plotted with the measured concentrations of the parameters as shown in Figure 12.5.14. O-N, I-N, O-P, and I-P were plotted separately in Figure 12.5.15 for reference.

Although the average levels of the simulated concentrations for the water quality parameters roughly met with those of the measured data, variations of the concentrations found in the measured data were not simulated enough. The high concentrations of COD, T-N, T-P, O-N, I-N, and O-P measured at stations 9, 10, and 11 near Hong Gai area were not simulated well. This suggested the existence of local pollution sources, which were not reflected well on the pollution loads estimation and/or setting load points for the model.

(2) Distributions of the Concentrations

The results of the nutrient cycling model were shown as the distributions of the concentrations in Figures 12.5.16 to 12.5.23. The high concentrations were found in Bai Chay bay for COD, T-N, T-P, O-N, I-N, and O-P. The concentrations decreased from the load points shown in Figure 12.2.2 to offshore and then increased toward the model boundaries of southern and southeastern ends. The Field Survey data showed such trend during the rainy season as shown in the concentrations of stations 9, 10, 11, 12, 13, 14, and 15 in Figures 12.5.14 and 12.5.15. The simulated water quality reflected this trend and suggested that the bays' water could be influenced by the water body with relatively high concentrations of COD, T-N, and T-P originating from outside of the study area.

Although the conditions of the eastern and northern boundaries were set lower than that of the southern boundary, the simulated concentrations near the eastern and northern boundaries were almost same as that near the southern boundary.

This is because that the water body with relatively lower concentrations of COD, T-N, and T-P in the canter of the bays is pushed out manly toward the southern boundary by the land based fresh water inflow in the model. This pushed out water body checked the rise in concentration of the southern boundary compared with the eastern and northern boundaries.

To have the active discussion on the model results, other model results were compared to those of the Study. The Ha Long Bay Environmental Pollution Study, February 1998, gave its model results for BOD in a part of the study area. Therefore, a simple conversion factor of BOD = COD/4.9 derived from the Field Survey data was introduced so that the simulated COD could be converted to BOD for reference. The concentrations of BOD converted from the simulated COD are shown in Figure 12.5.24.

12.5.4 Validation of the Developed Model

On the above grounds, it is concluded that the developed numerical simulation model can be used for the projection of future water quality in the bays.