The Calculation and Allocation of Marine Environmental Capacity for Daya Bay Under the Policy of Total Waste Load Control

Master of Science Thesis in the Master Programme Environmental Measurements and Assessments

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Abstract

The system of total waste load control (TWLC) has been developed and implemented in China since 1980s. Environmental capacity is the most important concept of TWLC system and its calculation and allocation are the bases to set TWLC targets and to make pollutants reduction schemes. In 2008, Guangdong Provincial Oceanic and Fishery Administration (GPOFA) proposed the TWLC strategy for ocean based on the scientific evaluation of marine environmental capacity. Daya bay, a semi-enclosed bay located in the south of Guangdong Province was selected as the research objective. In this thesis, the environmental capacities of Daya Bay in terms of chemical oxygen demand (CODcr), nitrogen existed as ammonia (NH_3-N) and reactive phosphate (PO_4^-) are calculated and allocated to the administrative districts located in Daya Bay's catchment basin. By combining the accounting and prediction results of pollutants discharge amounts, total waste load control and reduction schemes are developed.

Keywords: Total waste load control; Environmental capacity; Calculation; Allocation.

Acknowledgement

This master thesis is a part work of the project "Research on environmental capacity evaluation and total waste load control measures for Daya Bay area" undertaken by School of Environmental Science and Engineering of Sun Yat-sen University with the cooperation of Huizhou Municipal Oceanic and Fishery Bureau and Daya Bay Environmental Protection Bureau, in People's Republic of China.

I would like to thank my supervisors Professor Shiyu Li at Sun Yat-sen University of China and Karin Andersson at Chalmers University of Technology of Sweden. Further, I am also grateful to all the people in the Daya Bay project, especially PHD student Heng Zhang and master student Zhiyuan He of Sun Yat-sen University. I received much help and encouragement from them, and their work results were important bases of this master thesis. I would also like to thank all the people who have helped me finding information needed in the study.

Last but not least, I would like to thank my parents and my elder sister, for their love and support. I know you will always be there for me like a guardian angel, my dear mother. I love you forever.

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Chapter 1 Introduction

1.1 Research background

1.1.1 Total waste load control

An essential perspective of sustainable development is that development activities should not exceed the carrying capacity of the environment. Even if the effluent concentration meets water quality standard, the receiving water can still to be impaired when the carrying capacity is exceeded due to the large amount of wastewater discharged. By realizing this, U.S. Environmental Protection Agency (USEPA) first developed the managing concept of total waste load control in 1972 and triggered the TDML (total daily maximum loads) program with the purpose of reducing the total waste load to large, closed water bodies faced with serious pollution (USEPA, 2008). In Japan, total waste load control system was introduced to preserve marine environment in 1970s (Yang & Wang, 2008).

The system of total waste load control (TWLC) has been developed and implemented in China since 1980s, initially deriving from Japan's concept and referring to techniques of USA (Yang & Wang, 2008). At present, in China, the key idea of TWLC for water is (Chen et al., 2007):

"Based on the natural environmental conditions and self-purification ability of environment, the total waste load should be restricted not to exceed the environmental carrying capacity of water via the continuous adjustment and balance between environmental quality objectives and development of society and economy."

The Chinese TWLC technical system includes following processes (Meng, 2008):

(1) The selection of indicative pollutants for TWLC;
(2) The accounting of current discharge amount and the prediction of future discharge amount of selected indicative pollutants;
(3) The partition of environmental function areas for the water body focused;
(4) The calculation of water environmental capacity;
(5) The allocation of environmental capacity among polluters or administrative districts;
(6) The establishment of pollutants reduction schemes and the supervising of the implementation of TWLC.

In recent years, a lot of research and practical projects with focus on the calculation and allocation of environmental capacity for different kinds of water bodies and big drainage areas have been done in China. Many research achievements have been gained, including the continuous complementarity of indicative pollutants inventory, general survey of pollution sources at the national and regional level, the formulation and development of mathematical models of water environment, various allocation methods towards different bodies based on single or multi objectives, etc

(Tang et al., 2008). The political, legal, theoretical and technical systems of China's TWLC are progressing gradually.

1.1.2 Environmental capacity

The most important concept of the TWLC system is environmental capacity, whose calculation and allocation are the bases to set TWLC targets and to make pollutants reduction schemes. According to the definition of GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Pollution) of U.N., environmental capacity is used to describe the property of the environment to accommodate a particular activity or rate of activity without unacceptable impact (GESAMP, 1986). With respect to water pollution problem, environmental capacity is mentioned as the maximum amount of waste load which is allowable to enter water from given discharge places under the precondition of complying with water quality standard (Wang et al., 2006). The term "environmental capacity" is popular in China and Japan, while in Europe and U.S. researchers often use "critical load", "carrying capacity", "assimilative capacity" (Cairns, 1977) or "the maximum allowable waste load". For instance, with respect to the problem of acid deposition, a critical load for acid deposition "is the highest deposition of acidifying compounds that will not cause chemical changes leading to long term harmful effects on ecosystem structure and function" (Nilsson & Grennfelt, 1988) and has the same meaning as environmental capacity.

1.1.3 Project background

After developing for about 30years, there have been great improvements in China's TWLC system. However, problems still exist and require solutions. One problem is the deficiency of relevant research for oceans, which is in disproportion with the abundant marine resources of China. As ocean has many unique characteristics compared with fresh water, and the hydrology situation of the ocean is much more complex than for rivers and lakes. TWLC system that suits the ocean should be constructed, mathematical models which are possible to simulate ocean must be developed, and the calculation and allocation approaches of oceanic environmental capacity should be investigated, especially under the background of the increasing exploitation and utilization of oceanic resources at present and in the future.

For the sustainable development of marine economy and the balance between ocean exploitation and protection, new methodology should be introduced into ocean management. In 2007, Guangdong Provincial Oceanic and Fishery Administration (GPOFA) proposed the TWLC strategy for ocean based on the scientific evaluation of oceanic environmental capacity. Then a semi-enclosed bay of Guangdong Province, Daya bay, was selected as the research objective and a project named "Research on environmental capacity evaluation and total waste load control measures for Daya Bay area" (written as Daya Bay project for short) funded by GPOFA was established. The project is undertaken by School of Environmental Science and Engineering of Sun Yat-sen University with the cooperation of Huizhou Municipal Oceanic and Fishery Bureau and Daya Bay Environmental Protection Bureau. The research period is from

April 2008 to April 2009.

1.2 Research framework

Figure 1.3-1 showed the research framework of the whole project. The Daya Bay project can be divided into three interactive parts. The yellow part is the preparation and survey stage, which is the basis of following work. The blue part is the calculation of environmental capacity based upon the modeling of water environment. The red part is the making of TWLC schemes grounded on the allocation of environmental capacity and former research results. These three parts are integrated to be an organic whole.

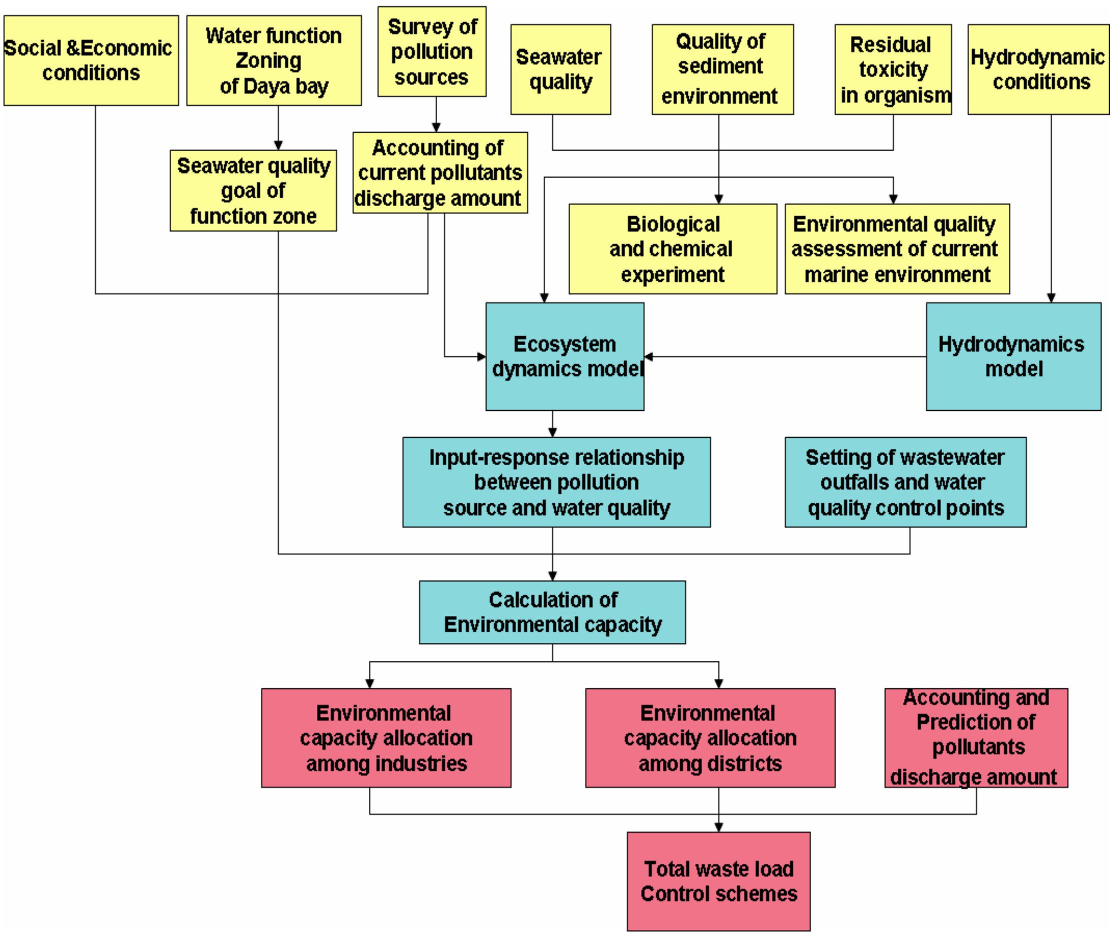

Figure 1-1 Research framework of the whole project

1.3 Thesis content

This master thesis is a part work of the project "Research on environmental capacity evaluation and total waste load control measures for Daya Bay area".

As the most important concept of TWLC, environmental capacity is used as the reference of environmental management and the main restriction condition in water resource planning and utilization. TWLC makes no sense until environmental capacity is allocated to pollution sources and based on which control and reduction schemes are made and implemented. Thus, the calculation and allocation of environmental capacity as well as the establishment of total waste load control schemes are the key parts of TWLC, which are the focus of this master thesis.

As a part of a big project, the work of this master thesis surely is not independent and is based on other research results of the project. Chapter 2 is a cooperation result worked with master student Zhiyuan He. Most of Chapter 3 is done independently, except the estimation of pollutants discharge amounts from non-point sources which is done by master student Bangxiong Chen. Chapter 4 is also a cooperation result made by several students, and the modeling part is worked mainly by PHD student Heng Zhang with the assist of PHD student Bingxu Geng. Chapter 5 and 6 is independent work. The writing of this master thesis is finished independently, and the pictures and tables in the text are made by the thesis worker herself if there is no reference to point out that the picture/table is quoted from other research results.

1.4 Research method

The study is based on other work results of the project including information collection (social, economic, environmental, pollution sources, hydrologic, etc.), water quality monitoring, modeling of water dynamics and water quality of Daya Bay, simulation results of the input-response relationship between pollutants inputted and water quality, and so on. The study methods and tools used include:

(1). Literature review: to know the current research results of environmental capacity calculation and allocation method, and to master related background and knowledge. (2) Field survey: to grasp the general situation of Daya Bay area and to define wastewater outfalls.

(3) Information collection from relevant authorities: Oceanic and Fishery Bureau, Environmental Protection Bureau, Statistical Bureau, Water Conservancy Bureau, etc.

(4). MatLab: the linear programming function (linprog) of MatLab is used for the calculation of environmental capacity.

(5) Geological information system (GIS): The project commissioned Pearl River Water Conservancy Science Research Institute (PRWCSRI) to attain and handle satellite remote sensing images of Daya Bay area. Then theses remote sensing images can be used and edited in MapInfo (GIS software) for many purposes, such as the overlay of different layers containing different geological information, the setting of wastewater outfalls, the visual look of the distribution of pollution sources, and so on.

Chapter 2 Current situation of Daya Bay

2.1 Background information

Daya Bay is a large a semi-enclosed bay with an area of about 600km^2. It is located at Guangdong Province in southern China (114°29′42″~114°49′42″E , 22°31′12″~22°50′00″N), as shown in Figure 2.1-1. Daya Bay is surrounded by Dapeng Peninsula of Shenzhen City, south coastal area of Huizhou City and Renping Peninsula of Huizhou City, nearing Hong Kong, as shown in Figure 2.1-2.

Figure 2.1-1: Google earth image for the location of Daya Bay

Figure 2.1-2 Satellite remote sensing image of Daya Bay (PRWCRSI, 2009)

With excellent natural conditions, Daya Bay is characterized by complex habitats, tremendous biological resource, abundant biodiversity and plentiful marine products, which makes it one of the most important treasure houses for semi-tropic aquatic resource in China. In 1983, the foundation of "Nature reserve of Daya Bay's fishery resource" was approved by Guangdong provincial government. In 1985,

Since China launched the "reform and open-door policy" in 1980s, the economy and industries of Daya Bay area have a continuing rapid development. The most known projects include Daya Bay Nuclear Power Plant, Ling Ao Nuclear Power Plant, Daya Bay Reactor Neutrino Experiment, and South China Sea Petrochemical Projects cooperated by Shell and CNOOC (China National Offshore Oil Corporation). However, along with the development, the environment of Daya Bay is going through a continuous degradation. Several extensive and systematic environment surveys since from 1980s revealed that various aspects of Daya Bay's ecological environment, such as nutrition state, productivity and biomass, have been degraded rapidly (Wang, 2004).

The continuing increase of pollutants load is the main reason of ecological environmental degradation in Daya Bay. However, until now there is still no a scientific and effective pollution control and management method for that area. Undoubtedly it's significant to work for the development of such a method that can slow down and further stop the environmental degradation trend in Daya Bay.

2.2 Catchment basin of Daya Bay

2.2.1 Demarcation of Daya Bay's catchment basin

The Daya Bay project commissioned Pearl River Water Conservancy Science Research Institute (PRWCSRI) to attain and handle satellite remote sensing images of Daya Bay area. Based on 10m resolutions DEM (Digital Elevation Model) of the Daya Bay area, ArcGIS (GIS software) delineated the catchment basin and further divided it into 43 sub-catchments (PRWCRSI, 2009), as shown in Figure 2.2-1 and Figure 2.2-2.

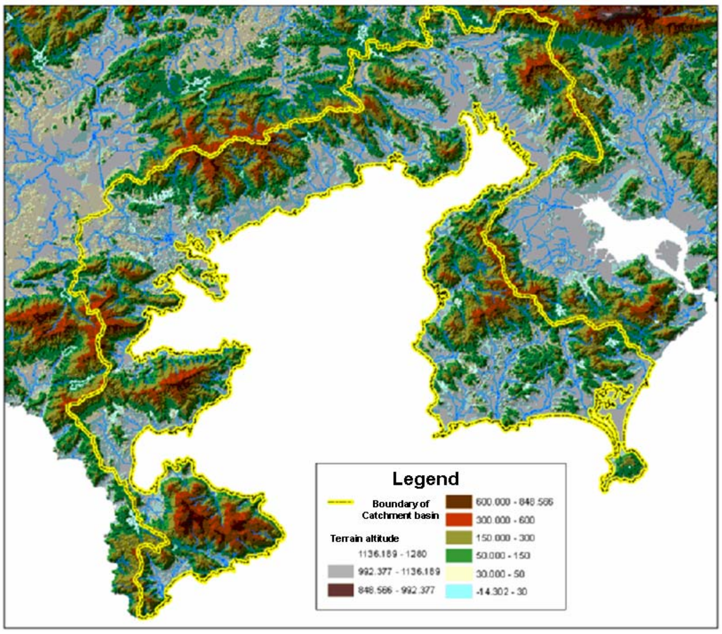

Figure 2.2-1 Catchment basin of Daya Bay area (PRWCRSI, 2009)

Figure 2.2-2 Sub-catchments of Daya Bay area (PRWCRSI, 2009)

2.2.2 Regionalism of Daya Bay's catchment basin

By overlaying the catchment basin map and the administration map in MapInfo, a preliminary result of the regionalism of Daya Bay's catchment basin can be obtained, as shown in Figure 2.2-3. More information about the regionalism is collected through field survey. And then combining the results of GIS operation and field survey, administrative districts which lie in the catchment basin of Daya Bay are defined, as listed in Table 2.2-1. These administrative districts are the targets and management units of TWLC.

Figure 2.2-3 Regionalism of Daya Bay's catchment basin

Table 2.2-1 Administrative districts lie in the catchment basin of Daya Bay

Administrative district at prefecture level	Administrative district at county level	Administrative district at town level
Huizhou City	Daya Bay Economy and Technology Development Zone	Western Region
		Aotou
		Xiachong
	Huidong County	Renshan
		Pinghai
Shenzhen City	Longgang District	Kuichong Subdistrict（Baguang Community）
		Dapeng Subdistrict（Dapeng, Pengcheng, Ling Ao, Shuitou, Buxin, Wangmu Community）
		Nanao Subdistrict (Dongyu, Dongshan, Xinda, Dongchong, Xichong Community）

2.3 Water function zoning and water quality goals

In general, surface water is multifunctional and is used for lots of different purposes in social and economic development. The concentration above which water pollutants adversely affect a particular water use may differ widely. Therefore, water area is usually partitioned into various water function zones according to the purpose of utilization (Chen et al., 2007). Water quality requirements, expressed as water quality standards or goals, are use-specific or are targeted to the protection of the most sensitive water use among a number of existing or planned uses within a catchment. Water function zoning is the basis and precondition for protecting water environment effectively, and water quality goals set for different function zones are an indispensable constituent in the calculation of environmental capacity.

Based on *Water Function Zoning of Nearshore Area in Guangdong Province* (PGGP, 1999) and *Water Function Zoning of Daya Bay Fishery Resource Nature Reserve* (PGHC, 2007), the map of water function zones was made by using MapInfo, as shown in Figure 2.3-1. Tale 2.3-1 illuminates the function of each zone and corresponding wager quality goal.

Table 2.3-1 Water function zones of Daya Bay and water quality goals (PGGP, 1999; PGHC, 2007)

Code	Main function	Water quality goals
503	Turtle protection	the first-class
504C	Fishery resource protection	the second-class
504B	Industrial pollution dilution zone	the third-class
504A	Fishery resource protection	the second-class
505	Fishery resource protection	the second-class
506A	Fishery resource protection	the second-class
506B	Industrial use	the third-class
506C	Harbor and wharf	the third-class
506D	Industrial use	the third-class
507	Harbor, industry, human life and landscape	the third-class
508	Mariculture	the second-class
509	Industrial and municipal wastewater discharge	the third-class
510	Wastewater discharge for harbor areas	the third-class
60l	Mariculture and tourism	the second-class
602	Water supply for industries and nuclear power stations, and tourism	the third-class
603	Mariculture, bathing spot and marine sports	the second-class
Northern Experimental area	Industrial and municipal wastewater discharge	the second-class
Middle core area	Fishery resource protection	the first-class
Middle buffering area	Pollution buffering	the first-class
Southern core area	Fishery resource protection	the first-class
Southern experimental area	Planned use for industrial and municipal wastewater discharge	the first-class

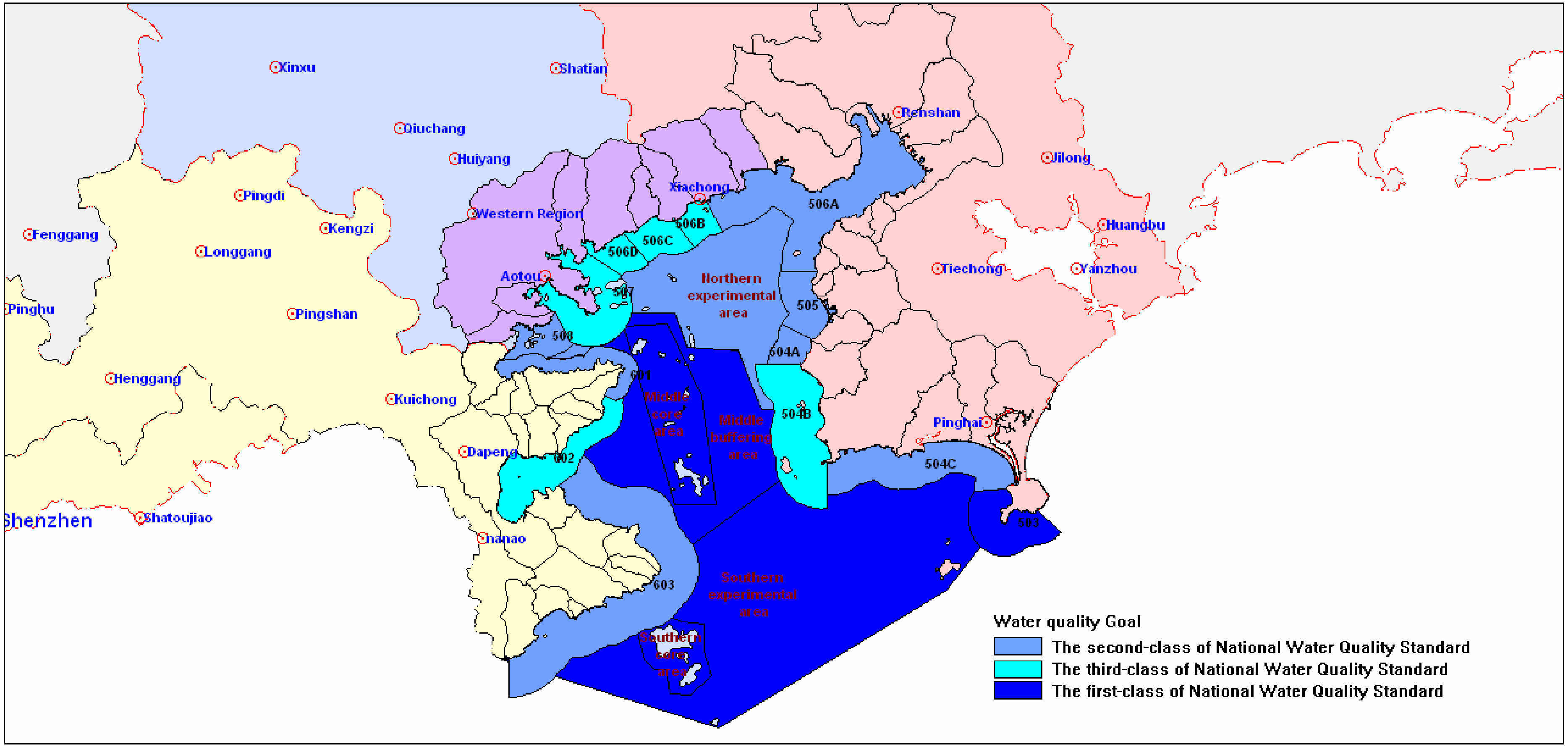

Figure 2.3-1 Water function zones of Daya Bay

2.4 Main environmental problems

The negative result of rapid social and economic development at Daya Bay area is the degradation of environment. As mentioned in former part, various aspects of Daya Bay's ecological environment, such as nutrition state, productivity and biomass, have been degraded rapidly since 1980s. At current the main environmental problems of Daya Bay include (SCSFRI, 2008):

(1) Marine pollution is serious in some area of Daya Bay

PRWCRSI developed a semi-quantitative model to present the integrated pollutant concentration by remote sensing based on the physical process of water spectral reflectance. Then two images which present the water quality status of Daya Bay in flood period of dry season (Date: 2007-10-24, the left one) and in ebb period of flood season (Date: 2008-08-20, the right one) are obtained, as shown in Figure 2.4-1.

By comparing Figure 2.4-1 and Figure 2.3-1, it can be known that both in dry season and in flood season, the water quality of some near-shore area of Daya Bay is worse than water quality goals regulated by government.

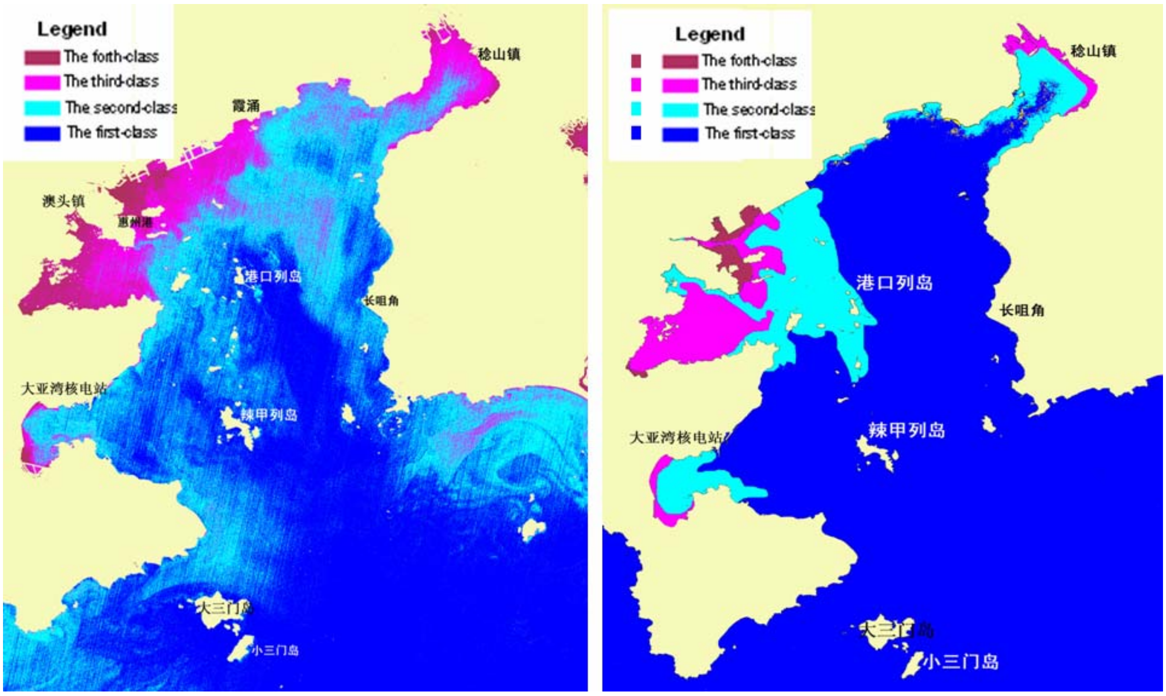

Figure 2.4-1 Water quality status of Daya Bay (PRWCRSI, 2009)

(2) Aggravating fragmentation of ecosystem

Now in Daya Bay, the fragmentation of natural ecosystem is aggravating: important ecological buffer area is compressed; key ecological transition zone, node and ecological channel is badly damaged; the area of important function zone is reduced rapidly; biodiversity is keeping lost; etc.

(3) Severe recession of Marine biological resources

The species of plankton, benthic and intertidal organisms have obvious succession; large seaweed field areas are gradually narrowing; the fish caught is changing to small size, low age and low economic value.

(4) More and more frequent appearance of red tide

The characteristics of Daya Bay's red tide events are changing from sporadic and transient to frequent and continuing. According to statistic data, during1983 ~ 2006 Huizhou City monitored 14 times of red tides on large scale. The frequency of red tide showed clear ascendant trend since 1998. In near nine years, Daya Bay had more than 10 times of red tide event.

Chapter 3 Indicative pollutants of TWLC and their discharge amounts

3.1 Selection of Indicative pollutants

The determination of indicative pollutants of TWLC is the basis of the calculation of environmental capacity and the establishment of pollutants reduction schemes as well as the supervising of the implementation of TWLC. The selection of indicative pollutants should obey following principles:

(1) Choose the pollutants that usually are included in routine monitoring by ocean management agency and are considered in the plan of marine pollution control and treatment by government and relevant agencies.

(2) Choose the pollutants that usually are included in routine monitoring by environmental protection agency and are used as indicative pollutants in environmental management and pollution control by government and relevant agencies.

(3) Choose the pollutants which correspond to the characteristics of Daya Bay's water pollution problem and are able to reflect the pollution degree of Daya Bay.

(4) Choose the pollutants which can reflect the current status and the trend of pollutants discharge and dominate the water quality of Daya Bay.

(5) Choose the pollutants contained in *National Sea water Quality Standard* (MEPPRC, 1997) and *Integrated wastewater discharge standard* (MEPPRC, 1996).

Organic pollution and eutrophication are the most severe environmental problems in Daya Bay area. So COD (chemical oxygen demand), N and P are the pollutants focused by local government. However, there are some conflicts among above principles. In China's *National Sea water Quality Standard*, COD determined by potassium permanganate method (COD_{Mn}), dissolved inorganic nitrogen (DIN) and reactive phosphate (PO_4^-) are used as indicative pollutants. But in environmental protection agency's routine monitoring and in China's *Integrated wastewater discharge standard*, COD determined by potassium dichromate method (CODcr), nitrogen existed as ammonia (NH_3-N) and reactive phosphate (PO_4^-) are used as indicative pollutants.

Because in practical TWLC usually aims at domestic and industry pollution control and reduction, CODcr, NH_3-N and PO_4^- are selected as indicative pollutants for the convenience of management. But the calculation results of environmental capacity are presented as COD_{Mn}, DIN and PO_4^- due to sea water quality standard is an indispensable condition in the calculation. So transfer coefficients between COD_{Mn} and CODcr, DIN and NH_3-N should be determined.

To determine the transfer coefficient between CODcr and COD_{Mn}, COD values of Daya Bay's water samples were determined both by potassium permanganate method and by potassium dichromate method. The average value of ratios between COD_{Mn} and CODcr is used as the transfer coefficient, which is:

$$COD_{cr} = 2.7 * COD_{Mn}$$

To determine the transfer coefficient between DIN and NH_3-N, historical monitoring data for Daya Bay were analyzed and the average value of ratios between DIN and NH_3-N is used as the transfer coefficient, which is:

$$NH_3\text{-}N = 0.55 * DIN$$

3.2 Accounting of indicative pollutants discharge

Indicative pollutants produced from domestic life, industries, mariculture, livestock & poultry breeding and non-point sources which are the main pollution sources of Daya Bay area are accounted into the calculation of discharge amounts. Because the latest statistical data was updated to Year 2007 during the work period of Daya Bay project, data of 2007 were used for the calculation of "current" pollutants discharge amount. And Year 2007 was defined as the benchmark year to do the prediction of pollutants discharge amounts in planning period. The last year of "The 11th Five-year Plan (2006~2010)", "The 12th Five-year Plan (2011~2015)" and "The 13th Five-year Plan (2016~2020)", that is, Year 2010, 2015 and 2020, are selected as the plan years to do the prediction.

Five-year Plan is a kind of development policy with Chinese characteristics. The Five-Year Plans of China are a series of economic and social development initiatives from national level to county and even town level. The national Five-year Plan is made by the Chinese Communist Party through the plenary sessions of the Central Committee and national congresses (Wikipedia, 2009). And based on the national Five-year plan, governments at different levels will make their Five-year Plans. Five-year plan is a main reference for the making of other plans, including environmental planning and management.

3.2.1 Current discharge amounts of indicative pollutants

3.2.1.1 Domestic pollution

Pollutant-creating coefficients are used for the accounting of domestic pollution (Meng, 2008). Based on the national and regional survey of pollutants production situation, including the population covered by the survey, the lifestyle, level of consumption and water usage, the discharge way of wastewater, the proportion of wastewater going into treatment plant, the concentration of pollutants before and after treatment etc., national average and regional average pollutants discharge amount produced by a person per in a day can be calculated, which are used as pollutant-creating coefficients. According to the results of surveys and experiments done at Huizhou City and Shenzhen City (SCIES, 2005), the pollutant-creating coefficients adopted for Daya Bay area are listed in Table 3.2-1.

To multiply the pollutant-creating coefficients by the population of each district (SBHZ, 2007) (SBLD, 2007), the discharge amount of indicative pollutants from domestic pollution sources can be calculated, and the results are presented in Appendix I table I-1.

Table 3.2-1 Pollutant-creating coefficients of domestic life for Daya Bay area (Unit: gram per person per day)

	CODcr	NH_3-N	PO_4^-
City and town	64.8	4.48	0.21
Country	62.5	4	0.21

3.2.1.2 Industrial pollution

The data of pollutants discharge amounts from industries of Daya Bay Economy and Technology Development Zone and Huidong County, and data of Longgang District, are provided by Huizhou Municipal Environmental Protection Bureau() and Shenzhen Municipal Environmental Protection Bureau(), respectively. The results are listed in Appendix I Table I-2.

3.2.1.3 Mariculture pollution

Pollutant-creating coefficients are used for the accounting of mariculture pollution. A lot of researches have been done at the Dapengao Cove of Daya Bay to investigate the pollution problems caused by mariculture by different scientific institutions before the launch of Daya Bay project, and many papers have been published. The pollutants-creating coefficients of mariculture for Daya Bay area adopt the research results gained at Dapengao Cove (Wang et al., 2003), as shown in Table 3.2- 2.

To multiply the pollutant-creating coefficients by the mariculture yield of each district (SBHZ, 2007) (SBLD, 2007), the discharge amount of indicative pollutants from mariculture can be calculated, and the results are presented in Appendix I Table I-3.

Table 3.2-2 Pollutant-creating coefficients of mariculture for Daya Bay area (Unit: kilogram per ton of marine product per year）

	CODcr	NH_3-N	PO_4^-
Pollutant-creating coefficient	105	7.3	6.94

3.2.1.4 Livestock and poultry breeding pollution

Table 3.2-3 shows the pollutant-creating coefficients used for the accounting of livestock and poultry breeding pollution. Table 3.2-4 shows the transfer coefficients between pig and other kinds of animals. All of these data are adopted from *Discharge standards of pollutants for livestock and poultry breeding of the People's Republic of China* (MEPPRC, 2001).

By using the transfer coefficients, the yields of different kinds of animals can be integrated and presented as the yield of pig. And then to multiply the pollutant-creating coefficients by the pig yield of each district (SBHZ, 2007) (SBLD, 2007), the discharge amount of indicative pollutants from livestock and poultry breeding can be calculated, and the results are presented in Appendix I Table I-4.

Table 3.2-3 Pollutant-creating coefficients of livestock and poultry breeding

Pollutant-creating coefficients（gram per pig per day）			Breeding period (day)
CODcr	NH_3-N	PO_4^-	
133.7	10.82	0.68	199

Table 3.2-4 Transfer coefficients between different kinds of animals and pig

	Cattle	Sheep	Chicken, duck and goose
Pig	5	1/3	1/60

3.2.1.5 Non-point source pollution

Nowadays non-point source pollution has been considered as one of the most important reasons of water quality degradation, especially for urban areas. During dry days, natural and human-made pollutants are deposited on the ground surface and accumulated. The dirty surface was flushed by rainfall or snowmelt moving over and through the ground, and the contaminants were picked up and carried away by the movement of runoff, and finally be deposited into different kinds of water body.

SWAT (Soil and Water Assessment Tool), a distributed hydrologic model developed by the Agricultural Research Service of United States Department of Agriculture (USDA), which integrated with geographic information system and remote sensing, was used by the Daya Bay project for the estimation of non-point source pollution load.

Based on 10m resolutions DEM (Digital Elevation Model) of the study catchment, GIS delineated the catchment basin and further divided it into 43 sub-catchments (PRWCRSI, 2009)， as mentioned in part 2.2.1 and shown in Figure 2.2-2. The land use map of the catchment was obtained by remote sensing image processing system, as shown in Figure 3.2-1. Then based on the pollutant-output coefficients of different types of land use, pollutants output from non-point sources of each sub-catchment were calculated.

When pollutants transport from diffused sources to receiving water, there are many physical and chemical reactions in the process of transportation, such as the intercept of plants and soil, the infiltration into groundwater etc., not all pollutants outputted from non-point sources will enter receiving water. Thus, input coefficients should be used to calculate the amounts of pollutants that ultimately flow into water. Finally, by overlapping the catchment map and the administration map in MapInfo, non-point source pollution of each district can be calculated.

The main types of land use in Daya Bay area are listed in Table 3.2-5. And corresponding pollutant-output coefficients and pollutant-input coefficients (Daya Bay project, 2009a) are presented in Appendix I Table I-5 and Table I-6, respectively. The amount of pollutants entering water from non-point sources of each sub-catchment (Daya Bay project, 2009a) and of each district are showed in Appendix I Table I-7 and Table I-8, respectively.

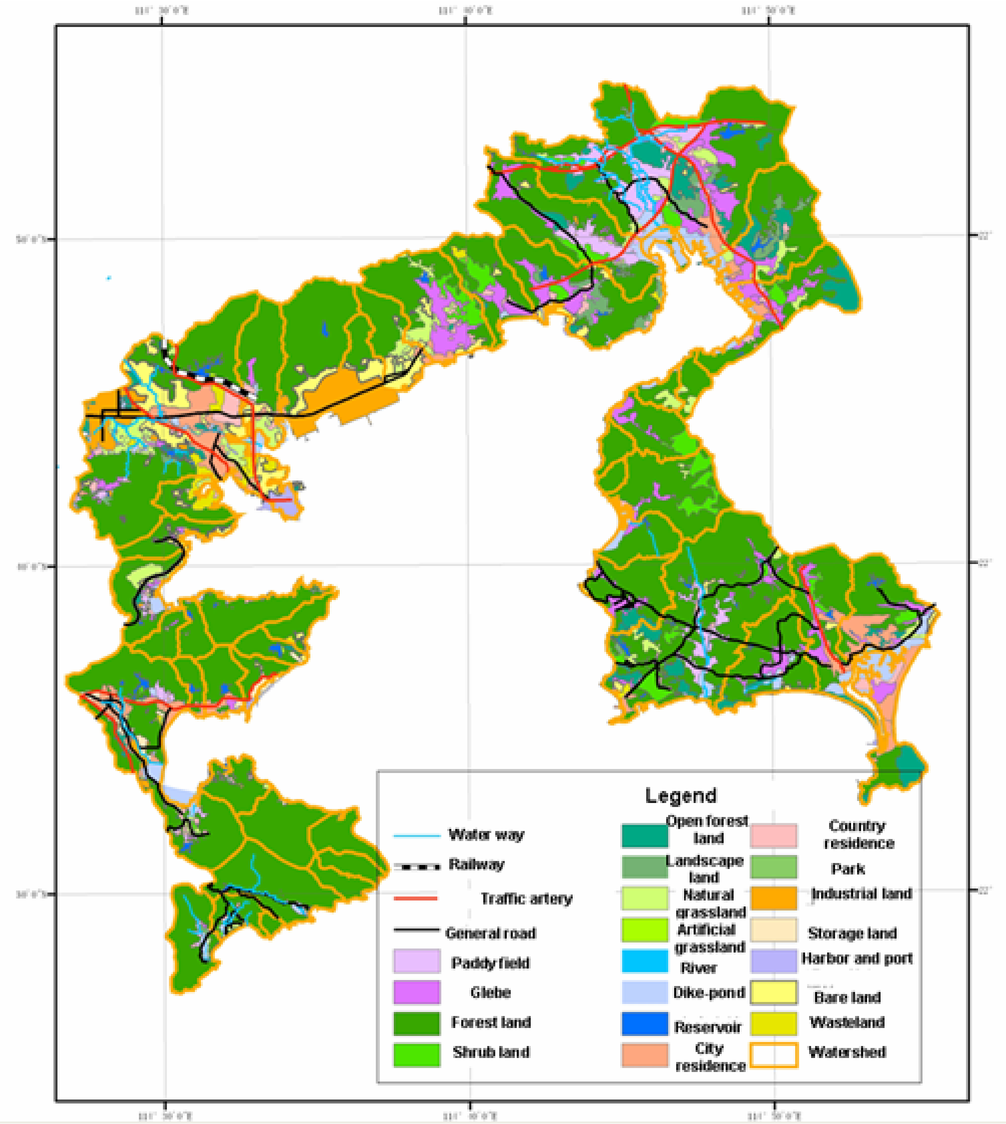

Figure 3.2-1 Land use map of Daya Bay catchment basin (PRWCRSI, 2009)

Table 3.2-5 Types of land use in Daya Bay area (Daya Bay project, 2009a)

Code	Land use type	Code	Land use type
A	Arable land	D	Unultilized land
A1	Paddy field	D1	Bare land
A2	Glebe	D2	Wasteland
B	Forest	E	Residential land
B1	Forest land	E1	City and Town
B2	Shrub land	E2	Country
B3	Open forest land	E3	Park
B4	Landscape land	F	Industrial land
C	Grassland	G	Traffic land
C1	Natural grassland	G1	Traffic artery
C2	Artificial grassland	G2	General roads

3.2.2 Prediction of indicative pollutants discharge amounts

3.2.2.1 The prediction of domestic pollution

The pollutants discharge amounts from domestic life was calculated via multiplying pollutant-creating coefficients by district population, so the pollutants discharge amounts are positively related to the district population. In case of there is no change for pollutant-creating coefficients in planning period, then the increase ratio of domestic pollution is equal to the growth rate of population.

By analyzing the population variation of each district in recent ten years (SBHZ, 2007) (SBLD, 2007), the average annual growth rate of population was obtained, as shown in Table 3.2-6. Based on the population forecast of each district, the pollutants discharge amount in every plan year can be calculated, as listed in Appendix I Table I-9~11.

Table 3.2-6 10-year average annual growth rate of population

District	Daya Bay Economy and Technology Development Zone	Huidong County	Longgang District
Average annual growth rate of population	7.36%	2.10%	5.80%

3.2.2.2 The prediction of industrial pollution

A common approach to predict the industrial pollutants emissions is the using of economic data, which is, to multiply the gross industrial output value by the pollutants amounts created per ten thousands yuan of industrial production value. Because Chinese government have paid more and more attention to environmental problems and keep to strengthen the supervision and control of pollution sources, it’s reasonable to believe that, in planning period, the pollutants amounts created per ten thousands yuan of industrial production value will be controlled effectively, and will be reduced gradually with the improvement of technological level and pollution treatment level. Adopting the conservative scenario, namely the pollutant-creating coefficients will constant in the planning period, then the increase ratio of industrial pollutants emissions will equal to the growth rate of gross industrial output value.

Table 3.2-7 presents the growth rate of gross industrial output value of each district (SBHZ, 2007) (SBLD, 2007) (SCIES, 2007). The prediction results of industrial pollutants emissions are presented in Appendix I Table I-12~14.

Table 3.2-7 Growth rate of gross industrial output value in planning period

District	Sub-district	Growth rate	
		2007~2010	2011~2020
Daya Bay Economy and Technology Development Zone	Petrochemical industry Region	51.12%	7.18%
	Other sub-districts	16.18%	7.18%
Huidong County		14.00%	14.00%
Longgang District		29.30%	29.30%

3.2.2.3 The prediction of mariculture pollution

As domestic pollution, the calculation of pollutants discharge amounts from mariculture is also by using pollutant-creating coefficients, and so the prediction is based on the forecast of mariculture yield of each district. In case of there is no change for pollutant-creating coefficients in planning period, then the increase ratio of mariculture pollution is equal to the growth rate of mariculture yield. Table 3.2-8 shows the growth rate of mariculture yield (SBHZ, 2007) (SBLD, 2007). The pollutants prediction results of mariculture are showed in Appendix I Table I-15~17.

Table 3.2-8 Growth rate of mariculture yield in planning period

District	Huizhou City		Longgang District		
	Daya Bay Economy and Technology Development Zone	Huidong County	Kuichong	Dapeng	Nanao
Average annual Growth rate of mariculture	7.5%	7.5%	6.07%	14.98%	2.65%

3.2.2.4 The prediction of livestock and poultry breeding pollution

As domestic and mariculture pollution, the calculation of pollutants discharge amounts from livestock and poultry breeding is by using pollutant-creating coefficients, too. Then if there is no change for pollutant-creating coefficients in planning period, the increase ratio of pollution is equal to the growth rate of livestock & poultry yield, as listed in Table 3.2-9 (SBHZ, 2007) (SBLD, 2007). The pollutants prediction results of livestock & poultry breeding are presented in Appendix I Table I-18~20.

Table 3.2-9 Growth rate of livestock & poultry yield

District	Daya Bay Economy and Technology Development Zone	Huidong County	Longgang District
Average annual growth rate of population	5.50%	5.50%	5.80%

3.2.2.5 The prediction of non-point sources pollution

The forming process of non-point pollution is affected by many factors such as regional geography, climate, soil structure, land use patterns, vegetation cover and precipitation process. So non-point pollution is characterized by big randomicity, wide distribution, complex formation mechanism etc. Generally speaking, waste load caused by non-point sources will change with land use types, utilization methods and technology levels. For districts with relatively high extent of development and exploitation, it's reasonable to say that the land use patterns and methods will not change significantly in the next several decades. In other words, in this thesis the waste load of non-point source pollution is treated as constant in planning period.

3.2.3 Summary

By adding up the pollutants discharge amounts from various pollution sources, the total CODcr, NH_3-N and PO_4^- discharge amounts of Daya Bay area in Year 2007, 2010, 2015 and 2020 can be obtained, as shown in Table 3.2-10~12. Figure 3.2-2, 3.2-3 and

3.2-4 present the contribution of various pollution sources for the total discharge amount of CODcr, NH_3-N and PO_4^- in different years, respectively. Figure 3.2-5 shows the contribution ratios of the three administrative districts for the total pollutants discharge amounts of catchment basin in terms of CODcr, NH_3-N and PO_4^-.

It's easy to know from Figures 3.2-2~4 that in terms of CODcr and NH_3-N, non-point pollution sources have the largest contribution for all the three districts. The contribution degree of non-point pollution sources will be reduced gradually in planning period but will still be the most dominant one. Mariculture and domestic pollution are also important sources on the whole. For Daya Bay Economy and Technology Development Zone, industry should be reckoned among important sources, both current and future. For Longgang District, the CODcr and NH_3-N contribution of industry is insignificant at current but the contribution degree will be increased in planning period. With respect to Huidong County, industry is not an important pollution source.

For PO_4^-, mariculture contributes most to the total discharge amount, followed by non-point sources, livestock and poultry breeding and domestic life. Other kinds of pollution sources are of no importance.

From Figure 3.2-5, it can be known that for the total pollutants discharge amounts of the whole Daya Bay catchment basin, Huidong Country contributes the largest part which is around 50%, and Daya Bay Economy and Technology Development Zone is the second-largest contributor. Longgang District contributes least to the total pollutants discharge amounts. Although the contribution degrees of districts will have small changes in planning period, the order will keep the same. The situations are the same for CODcr, NH_3-N and PO_4^-.

Table 3.2-10 Total CODcr discharge amount of Daya Bay area in different years (Unit: ton per year)

<table>
<tr><th>Administrative Districts</th><th>Subdistricts</th><th>2007</th><th>2010</th><th>2015</th><th>2020</th></tr>
<tr><td rowspan="7">Daya Bay Economy And Technology Development Zone</td><td>Western Region</td><td>4941.60</td><td>5477.36</td><td>6325.37</td><td>7516.36</td></tr>
<tr><td>Central Region</td><td>7905.25</td><td>8285.00</td><td>9064.51</td><td>10154.65</td></tr>
<tr><td>Harbor Region</td><td>1888.50</td><td>1935.16</td><td>2035.61</td><td>2176.00</td></tr>
<tr><td>Petrochemical Industry Region</td><td>2774.26</td><td>5008.45</td><td>6436.48</td><td>8453.35</td></tr>
<tr><td>Xiachong</td><td>3187.44</td><td>3423.84</td><td>3929.45</td><td>4636.17</td></tr>
<tr><td>Islands</td><td>2137.70</td><td>2655.65</td><td>3812.53</td><td>5473.38</td></tr>
<tr><td>Subtotal</td><td>22834.75</td><td>26785.46</td><td>31603.96</td><td>38409.91</td></tr>
<tr><td rowspan="3">Huidong County</td><td>Pinghai</td><td>23214.02</td><td>24293.40</td><td>26657.94</td><td>29992.48</td></tr>
<tr><td>Renshan</td><td>20823.63</td><td>21459.54</td><td>22844.75</td><td>24804.08</td></tr>
<tr><td>Subtotal</td><td>44037.66</td><td>45752.94</td><td>49502.68</td><td>54796.57</td></tr>
<tr><td rowspan="4">Longgang District</td><td>Kuichong</td><td>1811.26</td><td>1849.60</td><td>1930.40</td><td>2038.41</td></tr>
<tr><td>Dapeng</td><td>7987.06</td><td>8319.90</td><td>9766.81</td><td>14637.87</td></tr>
<tr><td>Nanao</td><td>7255.87</td><td>7322.18</td><td>7452.34</td><td>7612.62</td></tr>
<tr><td>Subtotal</td><td>17054.18</td><td>17492.24</td><td>19154.91</td><td>24320.45</td></tr>
<tr><td colspan="2">Total</td><td>83926.59</td><td>90030.64</td><td>100261.55</td><td>117526.92</td></tr>
</table>

Table 3.2-11 Total NH_3-N discharge amount of Daya Bay area in different years (Unit: ton per year)

Administrative Districts	Subdistricts	2007	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	209.70	238.62	288.58	358.52
	Central Region	312.34	336.35	388.61	461.44
	Harbor Region	71.27	74.69	81.99	92.15
	Petrochemical Industry Region	114.64	209.36	273.59	364.17
	Xiachong	138.08	154.80	190.82	241.03
	Islands	148.62	184.63	265.06	380.53
	Subtotal	994.65	1198.46	1488.65	1897.85
Huidong County	Pinghai	921.97	997.16	1161.24	1391.21
	Renshan	896.69	939.17	1030.09	1155.08
	Subtotal	1818.65	1936.32	2191.33	2546.30
Longgang District	Kuichong	59.80	62.47	68.10	75.62
	Dapeng	263.05	270.50	294.78	357.63
	Nanao	248.91	253.52	262.57	273.72
	Subtotal	571.76	586.50	625.50	707.24
Total		3385.07	3721.28	4305.47	5151.38

Table 3.2-12 Total PO_4^- discharge amount of Daya Bay area in different years (Unit: ton per year)

Administrative Districts	Subdistricts	2007	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	10.43	12.31	15.79	20.54
	Central Region	14.49	16.48	20.69	26.42
	Harbor Region	2.69	2.97	3.55	4.34
	Petrochemical Industry Region	5.11	8.78	11.64	15.62
	Xiachong	7.74	9.11	11.99	15.91
	Islands	141.38	175.64	252.15	362.00
	Subtotal	181.84	225.28	315.81	444.82
Huidong County	Pinghai	254.49	312.96	443.16	629.48
	Renshan	129.98	156.85	216.48	301.53
	Subtotal	384.47	469.81	659.64	931.01
Longgang District	Kuichong	9.41	11.13	14.78	19.68
	Dapeng	10.41	13.43	22.40	40.94
	Nanao	32.35	34.82	39.42	44.70
	Subtotal	52.17	59.38	76.59	105.31
Total		618.48	754.46	1052.04	1481.15

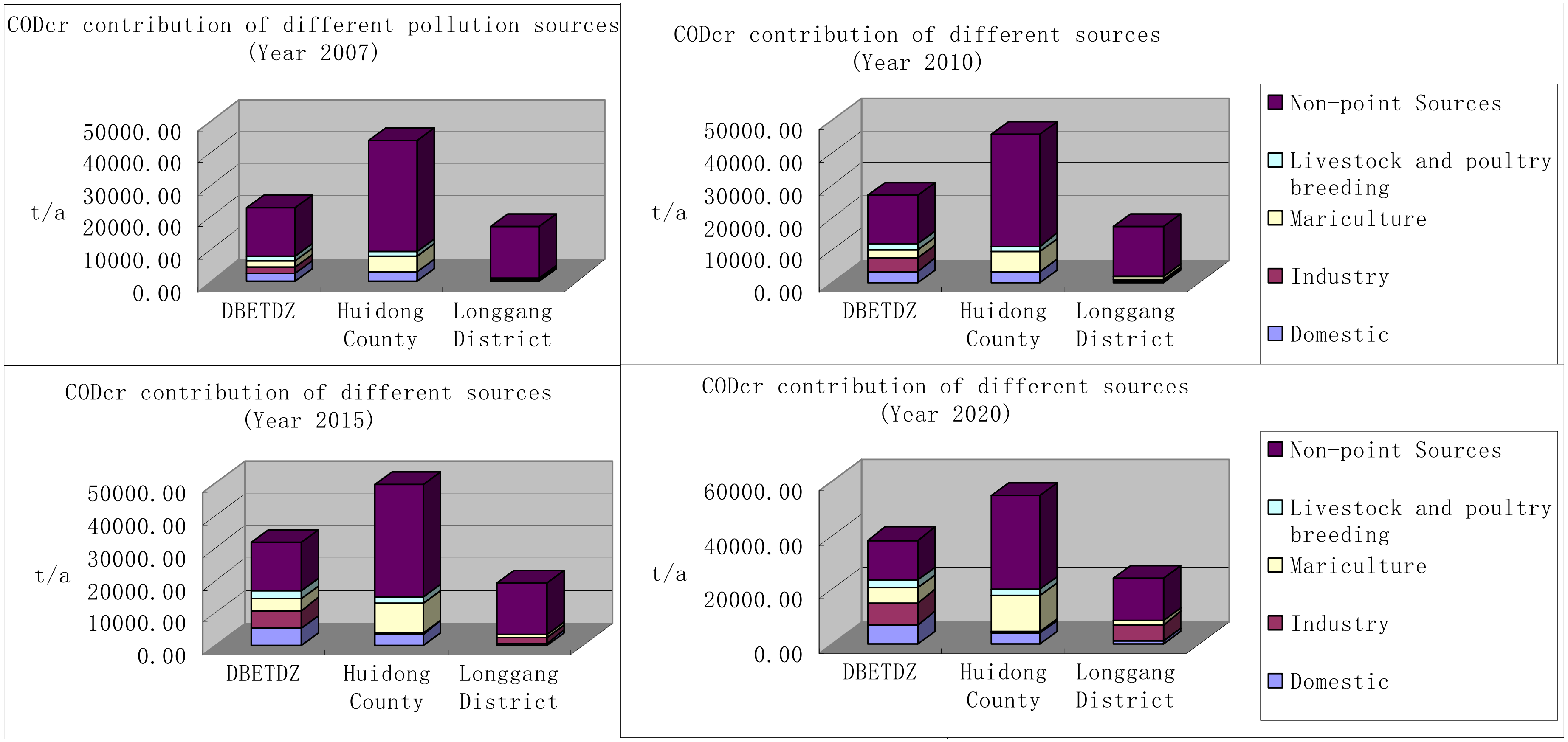

Figure 3.2-2 CODcr contribution of different pollution sources

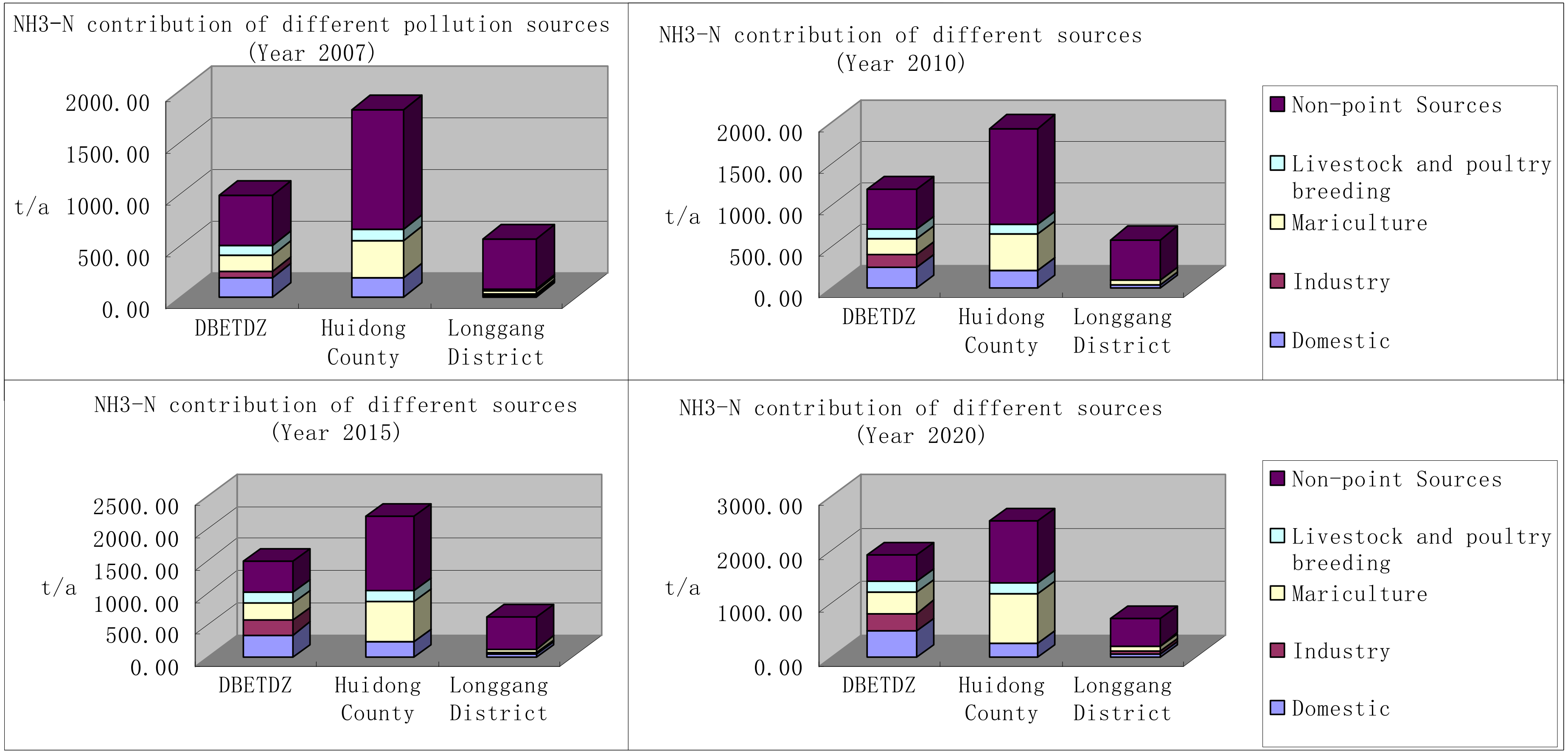

Figure 3.2-3 NH_3-N contribution of different pollution sources

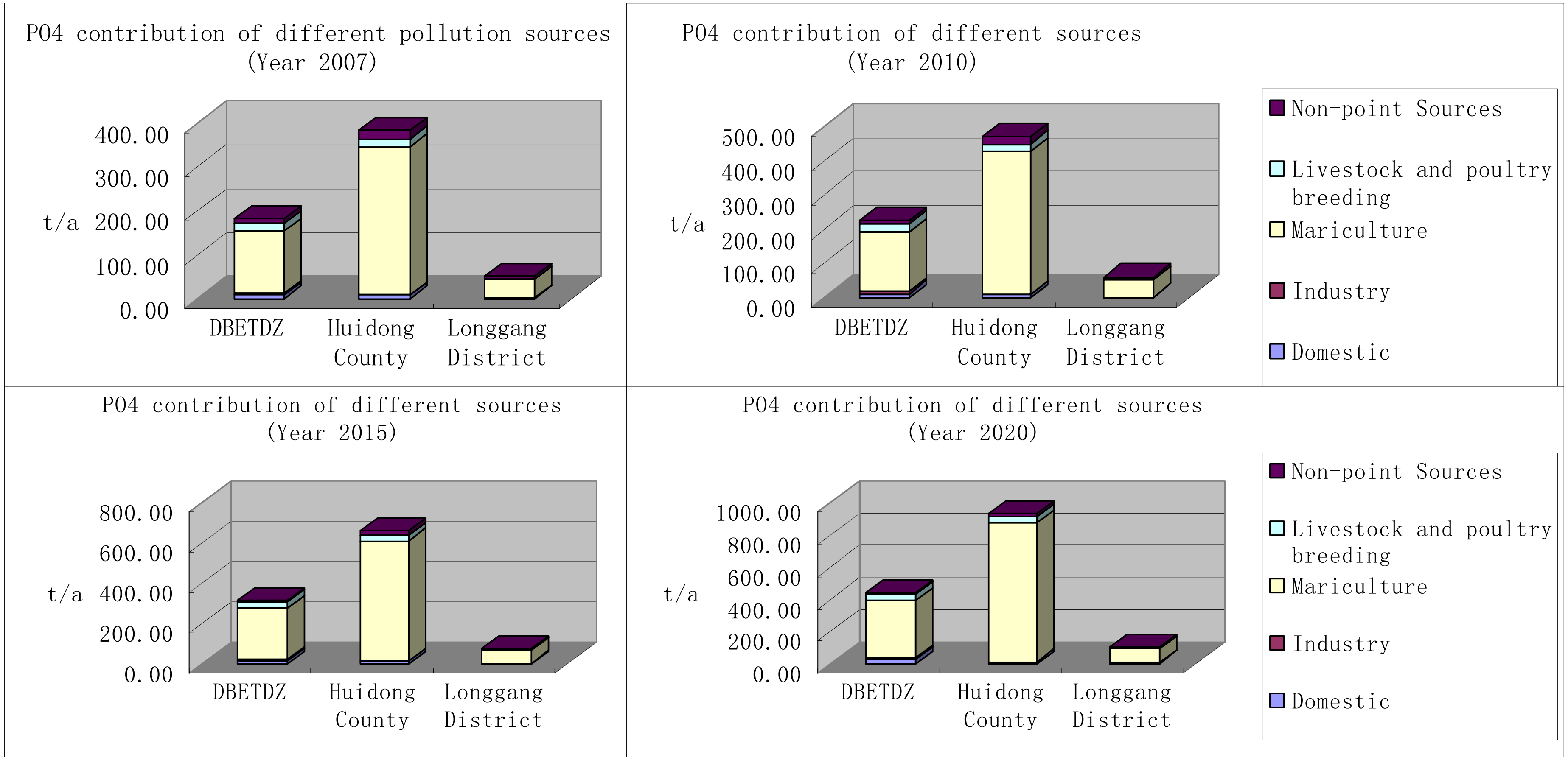

Figure 3.2-4 PO_4^- contribution of different pollution sources

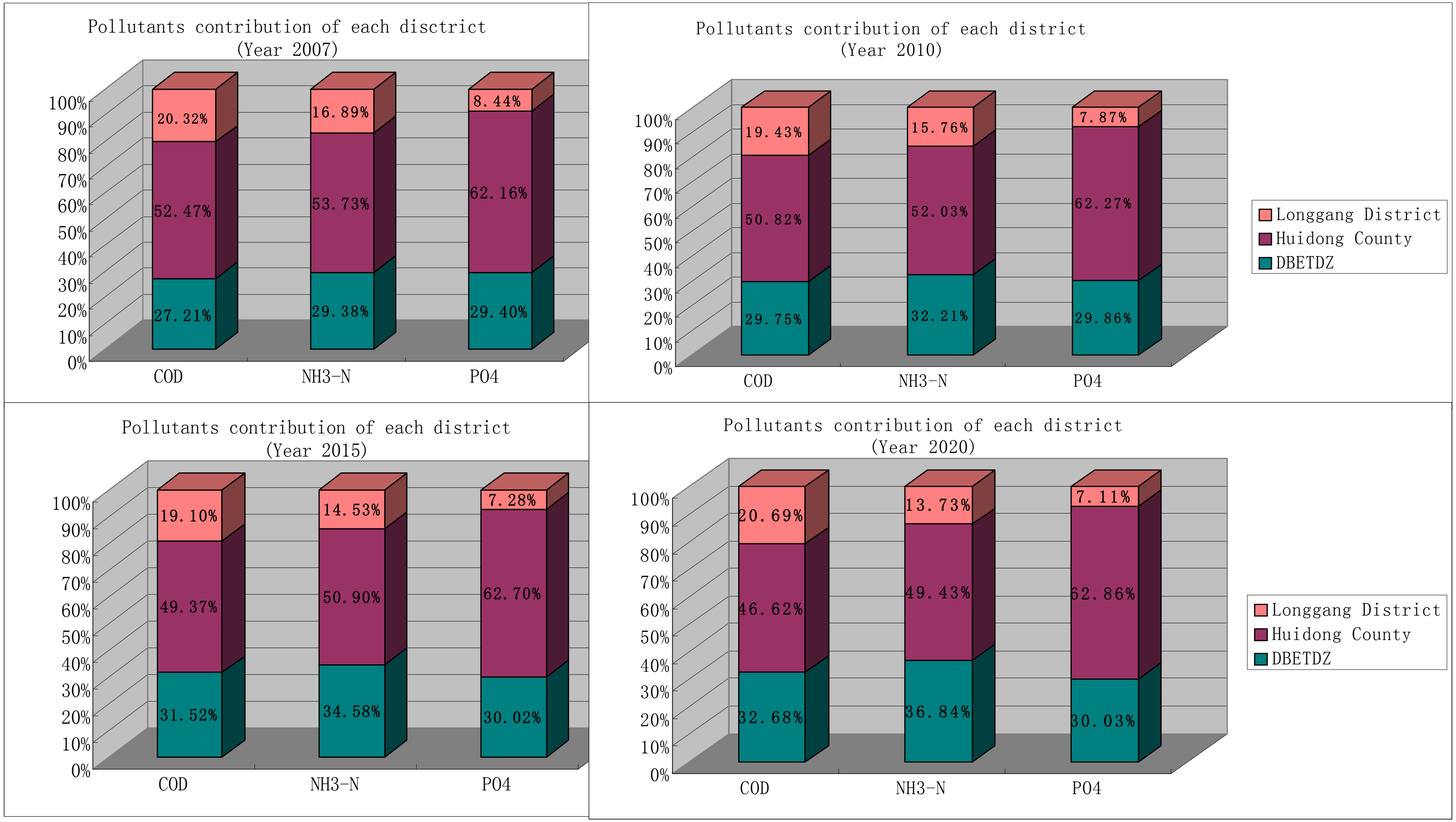

Figure 3.2-5 Contribution ratios of each administrative district

Chapter 4 Calculation of water environmental capacity

4.1 Introduction of calculation method

Water environmental capacity is defined as the maximum amount of waste load which is allowable to enter water from given discharge places under the precondition of complying with water quality standard (Wang et al., 2006). The numerical value of environmental capacity is decided by the self-purification ability, background pollutant concentration and water quality requirement of given place. Generally, for large catchment basin, the maximization of total environmental capacity is the objective of planning, so the environmental capacity of water body can be calculated by using following linear programming model (Li et al., 1999):

Objective $$\max TL = \sum_{i=1}^{n} x_i$$

Subject to $$TL = \sum_{i=1}^{m} x_i$$

$$\sum_{i=1}^{m} a_{ij} x_i + c_{bj} \le c_{sj} \qquad (j = 1, 2, \ldots, n)$$

$$x_i \ge 0 \qquad (i = 1, 2, \ldots, m)$$

Where TL is the total waste load which is allowed to discharge (equals to environmental capacity); x is the allowable waste load of wastewater outfall, i is the serial number of wastewater outfall, m is the number of wastewater outfall; a_{ij} is the input-response coefficient between wastewater outfall i and water quality control section j, n is the number of water quality control section; C_{bj} is the background concentration of pollutant at water quality control section j, C_{sj} is the water quality standard adopted at water control point j.

Input-response coefficient is one of the most important factors in the calculation of environmental capacity. The calculation method of input-response coefficient between wastewater outfall and water quality control section is: (1) suppose that there is one unit of pollutant, for example, 1t/d COD, inputting into water from wastewater outfall i, and both the COD inputs of other wastewater outfalls and COD background concentration are zero; (2) simulate the COD concentration distribution at the surface of water by hydrodynamic and water quality models, then the COD concentration value at water quality control section j is the input-response coefficient α_{ij} between wastewater outfall i and water quality control section j; (3) repeat step (1) and (2) for other wastewater outfalls; (4)obtain all the input-response coefficients and build the matrix $[\alpha_{ij}]$ (Li et al, 1999).

After obtaining the numerical value of all parameters needed, then the linear programming model can be calculated by the linear programming function (linprog) of

MatLab.

Here a hypothetical simple case is used to illuminate the calculation of environmental capacity. As shown in Figure 4.1-1, along the bank of a small river there are two wastewater outfalls named 1and 2. There are two water control sections L1 and L2. The values of input-response coefficients (Unit: $mg \cdot L^{-1} \cdot t^{-1} \cdot d$), pollutant background concentrations and water quality standards are listed in the figure.

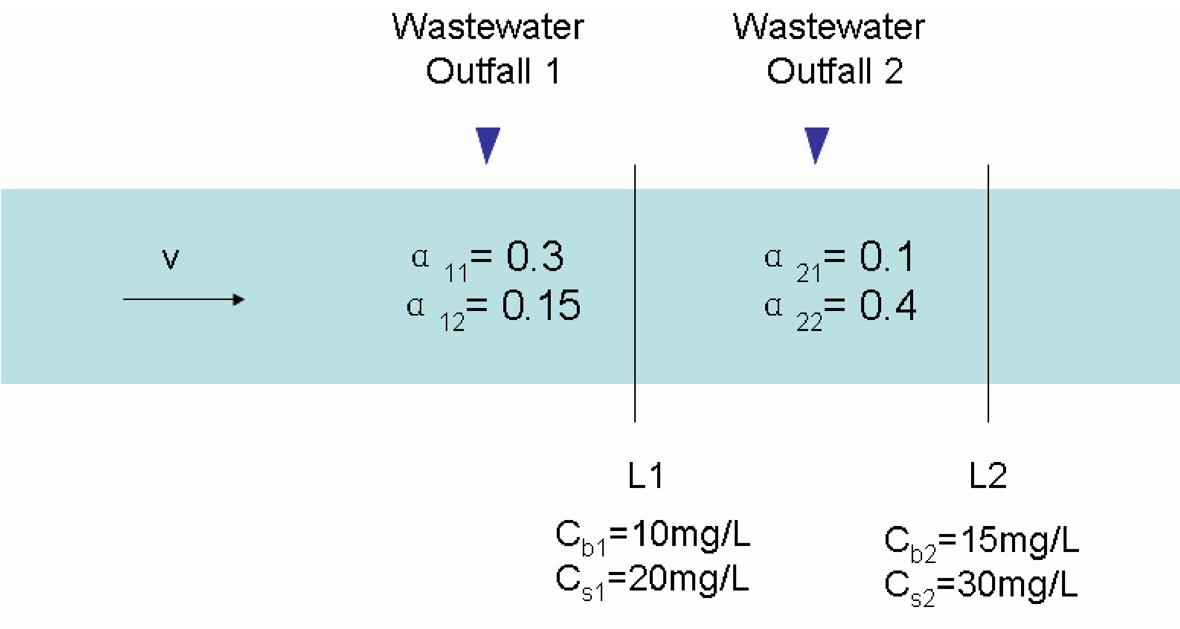

Figure 4.1-1 Hypothetical case

Then the linear programming equation is written as:

$$\text{Objective} \quad \max TL = x_1 + x_2$$

$$\text{Subject to} \quad \begin{cases} TL = x_1 + x_2 \\ \alpha_{11} x_1 + \alpha_{21} x_2 + C_{b1} \le C_{s1} \\ \alpha_{12} x_1 + \alpha_{22} x_2 + C_{b2} \le C_{s2} \\ x_1 \ge 0, x_2 \ge 0 \end{cases}$$

Writing the calculation program in MatLab and running it, as shown in Figure 4.1-2, the optimization result is:

$$x_1 = 23.8095t$$
$$x_2 = 28.5714t$$
$$TL = x_1 + x_2 = 52.3810t$$

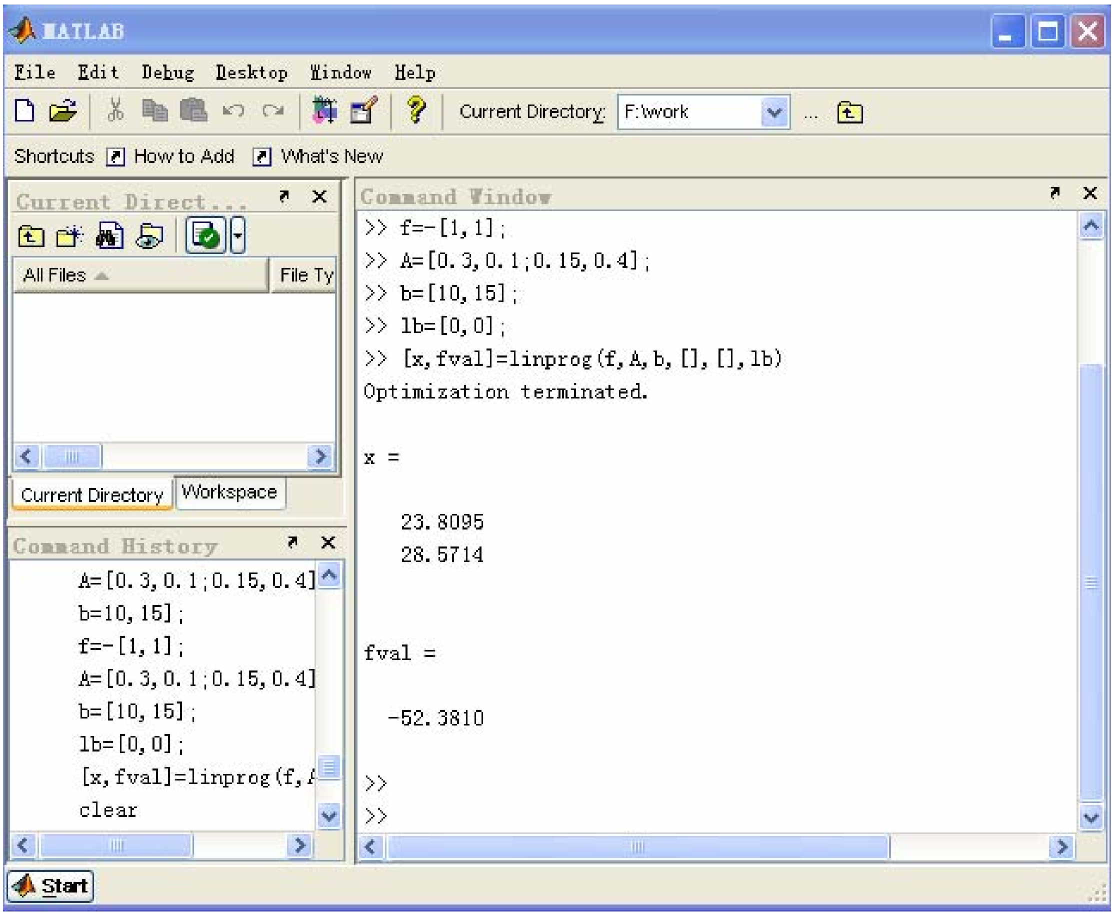

Figure 4.1-2 Optimization result by MatLab

4.2 Modeling of Daya Bay's water environment

The computation of input-response coefficient by using mathematical models is one of the most important steps in the calculation of environmental capacity, which is not the work of this master thesis. The Daya Bay project built the hydrodynamic and water quality models suited for Daya Bay on the basis of comprehensive investigation of Daya Bay's oceanic environment and historical research results for this area. The hydrodynamic and water quality models were constructed and operated by two PHD students who major in ocean modeling and there was an independent technical report to illustrate the detailed processes of model construction, simulation and calibration and the calculation of input-response coefficients and environmental capacity. The next parts of this section are general overviews of the modeling.

4.2.1 Hydrodynamic modeling

ECOMSED (estuaries and coastal ocean model with sediment module) is used to simulate the hydrodynamic conditions of Daya Bay. ECOMSED has a long history of successful applications to oceanic, coastal, and estuarine waters. It was originally developed for application to marine and freshwater systems by HydroQual, an ENR Environmental 200 firm (HydroQual n.d.).

According to the introduction document of USEPA *ECOMSED: Estuary and*

Coastal Ocean Model with Sediment Transport, "ECOMSED is a three-dimensional hydrodynamic and sediment transport model. The hydrodynamic module solves the conservation of mass and momentum equations with a 2.5-level turbulent closure scheme on a curvilinear orthogonal grid in horizontal plane and σ-coordinate in the vertical direction. Water circulation, salinity, and temperature are obtained from the hydrodynamic module. The sediment transport module computes the sediment settling and resuspension processes for both cohesive and noncohesive sediments under the impact of waves and currents. The hydrodynamic component is same as the ECOM3D/POM model." (USEPA n.d.)

The simulation period is from 2008-01-01 00:00 to 2009-02-01 00:00. Simulated results on 2008-09-12 and 2009-01-11 are calibrated by measured data on these two days. The calibration results proved that both in summer and winter the ECOMSED model modified by the project could well simulate the hydrodynamic conditions of Daya Bay. Because the package of calibration data and result is too big, it will not be given out in this master thesis.

Figure 4.2-1~4 (Daya Bay project, 2009b) present the simulation results of surface current, surface residual current, surface & bottom temperature and surface salinity distribution on 2008-09 (stands for summer) and 2009-01 (stands for winter), respectively. The values used in figures are of monthly average.

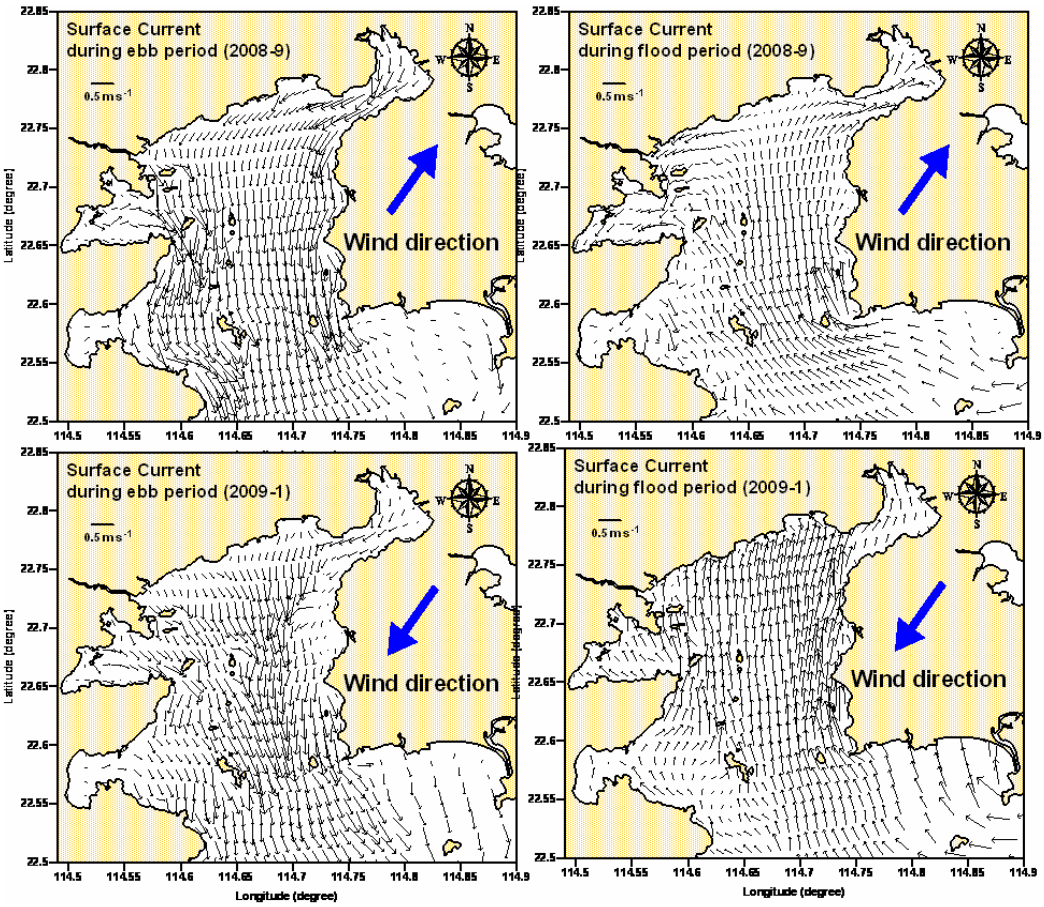

Figure 4.2-1 Surface current during ebb and flood period

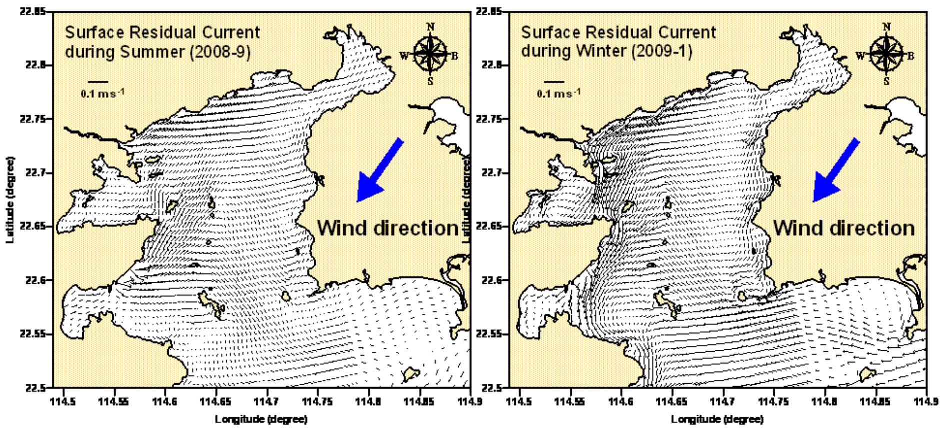

Figure 4.2-1 Surface residual current during summer and winter

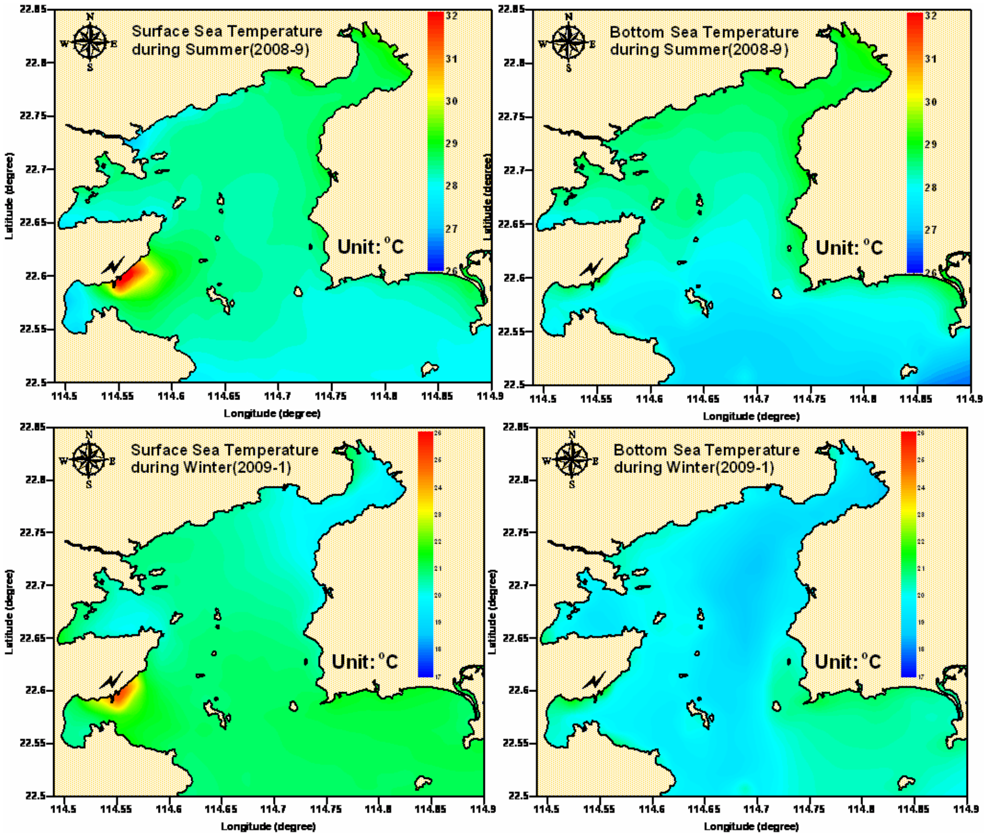

Figure 4.2-3 Surface and bottom temperature in summer and winter

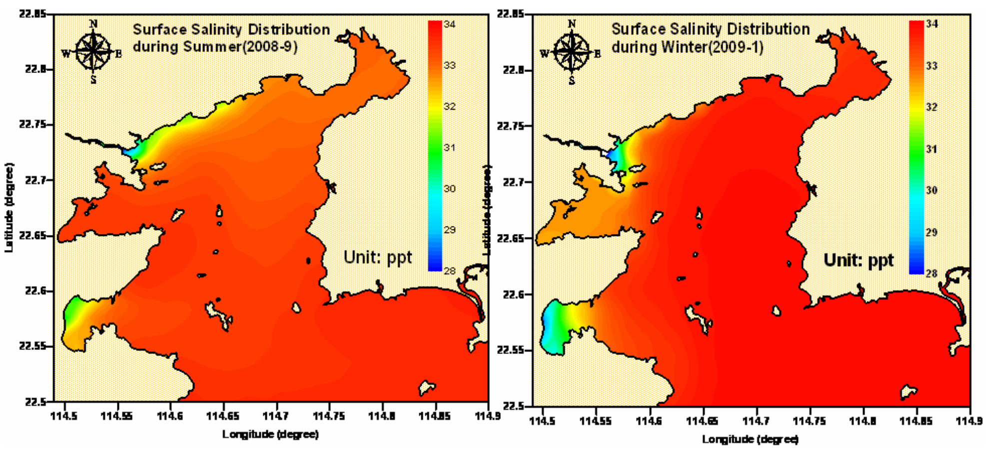

Figure 4.2-4 Surface salinity distribution during summer and winter

4.2.2 Water quality modeling

RCA, a Row-Column version of AESOP was used to simulate water quality of Daya Bay. AESOP is a water quality modeling code originated from WASP model of USEPA and is developed by HydroQual. By using mass conserving finite difference techniques, RCA has been applied to simulate the fate and transport of conventional and toxic pollutants in lakes, rivers, estuaries, and coastal systems. RCA was developed to directly interface with ECOMSED which provided information about the advective and dispersive transport fields (Fitzpatrick, 2004).

RCA includes five interactive systems: DO, nitrogen cycle, phosphorus cycle, carbon cycle (including the growth of phytoplankton) and silicon cycle. Figure 4.2-5 is the conceptual framework of RCA model.

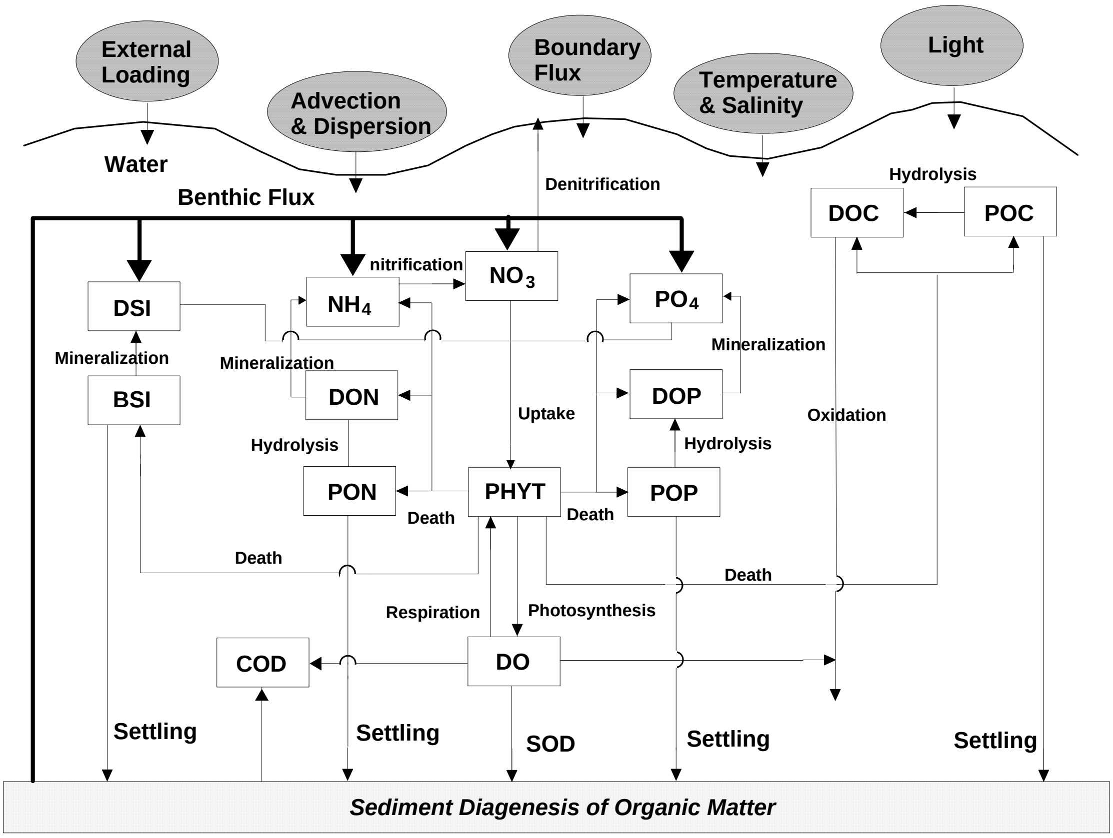

Figure 4.2-5 Conceptual framework of RCA ecosystem dynamics model (Modified from Fitzpatrick, 2004)

As illuminated in *User's Guide for RCA (Release 3.0)*, RCA

"…formulates mass balance equations for each model segment for each water quality constituent or state-variable of interest. The conservation of mass accounts for all of a material entering or leaving a body of water, transport of the material within the water body, and physical, chemical and biological transformations of the material. For an infinitesimal volume oriented along the axis of a three-dimensional coordinate system, a mathematical formulation of the conservation of mass may be written as:

$$\frac{\partial c}{\partial t}=\frac{\partial}{\partial x}\left(E_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(E_y\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(E_Z\frac{\partial c}{\partial z}\right)-U_x\frac{\partial c}{\partial x}-U_y\frac{\partial c}{\partial y}-U_z\frac{\partial c}{\partial z} \quad ,,$$

$$\pm S(x,y,z,t)+W(x,y,z,t)$$

Where c is concentration of the water quality variable (mg/L); t is time(s); E is dispersion (mixing) coefficient due to tides and density and velocity gradients (m^2 s^{-1}); U is advective velocity (m s^{-1}); S is sources and sinks of the water quality variable, representing kinetic interactions (mg l^{-1} s^{-1}); W is external inputs of the variable c (mg l^{-1} s^{-1}); x, y, z are longitudinal, lateral and vertical coordinates, respectively (Fitzpatrick, 2004).

Further information about water quality variables and their reaction equations used in RCA, as well as parameter values adopted for Daya Bay's water quality modeling, see Appendix II. Parameter values are established by two steps: firstly according to *User's Guide for RCA (Release 3.0)* and then calibrated by monitoring data.

Figure 4.2-6~8 (Daya Bay project, 2009b) present the simulation results of surface distribution of COD_{Mn}, DIN (dissolved inorganic nitrogen) and PO_4^- on 2008-09 and 2009-01, respectively. The values used in figures are of monthly average.

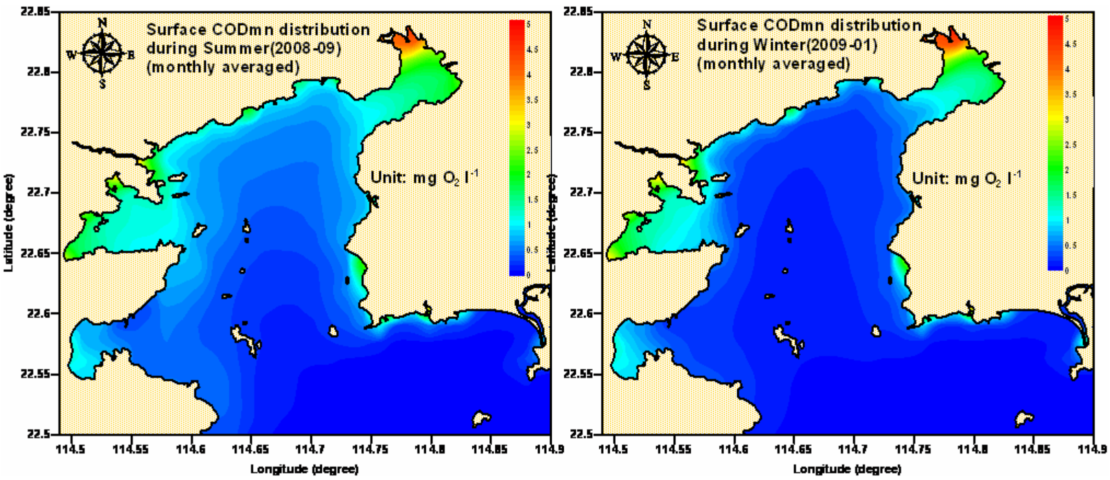

Figure 4.2-6 Surface COD_{Mn} distribution of during summer and winter

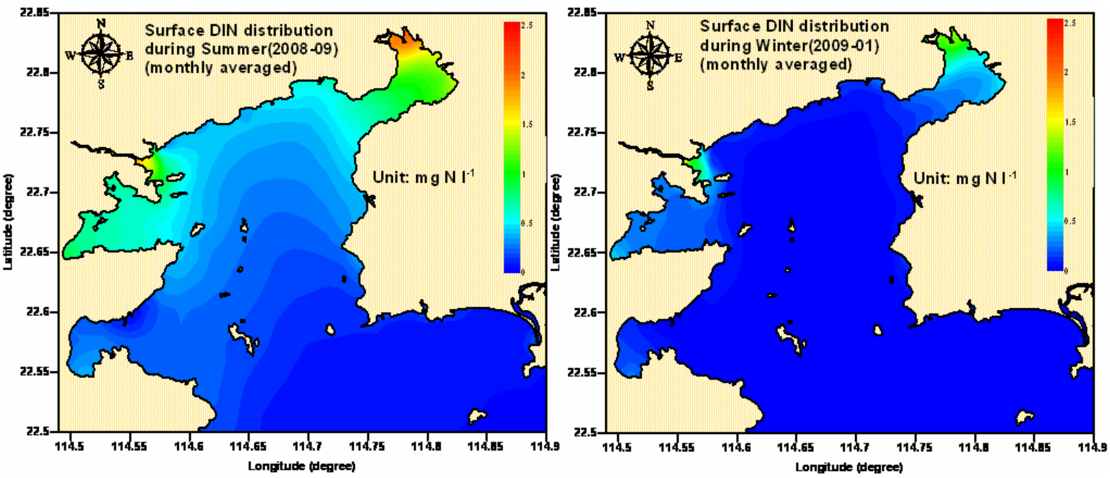

Figure 4.2-7 Surface DIN distribution of during summer and winter

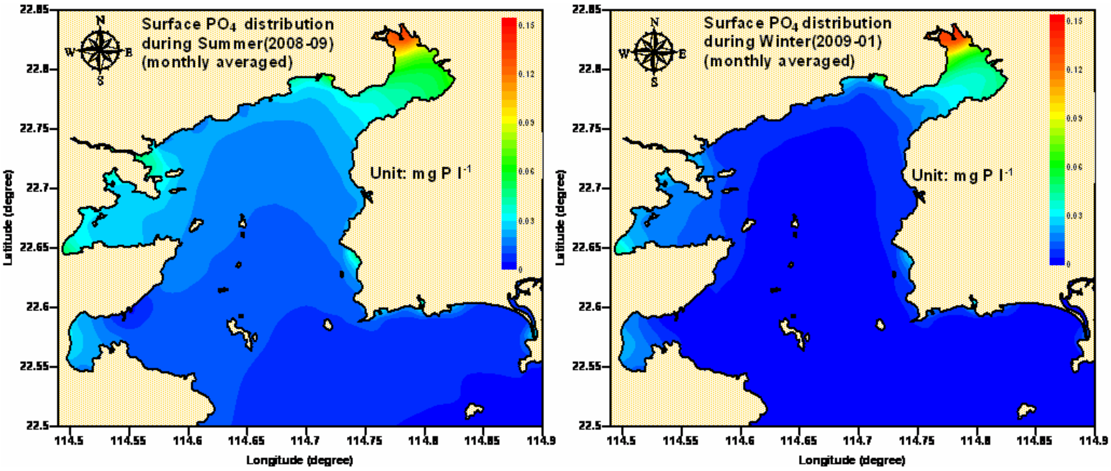

Figure 4.2-8 Surface PO_4^- distribution of during summer and winter

4.3 Calculation processes

4.3.1 The formulation of linear programming model

Objective $$\max TL = \sum_{i=1}^{n} x_i$$

Subject to $$TL = \sum_{i=1}^{m} x_i$$

$$\sum_{i=1}^{m} a_{ij} x_i + c_{bj} \le c_{sj} \qquad (j = 1, 2, \ldots, n)$$

$$x_i \ge 0 \qquad (i = 1, 2, \ldots, m)$$

The definition of each item is the same as the one in Section 4.1.

4.3.2 Setting of Wastewater outfalls

Wastewater outfall x in the linear programming model can be real or hypothetic ones. The scenario is that wastewater from a specified area in the catchment basin will be discharged at the places where wastewater outfalls are set.

When setting wastewater outfalls, following principles should be followed: (1) Wastewater outfalls must be set at the places which have real wastewater outfalls; (2) Wastewater outfalls must be set at the places which have planned pollution discharge; (3) Wastewater outfalls must be set at the mouths of rivers which directly flow into Daya Bay; (4) Each sub-catchment should have at least one wastewater outfall; (5) Each water function zone should have at least one wastewater outfall.

Based on these four principles, sixty wastewater outfalls are set for the catchment basin of Daya Bay, as shown in Figure 4.3-1 (not all wastewater outfalls are presented in the figure due to the zoom size of map in MapInfo) and listed in Appendix III Table III-1.

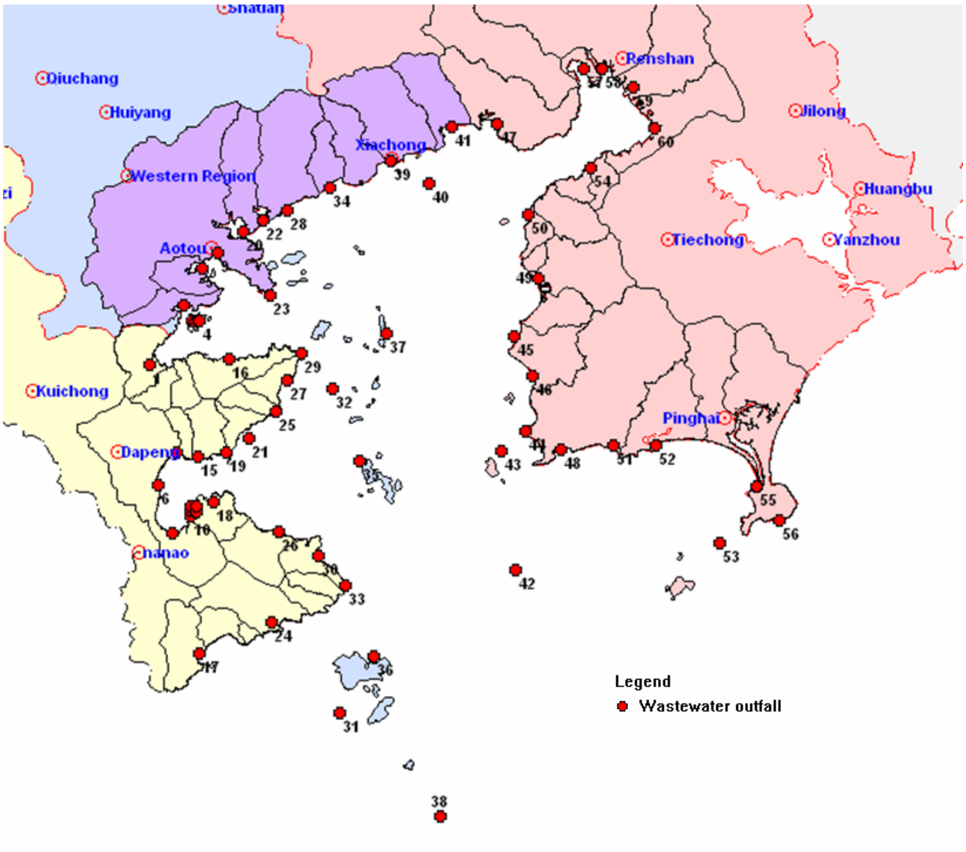

Figure 4.3-1 Distribution of wastewater outfalls set for the catchment basin of Daya Bay

4.3.3 Water quality control points and adopted standards

The purpose of setting water quality control points is to assure that the water quality standard of each water function zone will not be violated. Water quality control points should be set both at the boundary and in the interior of water function zone, as illustrated in Figure 4.3-2. Based on this principle, 339 water quality control points are set, as shown in Figure 4.3-3. There are 105 water quality control points adopting the first class of national sea water quality standard, 163 ones adopting the second class and 71 ones adopting the third class. Table 4.3-2 lists the value of Chinese sea water quality standard.

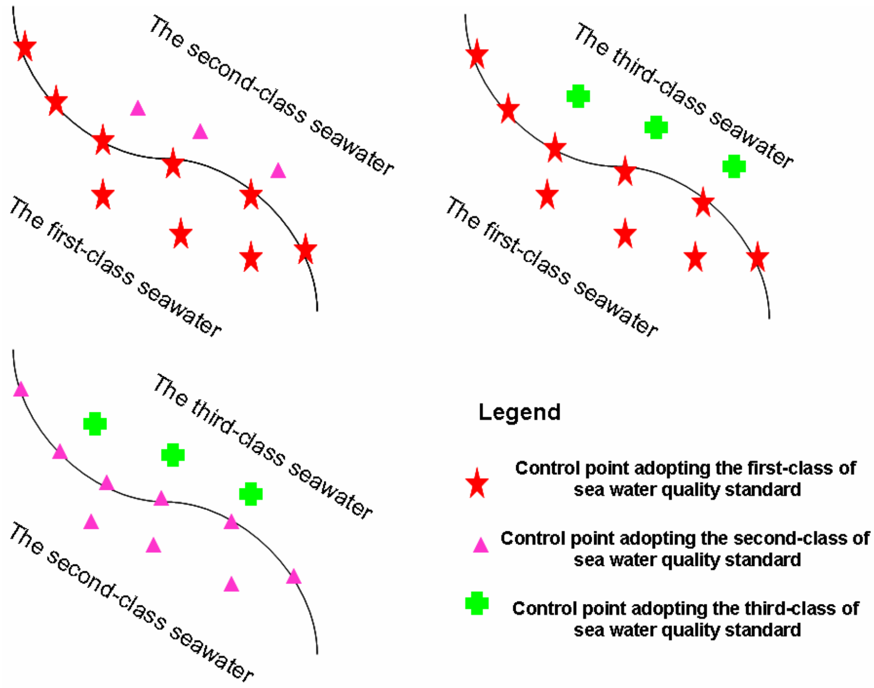

Figure 4.3-2 Principle of setting water quality control point

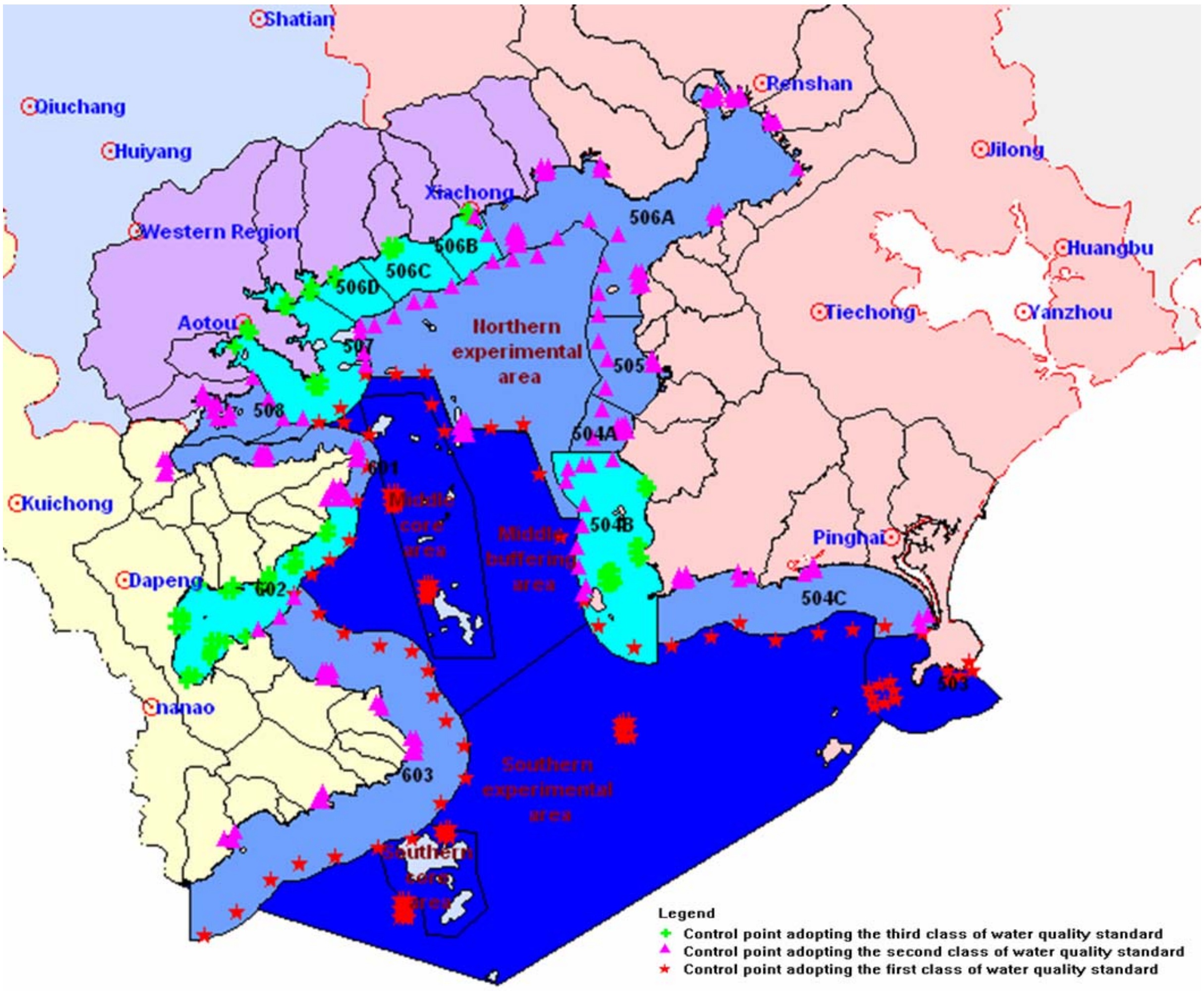

Figure 4.3-3 Distribution of water quality control points

Table 4.3-2 National sea water quality standard (MEPPRC, 1997)

	The first class	The second class	The third class
COD_{Mn}	<2mg/L	<3mg/L	<4mg/L
DIN	<0.20mg/L	<0.30mg/L	<0.40mg/L
PO_4^-	<0.015mg/L	<0.030mg/L	<0.030mg/L

4.3.4 Background concentration

The pollutant background concentration at each water quality control point is obtained by this way: Suppose there is no pollutant discharge into Daya Bay from its catchment basin, then pollutants existing in the sea water of Daya Bay are all come from open sea. External pollutants input are given at the outer boundary of Daya Bay, and then the transportation and transformation of these pollutants are modeled by ECOMSED and RCA, in succession from the simulation results of the pollutants concentration distributions at the surface of water the pollutants background concentration at each water quality control point can gained.

The data used for external pollutants input are obtained by analyzing the historical monitoring results for the outer boundary area and using the annual average value (Daya Bay project, 2009b).

Because the package of background concentration data is too big, it will not be given out in this master thesis.

4.3.5 Calculation of input-response coefficient

The calculation method of input-response coefficient has been explained in Section 4.1 and is not repeated here. Due to the package of background concentration data is too big which is a 339*60 matrix, it will not be given out in this master thesis.

4.4 Calculation results

The environmental capacity calculation result of each wastewater outfall in terms of COD_{Mn}, DIN and PO_4^- is presented in Appendix III Table III-2. By using the transfer coefficients defined in Section 3.1, environmental capacity calculation result of each wastewater outfall in terms of CODcr, NH_3-N and PO_4^- is presented in Table III-3.

Figure 4.4-1~3 are the distribution maps of environmental capacity in terms of CODcr, NH_3-N and PO_4^-, respectively. Compared three figures with each other, it can be known that the environmental capacity of CODcr, NH_3-N and PO_4^- have very similar distributions. From the figures it can be found that sea areas in the middle of Daya Bay and near the baymouth as well as the eastern shore have more environmental capacity than other places, which indicate that these places have better self-purification ability than other places.

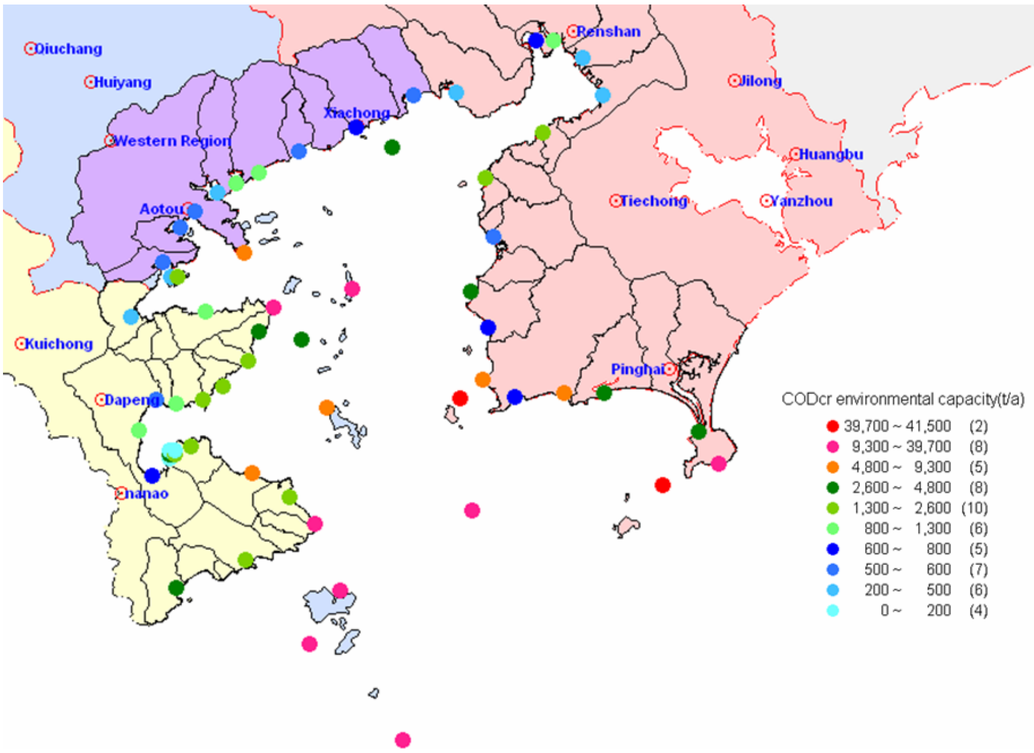

Figure 4.4-1 CODcr environmental capacity distribution map

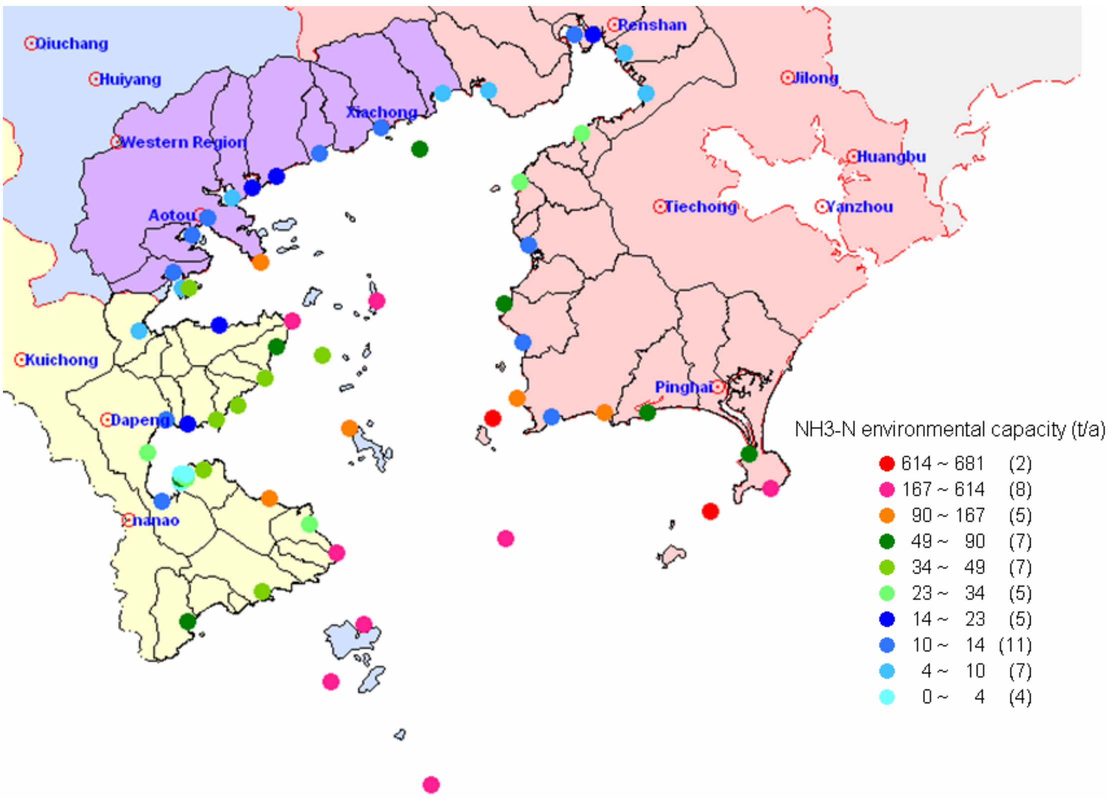

Figure 4.4-2 NH_3-N environmental capacity distribution map

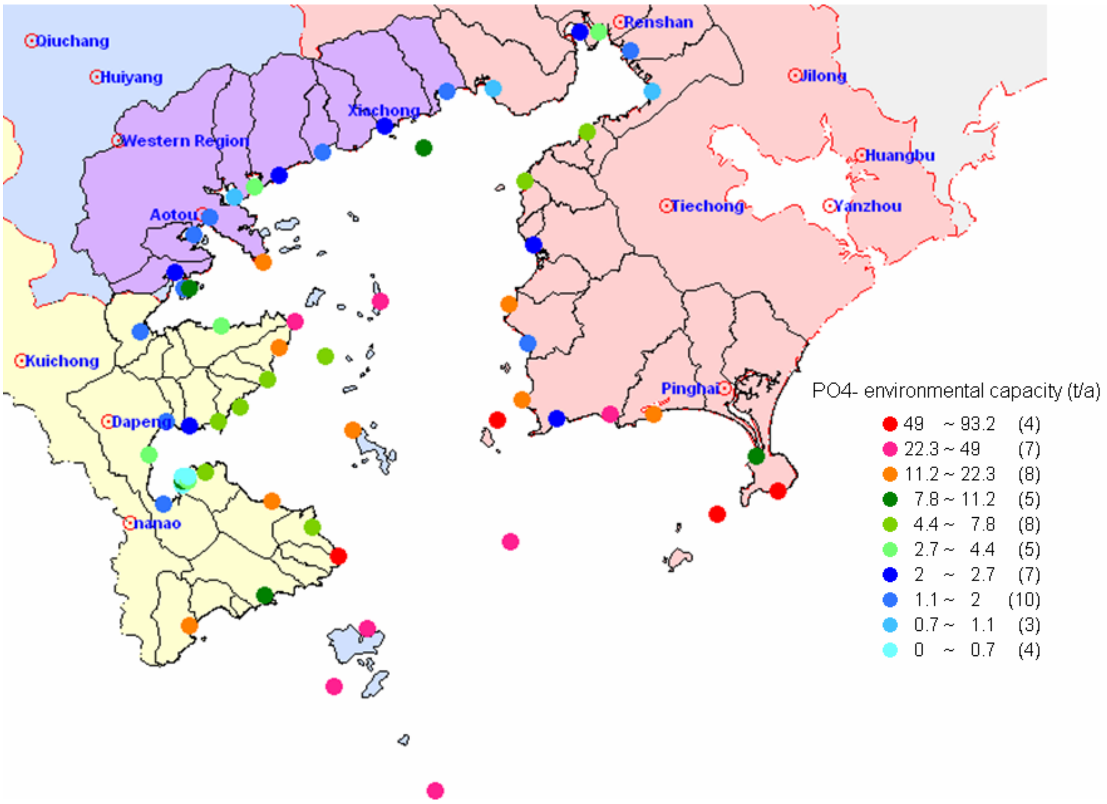

Figure 4.4-3 PO_4^- environmental capacity distribution map

Chapter 5 Allocation of environmental capacity among districts

TWLC makes no sense until environmental capacity is allocated to polluters and based on which control and reduction measures are implemented. Thus, the allocation of environmental capacity is one of the most important parts of TWLC and is also the precondition of the establishment of total waste load control schemes. Generally, the targets of environmental capacity allocation can be classified into two categories, districts and pollution sources (Meng, 2008). The allocation of environmental capacity among districts means that the water environmental capacity in terms of each indicative pollutant is allocated to administrative districts which lie in the catchment basin, and if necessary and possible, to sub-districts of these administrative districts. District is a kind of object that doesn't have direct behavior of pollutants discharging, and TWLC should be achieved via administrative means through restricting the discharge of pollutants by different polluters inside the district. The allocation of environmental capacity among polluters is not included in the content of this master thesis.

5.1 Allocation route

The allocation route of Daya Bay's environmental capacity among districts is shown in Figure 5.1-1. Firstly the environmental capacity of Daya Bay will be allocated to the three administrative districts at county level located in the catchment basin of Daya Bay: Daya Bay Economy and Technology Development Zone of Huizhou City, Huidong County of Huizhou City, and Longgang District of Shenzhen City. Then Daya Bay's environmental capacity will be allocated further to subdistricts.

For Huidong County and Longgang District, their administrative districts at town level which locate in the catchment basin of Daya Bay, that is, Renshan Town & Pinghai Town of Huidong County and Kuichong Subdistrict, Dapeng Subdistrict & Nanao Subdistrict, are used directly as the targets of allocation for subdistricts. With respect to Daya Bay Economy and Technology Development Zone, not its administrative districts at town level but its five industry-planning regions and the islands belonging to Daya Bay Economy and Technology Development Zone are selected as the allocation targets. The reason for the selection of industry-planning regions is that the environmental capacity allocation results will help local government make the economic & technological development plan scientifically based on the environmental capacity of each industry-planning region. Furthermore, the islands of Daya Bay Economy and Technology Development Zone are relatively independent objects compared with industry-planning regions, and so are also chosen as allocation targets.

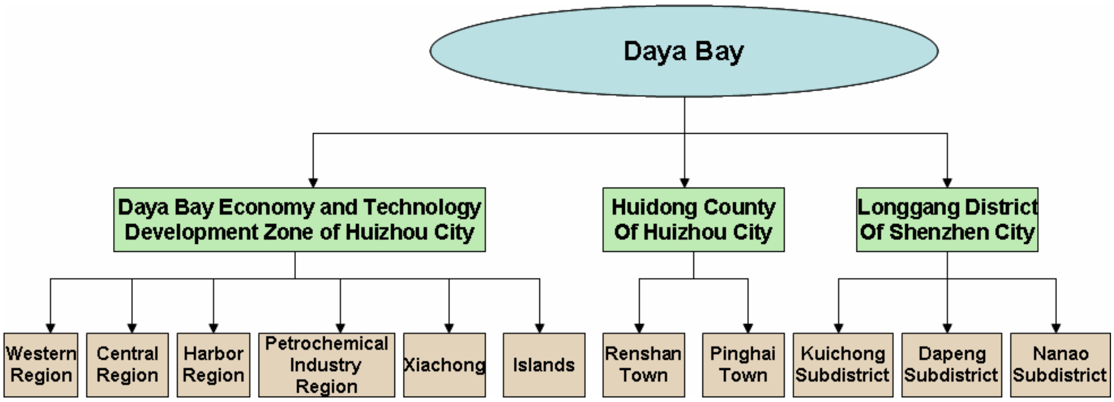

Figure 5.1-1: Route of environmental capacity allocation among districts

5.2 Allocation method

5.2.1 Districts without shared wastewater outfall

In order to allocate Daya Bay's environmental capacity to each district situated in the catchment basin, the corresponding relationship between districts and wastewater outfalls should be built. That's because environmental capacity is decided by the self-purification ability and water quality requirement of given place, in other words, a district's maximum pollutant amount which is allowable to emit into water is restricted by the locations of its wastewater outfalls. After defining the corresponding relationship between a district and its wastewater outfalls, the environmental capacity possessed by the district can be decided.

5.2.2 Districts with shared wastewater outfall

For two or more districts having common wastewater outfalls, the environmental capacity of these wastewater outfalls should be allocated based on some principles.

5.2.2.1 Current research results

USEPA recommended 19 kinds of allocation methods, as shown in table 2-1, which contained most research results of allocation methods until now.

Table 5.2-1: Recommended waste-load allocation methods (USEPA, 2008)

No.	Waste-load Allocation Methods
1	Equal percent removal (equal percent treatment)
2	Equal effluent concentrations
3	Equal total mass discharge per day
4	Equal mass discharger per capita per day
5	Equal reduction of raw load (pounds per day)
6	Equal ambient mean annual quality (mg/l)
7	Equal cost per pound of pollutant removed
8	Equal treatment cost per unit of production
9	Equal mass discharged per unit of raw material used
10	Equal mass discharged per unit of production
11a	Percent removal proportional to raw load per day
11b	Larger facilities to achieve higher removal rates
12	Percent removal proportional to community effective income
13a	Effluent charges (pounds per week)
13b	Effluent charge above some load limit
14	Seasonal limits based on cost-effectiveness analysis
15	Minimum total treatment cost
16	Best Available Technology (BAT for industry) plus some level for municipal inputs
17	Assimilative capacity divided to require an "equal effort among dischargers"
18a	Municipal: Treatment level proportional to plant size
18b	Industrial: equal percent between best practicable technology (BPT) and BAT
19	Industrial discharges given different treatment levels for different stream flows and seasons

5.2.2.2 Practical allocation methods

Although many research results about allocation methods have been published by now, these methods are usually operable in limited ranges due to the demands of abundant information of the region studied in many aspects, such as the distribution of natural resources, the states of society and economy, the kind and level of pollution treatment technology used, exact data about pollution sources, pollution treatment cost and benefit, and so on. For developed countries which have good information collection system and abundant statistic data, those complex and relative perfect allocation methods may be used in practical projects when the research area is not very big. However, for developing countries whose information collection and storage system are still far from perfect and for big practical projects covering with a large region, none but simplified and practical allocation methods will be adopted.

The most common used allocation methods are based on three "P": population, pollutants discharge amount and pollutants discharge right (Meng, 2008). Assume the environmental capacity need to be allocated among n districts, and then these three practical methods can be illustrated by the following common allocation formula:

$$W_i = k * W = \frac{P_i}{\sum_i^n P_i} * W \qquad (2\text{-}4)$$

Where W_i is the environmental capacity obtained by subdistrict i; k is called allocation factor; $k = \frac{P_i}{\sum_i^n P_i}$, P_i is the population / pollutants discharge amount / pollutants discharge right (usually decided by the supreme government of the region studied)of district i; W is the environmental capacity to be allocated.

5.3 Allocation results

5.3.1 For administrative districts at county level

There is no wastewater outfall shared by two or more administrative districts at county level. After defining the corresponding relationship between districts and wastewater outfalls, the no. of wastewater outfalls are renumbered according to the district to which they belong, for instance, DY1 means that it is a wastewater outfall of Daya Bay Economy and Technology Development Zone, HD1 possessed by Huidong and SZ1 belongs to Longgang District of Shenzhen City. Then the environmental capacity in terms of COD_{cr}, NH_3-N and PO_4^- is reckoned for each administrative district. The summarized result results are listed in Table 5.3-1 and the detailed allocation results are shown in Appendix III Table III 4-6.

Figure 5.3-1 presents the proportions possessed by each administrative district at county level of the total CODcr, NH_3-N and PO_4^-environment capacity of Daya Bay. It can be known that Daya Bay Economy and Technology Development Zone occupies the largest part of Daya Bay's environmental capacity in terms of CODcr, NH_3-N and PO_4^-. Huidong County has the second largest part which is not much less than Daya Bay Economy and Technology Development Zone. Longgang possesses the least part.

As mentioned in former part, environmental capacity is decided by the self-purification ability and water quality requirement of given place, and so a district's maximum pollutant amount which is allowable to emit into water is restricted by the locations of its wastewater outfalls. The different status of self-purification ability and water quality requirement of Daya Bay and the diverse distribution of wastewater outfalls, lead to the differences among environmental capacity allocation results.

Table 5.3-1 Environmental capacity allocation results for administrative districts at county level (Unit: ton per year)

Administrative district	CODcr	NH_3-N	PO_4^-
Daya Bay Economy and Technology Development Zone	118181.97	2000.67	275.40
Huidong County	104391.48	1670.73	269.07
Longgang District	56971.97	1054.96	187.64
Total	279545.42	4726.36	732.11

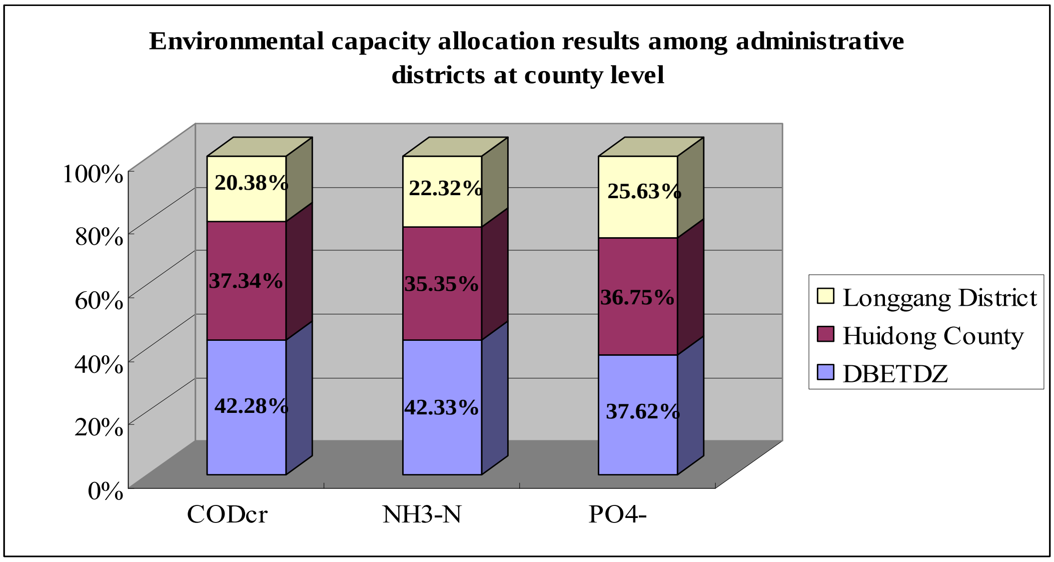

Figure 5.3-1 Proportion of each administrative district at county level

5.3.2 For subdistricts

5.3.2.1 Preliminary allocation

When allocating environmental capacity among subdistricts of each administrative district at county level, there are 6 wastewater outfalls shared by Western Region, Central Region and Harbor Region of Daya Bay Economy and Technology Development Zone. Here the preliminary allocation results are presented, Table 5.3-2 is the summarized result and detail allocation results are showed in Appendix III Table III 7~9. A further allocation among subdistricts with shared wastewater outfall will be explained in next part.

Table 5.3-2 Preliminary allocation results for subdistricts

Administrative district	Subdistrict	CODcr	NH_3-N	PO_4^-
Daya Bay Economy and Technology Development Zone	Western Region + Central Region + Harbor Region	9951.98	190.42	25.71
	Petrochemical industry Region	68231.46	1145.85	151.91
	Xiachong	3959.71	70.21	13.17
	Islands	36038.82	594.2	84.61
	Subtotal	118181.97	2000.67	275.40
Huidong County	Renshan Town	2676.92	44.62	8.18
	Pinghai Town	101714.56	1626.11	260.89
	Subtotal	104391.48	1670.73	269.07
Longgang District	Kuichong	1214.08	21.65	4.10
	Dapeng	21435.98	404.4	69.03
	Nanao	34321.91	628.91	114.51
	Subtotal	56971.97	1054.96	187.64
Total		279545.42	4726.36	732.11

5.3.2.2 Allocation among subdistricts with shared wastewater outfalls

As mentioned in part 5.2.2, the practical allocation method for districts with shared wastewater outfall can be based on three “P”: population, pollutants discharge amount and pollutants discharge right. Here the current pollutants discharge amounts are used to calculate the allocation factor k for Western Region, Central Region and Harbor Region. The accounting results of current pollutants discharge amounts and the calculation results of allocation factors are listed in Table 5.3-3 and Table 5.3-4, respectively. Table 5.3-5 shows the allocation results among subdistricts with shared wastewater outfalls

Table 5.3-3 Accounting results of current discharge amount of indicative pollutants for western, central and harbor region

Subdistrict	COD_{cr}（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
Western Region	4941.60	209.70	10.43
Central Region	7905.25	312.34	14.49
Harbor Region	1888.50	71.27	2.69

Table 5.3-4 Calculation results of allocation factors

Subdistrict	COD_{cr}（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
Western Region	0.335	0.353	0.378
Central Region	0.536	0.526	0.525
Harbor Region	0.128	0.120	0.098
Sum	1.000	1.000	1.000

Table5.3-5 Allocation results among subdistricts with shared wastewater outfalls

Subdistrict	COD_{cr}（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
Western Region	3337.46	67.30	9.71
Central Region	5339.06	100.24	13.49
Harbor Region	1275.46	22.87	2.50
Sum	9951.98	190.42	25.71

5.3.2.3 Final results

Summarized results of the final environmental capacity allocation among administrative districts and subdistricts are listed in Table5.3-6. Figure 5.3-2~4 present the proportions possessed by each subdistrict in the total CODcr, NH_3-N and PO_4^-environment capacity of its upper administrative district.

Table 5.3-6: Final allocation results of natural environmental capacity for administrative districts and subdistricts

Administrative Districts	Subdistricts	COD_{cr}（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
Daya Bay Economy And Technology Development Zone	Western Region	3337.46	67.30	9.71
	Central Region	5339.06	100.24	13.49
	Harbor Region	1275.46	22.87	2.50
	Petrochemical Industry Region	68231.46	1145.85	151.91
	Xiachong	3959.71	70.21	13.17
	Islands	36038.82	594.20	84.61
	Subtotal	118181.97	2000.68	275.40
Huidong County	Renshan Town	2676.92	44.62	8.18
	Pinghai Town	101714.56	1626.11	260.89
	Subtotal	104391.48	1670.73	269.07
Longgang District	Kongchong Subdistrict	1214.08	21.65	4.10
	Dapeng Subdistrict	21435.98	404.40	69.03
	Nanao Subdistrict	34321.91	628.91	114.51
	Subtotal	56971.97	1054.96	187.64
Total		279545.41	4726.37	732.11

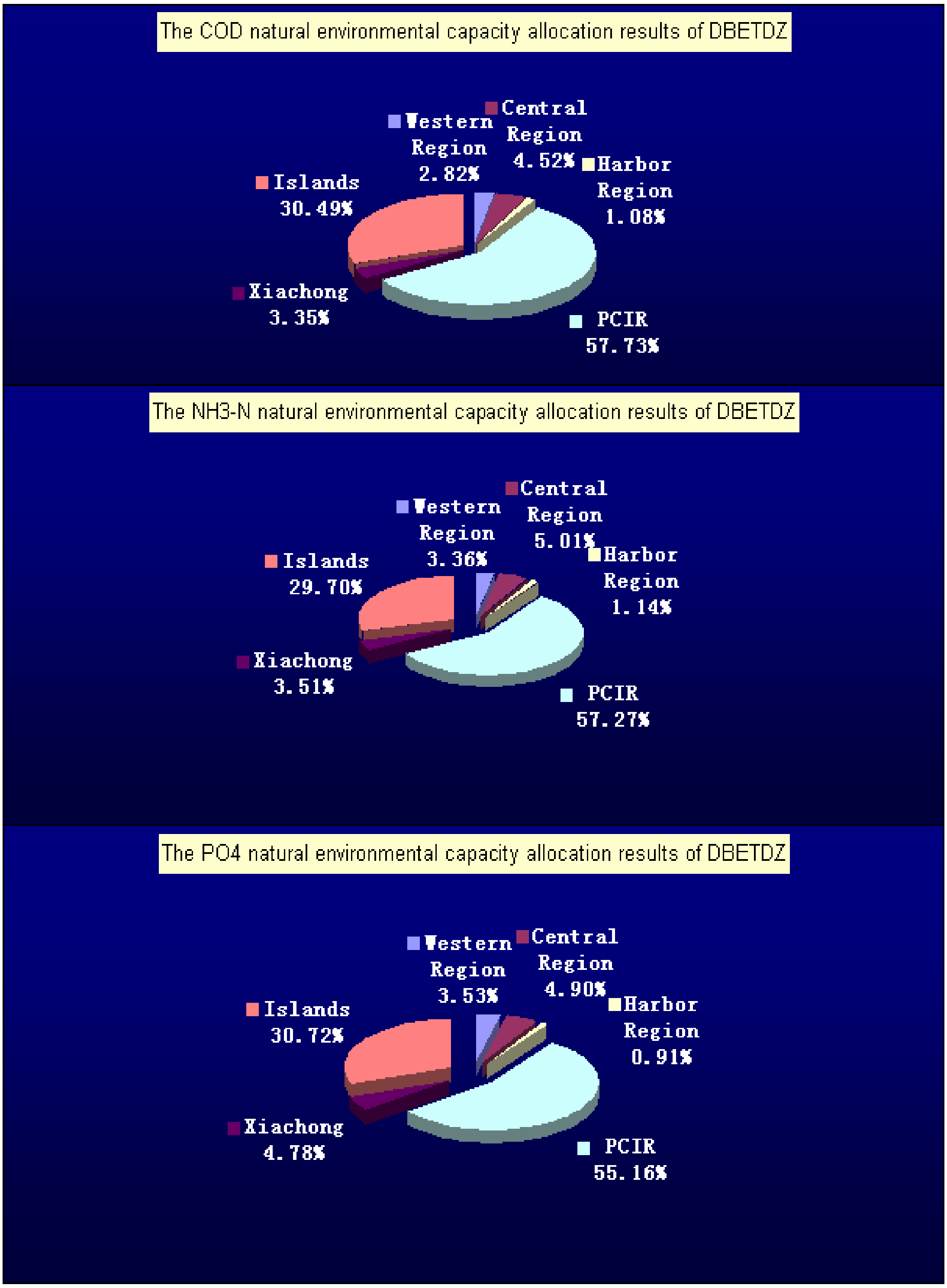

Figure 5.3-2 Environmental capacity Proportion of each subdistrict of Daya Bay Economy and Technology Development Zone

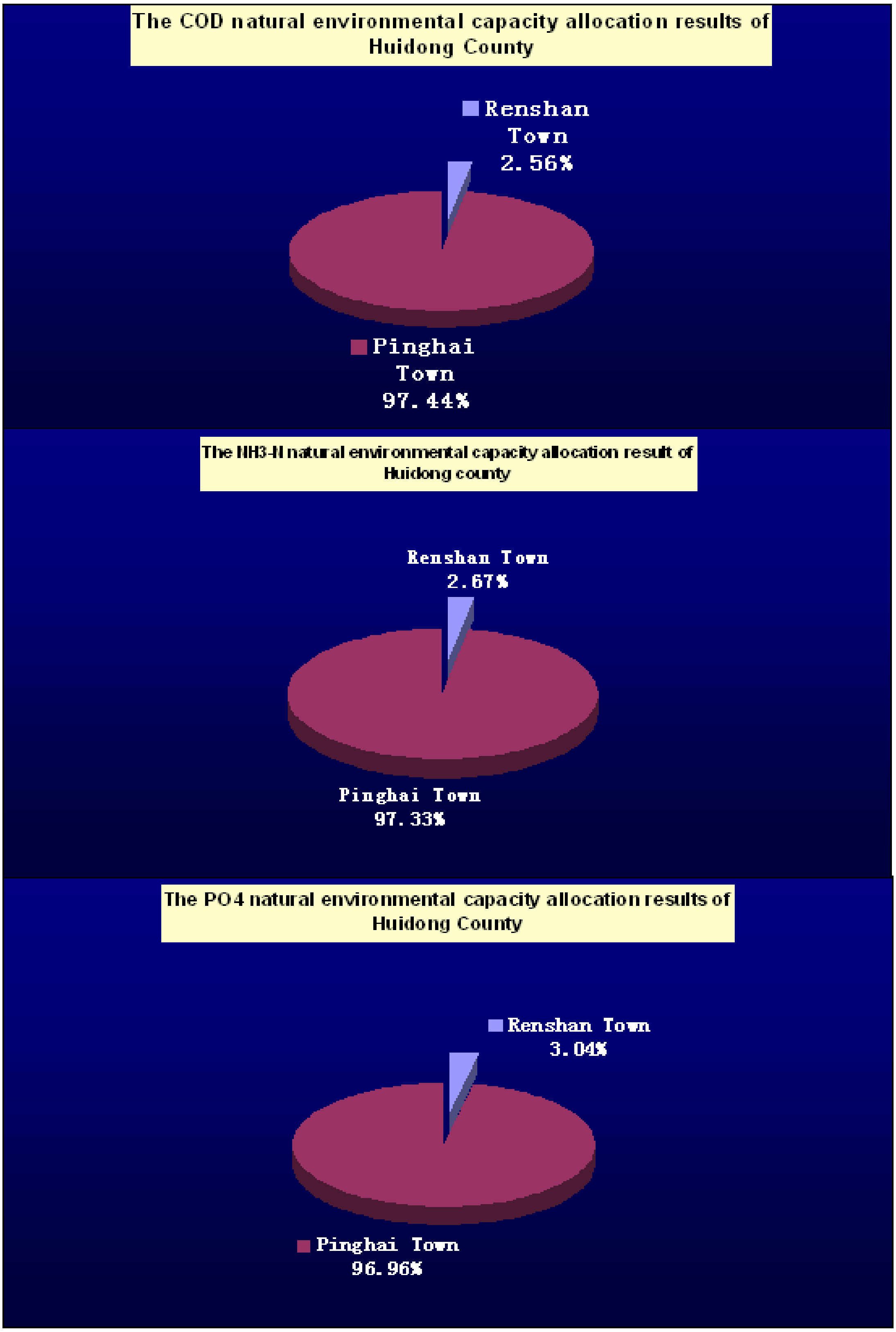

Figure 5.3-3 Environmental capacity Proportion of each subdistrict of Huidong County

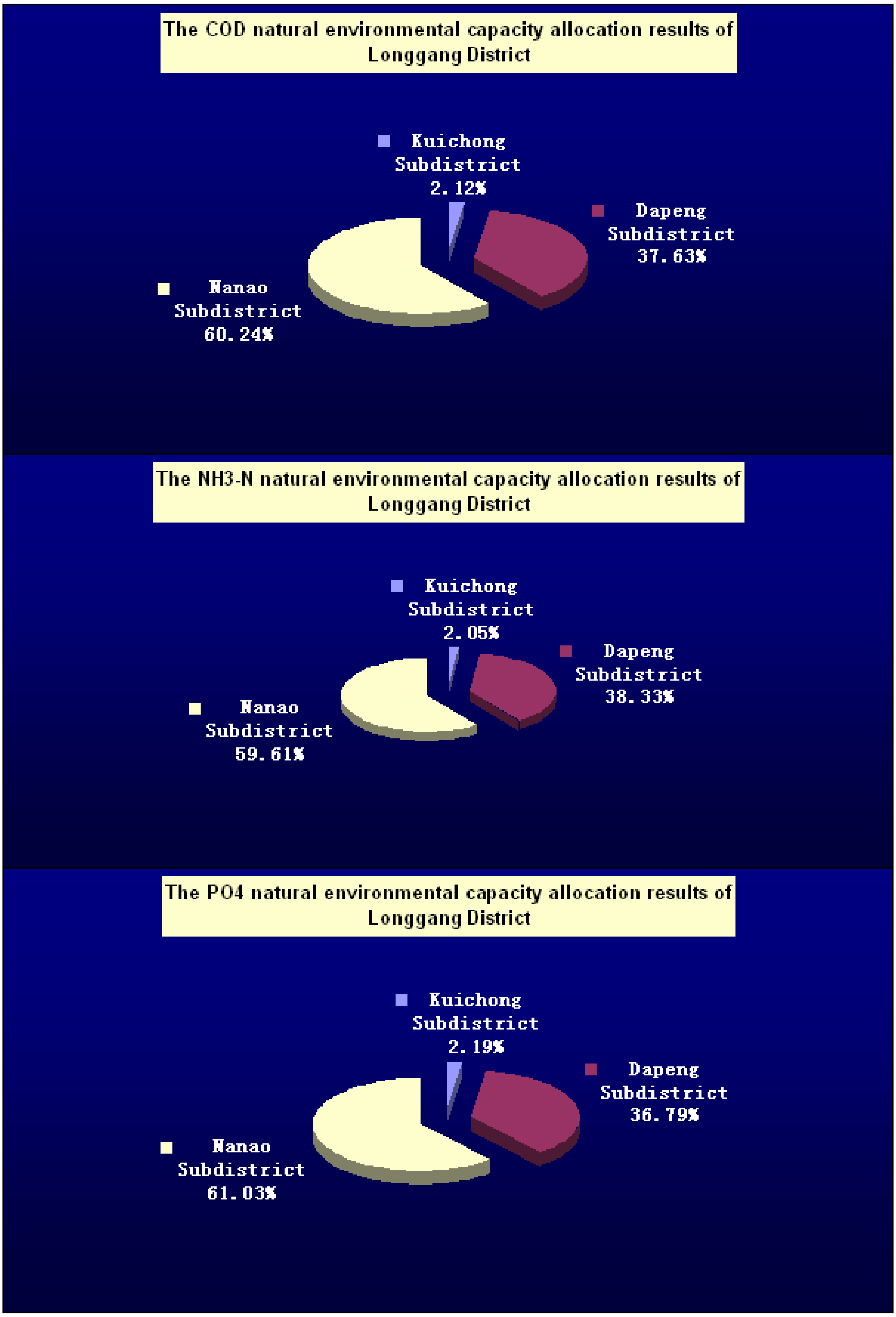

Figure 5.3-4 Environmental capacity Proportion of each subdistrict of Longgang District

Chapter 6 Total waste load control schemes

6.1 Available environmental capacity

Available environmental capacity is not equal to natural environmental capacity. In two kinds of situation, the water environmental capacity of certain place will be unable or unpractical to utilize (Meng, 2008).

According to the regulation of *Water pollutants discharge limits of Guangdong province* (PGGP, 2001), "It is unallowable to set new wastewater outfalls in special control areas; Current wastewater outfalls must obey the first class standard of pollutants discharge and the discharge amount cannot be increased". So for wastewater outfall HD17 which locate in the Natural Turtle Reserve, except the environmental capacity that have been used, the remaining capacity of this wastewater outfall cannot be utilized.

Another kind of situation is, when the economic and technical costs of environmental capacity utilization are too high, and then this part of environmental capacity will not be included in the available one. The wastewater outfall DY20 belongs to this category. Now this area is used as the temporary dumping area of dredged sludge produced from the Donglian/Mabianzhou Harbor project of CNOOC and Shell Petrochemicals Company Limited (CSPC). So the environmental capacity of this wastewater outfall is also excluded from future utilization.

After excluding the environmental capacity which is unable to use, the available environmental capacity can be obtained. Table III-10 in Appendix III lists the calculation results.

6.2 Calculation of Remaining & Exceeding of environmental capacity

Subtracting the accounting results of indicative pollutants discharge amounts in Year 2007 for each district from its available environmental capacity, then the remaining and exceeding of environmental capacity can be obtained, as listed in Table 6.2-1. From the calculation results it can be found that, based on current distribution of wastewater outfalls, whether and which districts have exceeded their environmental capacity that may harm the water quality and local ecosystem, and which ones still have environmental capacity left for future development, as shown by Figure 6.2-1~3. The positive value means there still have environmental capacities remained while the negative value stands for the exceedance of environmental capacity.

Although the total pollutant discharge amount from the catchment basin in 2007 did not higher than the total environmental capacity of Daya Bay in terms of CODcr, NH_3-N and PO_4^-, some subdistricts exceeded the limits of the maximum amounts of pollutants that can be discharged into Daya Bay from existing wastewater outfalls they used. These subdistricts include Western Region, Central Region and Harbor Region of Daya Bay Economy and Technology Development zone, Renshan Town of Huidong County, and Kuichong Subdistrict of Longgang District.

Table III-12: Remaining & Exceeding of environmental capacity in 2007

Administrative Districts	Subdistricts	CODcr (t/a)			NH_3-N (t/a)			PO_4^- (t/a)		
		Available Environmental capacity	discharge amount	Exceedance	Available Environmental capacity	discharge amount	Required reduction amount	Available Environmental capacity	discharge amount	Required reduction amount
Daya Bay Economy And Technology Development Zone	Western Region	3337.46	4941.60	1604.13	67.30	209.70	142.40	9.71	10.43	0.72
	Central Region	5339.06	7905.25	2566.20	100.24	312.34	212.09	13.49	14.49	1.00
	Harbor Region	1275.46	1888.50	613.05	22.87	71.27	48.40	2.50	2.69	0.19
	Petrochemical Industry Region	52231.45	2774.26	——	877.68	114.64	——	114.40	5.11	——
	Xiachong	3959.71	3187.44	——	70.21	138.08	67.88	13.17	7.74	——
	Islands	36038.82	2137.70	——	594.20	148.62	——	84.61	141.38	56.77
	Subtotal	102181.96	22834.75	——	1732.51	994.65	——	237.89	181.84	——
Huidong County	Renshan Town	2676.92	23214.02	20537.11	44.62	921.97	877.35	8.18	254.49	246.31
	Pinghai Town	77436.78	20823.63	——	1251.27	896.69		204.10	129.98	
	Subtotal	80113.70	44037.66	——	1295.89	1818.65	522.77	212.28	384.47	172.19
Longgang District	Kongchong Subdistrict	1214.08	1811.26	597.17	21.65	59.80	38.15	4.10	9.41	5.31
	Dapeng Subdistrict	21435.98	7987.06	——	404.40	263.05	——	69.03	10.41	——
	Nanao Subdistrict	34321.91	7255.87	——	628.91	248.91	——	114.51	32.35	——
	Subtotal	56971.97	17054.18	——	1054.96	571.76	——	187.64	52.17	——
Total		239267.62	83926.59	——	4083.36	3385.07	——	637.81	618.48	——

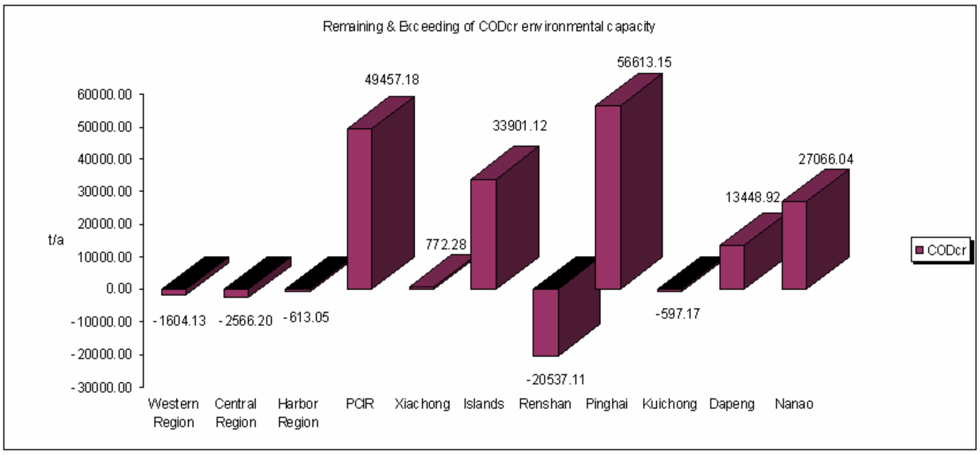

Figure 6.2-1 Remaining & Exceeding of CODcr environmental capacity

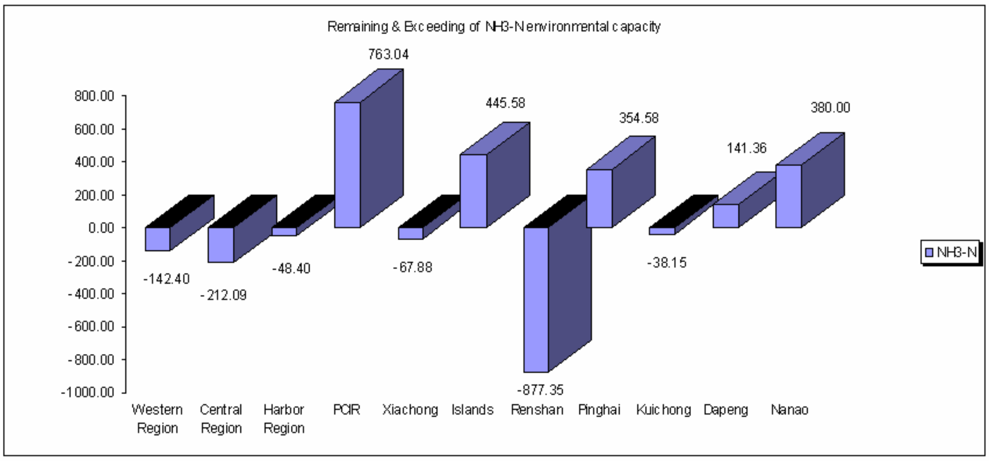

Figure 6.2-2 Remaining & Exceeding of CODcr environmental capacity

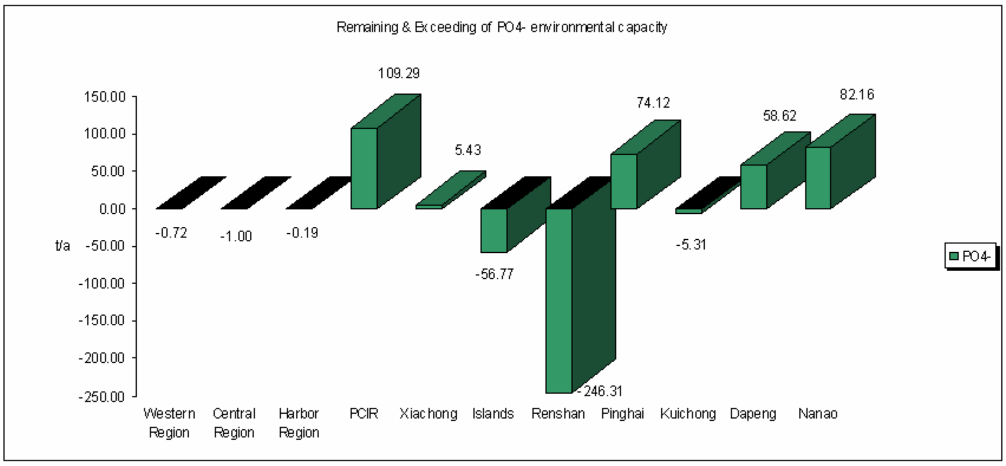

Figure 6.2-2 Remaining & Exceeding of CODcr environmental capacity

6.3 Pollutant control and reduction schemes

By comparing the prediction results of indicative pollutants discharge amounts in planning period for each district with its available environmental capacity, pollutants reduction schemes for 2010, 2015 and 2020 can be obtained, as shown in Table 6.3-1~3.

Table 6.3-1 CODcr reduction schemes for each district of Daya Bay in planning period

Administrative Districts	Subdistricts	Available Environmental capacity (t/a)	2010			2015			2020		
			Predicted CODcr discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)	Predicted CODcr discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)	Predicted CODcr discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)
Daya Bay Economy And Technology Development Zone	Western Region	3337.46	5477.36	2139.90	39.07	6325.37	2987.91	47.24	7516.36	4178.90	55.60
	Central Region	5339.06	8285.00	2945.94	35.56	9064.51	3725.45	41.10	10154.65	4815.59	47.42
	Harbor Region	1275.46	1935.16	659.70	34.09	2035.61	760.15	37.34	2176.00	900.54	41.39
	Petrochemical Industry Region	52231.45	5008.45	——	——	6436.48	——	——	8453.35	——	——
	Xiachong	3959.71	3423.84	——	——	3929.45	——	——	4636.17	676.46	14.59
	Islands	36038.82	2655.65	——	——	3812.53	——	——	5473.38	——	——
	Subtotal	102181.96	26785.46	——	——	31603.96	——	——	38409.91	——	——
Huidong County	Renshan Town	2676.92	24293.40	21616.48	88.98	26657.94	23981.02	89.96	29992.48	27315.57	91.07
	Pinghai Town	77436.78	21459.54	——	——	22844.75	——	——	24804.08	——	——
	Subtotal	80113.70	45752.94	——	——	49502.68	——	——	54796.57	——	——
Longgang District	Kongchong Subdistrict	1214.08	1849.60	635.52	34.36	1930.40	716.31	37.11	2038.41	824.33	40.44
	Dapeng Subdistrict	21435.98	8319.90	——	——	9766.81	——	——	14637.87	——	——
	Nanao Subdistrict	34321.91	7322.18	——	——	7452.34	——	——	7612.62	——	——
	Subtotal	56971.97	17492.24	——	——	19154.91	——	——	24320.45	——	——
Total		239267.62	90030.62	——	——	100261.54	——	——	117526.91	——	——

Table 6.3-2 NH_3-N reduction schemes for each district of Daya Bay in planning period

Administrative Districts	Subdistricts	Available natural Environmental capacity (t/a)	2010			2015			2020		
			Predicted NH_3-N discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)	Predicted NH_3-N discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)	Predicted NH_3-N discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)
Daya Bay Economy And Technology Development Zone	Western Region	67.30	238.62	171.31	71.79	288.58	221.28	76.68	358.52	291.21	81.23
	Central Region	100.24	336.35	236.11	70.20	388.61	288.36	74.20	461.44	361.20	78.28
	Harbor Region	22.87	74.69	51.82	69.38	81.99	59.11	72.10	92.15	69.28	75.18
	Petrochemical Industry Region	877.68	209.36	——	——	273.59	——	——	364.17	——	——
	Xiachong	70.21	154.80	84.60	54.65	190.82	120.62	63.21	241.03	170.83	70.87
	Islands	594.20	184.63	——	——	265.06	——	——	380.53	——	——
	Subtotal	1732.51	1198.46	——	——	1488.65	——	——	1897.85	165.34	8.71
Huidong County	Renshan Town	44.62	997.16	952.54	95.53	1161.24	1116.62	96.16	1391.21	1346.59	96.79
	Pinghai Town	1251.27	939.17	——	——	1030.09	——	——	1155.08	——	——
	Subtotal	1295.89	1936.32	640.43	33.07	2191.33	895.44	40.86	2546.30	1250.41	49.11
Longgang District	Kongchong Subdistrict	21.65	62.47	40.83	65.35	68.10	46.45	68.21	75.62	53.98	71.37
	Dapeng Subdistrict	404.40	270.50	——	——	294.78	——	——	357.63	——	——
	Nanao Subdistrict	628.91	253.52	——	——	262.57	——	——	273.72	——	——
	Subtotal	1054.96	586.50	——	——	625.50	——	——	707.24	——	——
Total		4083.36	3721.28	——	——	4305.47	222.11	5.16	5151.38	1068.03	20.73

Table 6.3-3 PO_4^- reduction schemes for each district of Daya Bay in planning period

Administrative Districts	Subdistricts	Available natural Environmental capacity (t/a)	2010			2015			2020		
			Predicted PO_4^- discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)	Predicted PO_4^- discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)	Predicted PO_4^- discharge amount (t/a)	Required reduction amount (t/a)	Reduction proportion (%)
Daya Bay Economy And Technology Development Zone	Western Region	9.71	12.31	2.60	21.10	15.79	6.07	38.47	20.54	10.83	52.71
	Central Region	13.49	16.48	2.98	18.11	20.69	7.20	34.79	26.42	12.93	48.93
	Harbor Region	2.50	2.97	0.46	15.63	3.55	1.04	29.41	4.34	1.83	42.22
	Petrochemical Industry Region	114.40	8.78	——	——	11.64	——	——	15.62	——	——
	Xiachong	13.17	9.11	——	——	11.99	——	——	15.91	2.74	17.21
	Islands	84.61	175.64	91.03	51.83	252.15	167.54	66.45	362.00	277.39	76.63
	Subtotal	237.89	225.28	——	——	315.81	77.92	24.67	444.82	206.93	46.52
Huidong County	Renshan Town	8.18	312.96	304.78	97.39	443.16	434.98	98.15	629.48	621.30	98.70
	Pinghai Town	204.10	156.85	——	——	216.48	12.38	5.72	301.53	97.43	32.31
	Subtotal	212.28	469.81	257.53	54.82	659.64	447.36	67.82	931.01	718.73	77.20
Longgang District	Kongchong Subdistrict	4.10	11.13	7.03	63.17	14.78	10.68	72.26	19.68	15.58	79.16
	Dapeng Subdistrict	69.03	13.43	——	——	22.40	——	——	40.94	——	——
	Nanao Subdistrict	114.51	34.82	——	——	39.42	——	——	44.70	——	——
	Subtotal	187.64	59.38	——	——	76.59	——	——	105.31	——	——
Total		637.81	754.46	116.65	15.46	1052.04	414.23	39.37	1481.15	843.34	56.94

Chapter 7 Conclusion

Along with the high-speed economy development in Daya Bay area, the environmental state of Daya Bay has been degraded rapidly in these years. The continuing increase of pollutants loading is the main reason of environmental degradation in Daya Bay. Although in history, several large scale surveys of environmental problems were undertaken in Daya Bay area, the survey results were not well linked to practical administrative management and just existed as packages of reports. TWLC plans have been suggested for some districts, but they are developed based on simple mathematical methods and are isolated from each other. Even there is no explicit definition of the catchment basin of Daya Bay. Hence, there is no doubt that it is very important and necessary to develop a systematic Total waste load control (TWLC) strategy for the total Daya Bay area. That's the research purpose of Daya Bay project.

Environmental capacity is the most important concept of TWLC, which equals to the maximum amount of waste load which is allowable to enter water from given discharge places without harmful effects on environmental quality. It's important to quantify the environmental capacity of each district located in the catchment basin and if it is exceeded. If the environmental capacity has been exceeded then pollutants reduction schemes must be made. That's the main work content of this master thesis, which correlates scientific research results with practical management.

Chapter 1 introduced the research background and basic project information, as well as the research contents and methods of this master thesis. Chapter 2 talked about the current situation of Daya Bay area: Firstly background information of Daya Bay area was introduced; Then based on the catchment basin defined by PRWCSRI, the regionalism of Daya Bay's catchment basin is obtained by overlaying the catchment basin map and the administration map in MapInfo with the complementarity of field survey, and so the allocation objects of environmental capacity are established; Next the water function zoning of Daya Bay and water quality goal of each zone were introduced; which was indispensable information in the calculation of environmental capacity; Finally the main environmental problems were illuminated. In Chapter 3, indicative pollutants of TWLC were selected and their discharge amounts both at current (Year 2007) and in future (Year 2010, 2015, 2020) were accounted and predicted. Chapter 4 is the calculation of Daya Bay's marine environmental capacity: when the maximization of total environmental capacity is the object of planning, the environmental capacity can be calculated by using a linear programming model which include the setting of wastewater outfalls and water quality control points, the establishment of water quality standard and background concentration of each control point, as well as the calculation of the most important input-response coefficients between every wastewater outfall and every water quality control through simulating the water environment of Daya Bay by water hydrodynamic and quality models. Chapter 5 allocated the environmental capacity to districts defined in Chapter 3. Then in Chapter 6, after subtracting the pollutants discharge amounts from environmental capacity of each district, the remaining and exceeding of environmental capacity in studied year were obtained and so the pollutants reduction schemes could be established, which is one of the most important outcomes of the project. Although the total pollutant discharge amount from the catchment basin was not higher than the total environmental capacity of Daya Bay in terms of CODcr, NH_3-N and PO_4^-, some subdistricts exceeded the limits of the maximum amounts of pollutants that can be discharged into Daya Bay from existing wastewater outfalls. Thus there is a potential harm of water environment and pollutants control and reduction measures should be taken to stop the environmental degradation trend.

There are some deficiencies of this master thesis: environmental capacity allocation among districts with shared wastewater outfalls is based on single principle - current pollutant discharge amount of each district, other factors such as the total pollution treatment cost & benefit, economical level and technique merit are not taken into consideration due to the limitation of information; the pollutant reduction schemes cannot be used directly because compromise or further requirement by local policy are not taken into account, and just can be used as references by relevant authorities in the planning of pollution control measures and schemes; and so on. Due to the limitations of time and available information, these deficiencies cannot be improved in this master thesis, but they should be considered and complemented in future study.

The Daya Bay project met many difficulties at each work stages and at every research part due to the huge gap between available information and required information in various aspects of society, economy & environment. Because the catchment basin defined by the project was regionalized into 2 administrative districts at prefecture level, 3 administrative districts at county level and 8 administrative districts at town level, communication and coordination between the project and different authorities were very complex. However, the project worked hard to overcome difficulties as much as possible and did its best to investigate and develop a scientific, reasonable and practical TWLC strategy for Daya Bay which would benefit both to the Daya Bay area and to future similar researches for other areas.

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Appendix I

Table I-1 Discharge amount of indicative pollutants from domestic pollution sources in 2007 (Unit: ton per year)

Administrative Districts	Subdistricts		Population	CODcr	NH_3-N	PO_4^-
Daya Bay Economy And Technology Development Zone	Western Region		30000	709.56	49.06	2.31
	Central Region		44000	1040.69	71.95	3.38
	Harbor Region		6000	141.91	9.81	0.46
	Petrochemical Industry Region		10300	243.62	16.84	0.79
	Xiachong		30000	709.56	49.06	2.31
	Subtotal		120300	2845.34	196.71	9.25
Huidong County	Pinghai	Town	18641	440.9	30.48	1.43
		Country	40018	912.91	58.43	3.08
		Sum	58659	1353.81	88.91	4.51
	Renshan	Town	11862	280.56	19.4	0.91
		Country	59410	1355.29	86.74	4.57
		Sum	71272	1635.85	106.14	5.48
	Subtotal		129931	2989.66	195.04	9.99
Longgang District	Kuichong		2796	66.13	4.57	0.22
	Dapeng		7260	171.71	11.87	0.56
	Nanao		6783	160.43	11.09	0.52
	Subtotal		16839	398.28	27.54	1.3
Total			267070	6233.27	419.29	20.54

Table I-2 Discharge amount of indicative pollutants from industrial pollution sources in 2007 (Unit: ton per year)

Administrative Districts	Subdistricts	CODcr	NH_3-N	PO_4^-
Daya Bay Economy And Technology Development Zone	Western Region	544.39	22.13	0.950
	Central Region	83.46	0.06	0.028
	Harbor Region	2.32	0.26	0.010
	Petrochemical Industry Region	879.71	36.35	1.310
	Xiachong	17.50	0.67	0.040
	Subtotal	1527.38	59.47	2.338
Huidong County	Pinghai	35.09	0.58	0.012
	Renshan	91.87	1.24	0.053
	Subtotal	126.96	1.82	0.065
Longgang District	Kuichong	0.00	0.00	0.000
	Dapeng	221.73	1.91	0.076
	Nanao	0.00	0.00	0.000
	Subtotal	221.73	1.91	0.076
Total		1876.06	63.20	2.479

Table I-3 Discharge amounts of indicative pollutants from mariculture in 2007 (Unit: ton per year)

Administrative Districts	Subdistricts	Mariculture Yield (ton)	CODcr	NH_3-N	PO_4^-
Daya Bay Economy And Technology Development Zone	Islands	20359	2137.70	148.62	141.38
Huidong County	Pinghai	33590	3526.96	245.21	233.27
	Renshan	14863	1560.60	108.50	103.22
	Subtotal	48453	5087.57	353.71	336.48
Longgang District	Kuichong	1247	130.94	9.10	8.66
	Dapeng	778	81.69	5.68	5.40
	Nanao	4157	436.49	30.35	28.87
	Subtotal	6182	649.11	45.13	42.93
Total		174935	7874.37	547.46	520.80

Table I-4 Discharge amount of indicative pollutants from livestock and poultry breeding in 2007 (Unit: ton per year)

Administrative Districts	Subdistricts	Number of Pig	CODcr	NH_3-N	PO_4^-
Daya Bay Economy And Technology Development Zone	Western Region	12524	332.73	26.93	4.55
	Central Region	18369	489.07	39.58	6.69
	Harbor Region	2505	66.81	5.41	0.91
	Petrochemical Industry Region	4300	114.92	9.30	1.57
	Xiachong	12524	332.73	26.93	4.55
	Subtotal	50223	1336.25	108.14	18.29
Huidong County	Pinghai	26060	693.36	56.11	9.49
	Renshan	23361	621.55	50.30	8.51
	Subtotal	49421	1314.91	106.41	18.00
Longgang District	Kuichong	171	4.54	0.37	0.06
	Dapeng	231	6.15	0.50	0.08
	Nanao	227	6.04	0.49	0.08
	Subtotal	629	16.72	1.35	0.23
Total		100273	2667.88	215.90	36.52

Table I-5 Pollutant-output coefficient of different kinds of land use type (Daya Bay project, 2009a)

Land use type		Pollutant-output coefficient		
		CODcr	NH_3-N	PO_4^-
Pervious surface	A1	8176	1617	9.3
	A2	16300	1540	18.8
	B1	4972	504.4	3.4
	B2	5469.2	554.8	3.8
	B3	6463.6	655.7	4.5
	B4	7610	1210	8.2
	C1	25922.5	406.7	11
	C2	37032.1	581	15.7
	D1	1050	23.5	22
	D2	1469	34.6	13.3
Impervious surface	E1	38688.3	2448.4	162.6
	E2	83240	1909	36
	E3	1682.1	504.6	20.6
	F	14578.2	2280.2	190.6
	G2	32757	8007	27

Table I-6 Pollutant-input coefficient of different kinds of land use type (Daya Bay project, 2009a)

Land use type	Arable land	Forest land	Shrub land	Grassland	City residence	Others
Input coefficient	0.73	0.71	0.69	0.67	0.65	0.69

Table I-7 Amounts of pollutants entering Daya Bay from non-point sources of sub-catchments in 2007 (Unit: ton per year) (Daya Bay project, 2009a)

Sub-catchment	y001	y002	y003	y004	y005	y006	y007
CODcr	553.64	1287.77	10.40	2069.96	38.04	60.37	120.56
NH3-N	16.45	36.63	0.39	61.04	1.43	2.26	4.55
PO_4^-	0.17	0.39	0.00	0.62	0.01	0.02	0.04
Sub-catchment	y008	y009	y010	y011	y012	y013	y014
CODcr	105.98	7218.77	391.80	1056.86	1150.25	48.87	45.50
NH3-N	2.89	244.02	11.46	30.98	34.49	1.80	1.68
PO_4^-	0.04	4.76	0.15	0.44	0.47	0.04	0.02
Sub-catchment	y015	y016	y017	y018	y019	y020	y021
CODcr	142.67	44.36	51.06	1371.55	419.69	88.75	1036.37
NH3-N	4.51	1.58	1.78	37.89	12.45	2.11	28.86
PO_4^-	0.03	0.01	0.01	0.42	0.14	0.04	0.41
Sub-catchment	y022	y023	y024	y025	y026	y027	y028
CODcr	540.19	2069.17	3101.73	9763.34	943.73	1035.83	129.92
NH3-N	16.09	74.83	110.59	372.39	34.22	38.48	2.58
PO_4^-	0.17	1.37	1.88	7.90	0.73	0.84	0.03
Sub-catchment	y029	y030	y031	y032	y033	y034	y035
CODcr	129.92	34.13	67.42	272.38	84.97	2716.88	6313.33
NH3-N	2.58	1.28	2.36	8.61	3.08	79.61	188.12
PO_4^-	0.03	0.01	0.03	0.07	0.02	0.83	1.96
Sub-catchment	y036	y037	y038	Danao River	Nanbianzao River	Bogang River	Xiachong River
CODcr	2862.03	2138.89	2854.95	10064.76	751.22	422.71	551.12
NH3-N	84.15	82.05	76.74	334.77	18.81	13.93	16.48
PO_4^-	0.88	1.93	1.42	7.85	0.28	0.37	0.26
Sub-catchment	Yanqiang River	Total					
CODcr	1113.29	65274.984					
NH3-N	38.21	2139.22					
PO_4^-	1.06	38.15					

Table I-8 Amounts of pollutants entering Daya Bay from non-point sources of districts in 2007 (Unit: ton per year)

Administrative Districts	Subdistricts	CODcr	NH_3-N	PO_4^-
Daya Bay Economy And Technology Development Zone	Western Region	3354.92	111.59	2.62
	Central Region	6292.04	200.76	4.39
	Harbor Region	1677.46	55.80	1.31
	Petrochemical Industry Region	1536.02	52.14	1.43
	Xiachong	2127.65	61.43	0.84
	Subtotal	14988.09	481.71	10.58
Huidong County	Pinghai	17604.80	531.16	7.21
	Renshan	16913.76	630.51	12.72
	Subtotal	34518.57	1161.67	19.93
Longgang District	Kuichong	1609.65	45.76	0.47
	Dapeng	7505.78	243.09	4.29
	Nanao	6652.92	206.98	2.88
	Subtotal	15768.34	495.83	7.64
Total		65274.99	2139.21	38.15

Table I-9 Prediction results of CODcr discharge amount from domestic pollution sources in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts		2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region		878.04	1252.36	1786.25
	Central Region		1287.80	1836.79	2619.83
	Harbor Region		175.61	250.47	357.25
	Petrochemical Industry Region		301.46	429.98	613.28
	Xiachong		878.04	1252.36	1786.25
	Subtotal		3520.96	5021.96	7162.85
Huidong County	Pinghai	Town	469.26	520.65	577.66
		Country	971.64	1078.04	1196.09
		Sum	1440.90	1598.68	1773.75
	Renshan	Town	298.61	331.31	367.59
		Country	1442.48	1600.44	1775.69
		Sum	1741.09	1931.74	2143.28
	Subtotal		3181.99	3530.43	3917.02
Longgang District	Kuichong		78.32	103.82	137.63
	Dapeng		203.36	269.58	357.37
	Nanao		190.00	251.87	333.89
	Subtotal		471.67	625.27	828.89
Total			7174.62	9177.66	11908.77

Table I-10 Prediction results of NH_3-N discharge amount from domestic pollution sources in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts		2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region		60.70	86.58	123.49
	Central Region		89.03	126.99	181.12
	Harbor Region		12.14	17.32	24.70
	Petrochemical Industry Region		20.84	29.73	42.40
	Xiachong		60.70	86.58	123.49
	Subtotal		243.42	347.20	495.21
Huidong County	Pinghai	Town	32.44	36.00	39.94
		Country	62.18	68.99	76.55
		Sum	94.63	104.99	116.49
	Renshan	Town	20.64	22.91	25.41
		Country	92.32	102.43	113.64
		Sum	112.96	125.33	139.06
	Subtotal		207.59	230.32	255.54
Longgang District	Kuichong		5.41	7.18	9.52
	Dapeng		14.06	18.64	24.71
	Nanao		13.14	17.41	23.08
	Subtotal		32.61	43.23	57.31
Total			483.62	620.75	808.06

Table I-11 Prediction results of PO_4^- discharge amount from domestic pollution sources in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts		2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region		1.06	1.52	2.16
	Central Region		1.56	2.22	3.17
	Harbor Region		0.21	0.30	0.43
	Petrochemical Industry Region		0.36	0.52	0.74
	Xiachong		1.06	1.52	2.16
	Subtotal		4.26	6.08	8.67
Huidong County	Pinghai	Town	0.57	0.63	0.70
		Country	1.22	1.35	1.50
		Sum	1.79	1.98	2.20
	Renshan	Town	0.36	0.40	0.44
		Country	1.81	2.01	2.23
		Sum	2.17	2.41	2.67
	Subtotal		3.96	4.39	4.87
Longgang District	Kuichong		0.09	0.13	0.17
	Dapeng		0.25	0.33	0.43
	Nanao		0.23	0.30	0.40
	Subtotal		0.57	0.76	1.00
Total			8.79	11.22	14.54

Table I-12 Prediction results of CODcr discharge amount from industrial pollution sources in planning period (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	853.70	1207.46	1707.82
	Central Region	130.88	185.11	261.82
	Harbor Region	3.64	5.14	7.28
	Petrochemical Industry Region	3036.03	4294.12	6073.55
	Xiachong	27.44	38.82	54.90
	Subtotal	4051.68	5730.65	8105.37
Huidong County	Pinghai	51.99	100.10	192.73
	Renshan	136.10	262.06	504.57
	Subtotal	188.09	362.15	697.29
Longgang District	Kuichong	0.00	0.00	0.00
	Dapeng	479.31	1732.26	6260.45
	Nanao	0.00	0.00	0.00
	Subtotal	479.87	1737.62	6291.99
Total		4719.64	7830.43	15094.66

Table I-13 Prediction results of NH_3-N discharge amount from industrial pollution sources in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	34.70	49.08	69.42
	Central Region	0.09	0.12	0.18
	Harbor Region	0.41	0.58	0.82
	Petrochemical Industry Region	125.46	177.45	250.98
	Xiachong	1.05	1.49	2.10
	Subtotal	161.71	228.72	323.50
Huidong County	Pinghai	0.86	1.65	3.19
	Renshan	1.84	3.54	6.82
	Subtotal	2.70	5.20	10.01
Longgang District	Kuichong	0.00	0.00	0.00
	Dapeng	4.13	14.92	53.93
	Nanao	0.00	0.00	0.00
	Subtotal	4.13	14.97	54.20
Total		168.54	248.89	387.71

Table I-14 Prediction results of PO_4^- discharge amount from industrial pollution sources in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	1.490	2.107	2.980
	Central Region	0.044	0.062	0.088
	Harbor Region	0.016	0.022	0.031
	Petrochemical Industry Region	4.521	6.394	9.044
	Xiachong	0.063	0.089	0.125
	Subtotal	6.133	8.675	12.269
Huidong County	Pinghai	0.018	0.034	0.066
	Renshan	0.079	0.151	0.291
	Subtotal	0.096	0.185	0.357
Longgang District	Kuichong	0.000	0.000	0.000
	Dapeng	0.164	0.594	2.146
	Nanao	0.000	0.000	0.000
	Subtotal	0.164	0.594	2.146
Total		6.394	9.454	14.772

Table I-15 Prediction results of CODcr discharge amount from mariculture in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy and Technology Development zone	islands	2655.65	3812.53	5473.38
Huidong County	Pinghai	4381.53	6290.26	9030.48
	Renshan	1938.73	2783.30	3995.79
	Subtotal	6320.27	9073.56	13026.27
Longgang District	Kuichong	156.25	209.80	281.68
	Dapeng	124.18	249.54	501.49
	Nanao	472.11	538.07	613.25
	Subtotal	752.54	997.41	1396.42
Total		9728.46	13883.50	19896.07

Table I-16 Prediction results of NH_3-N discharge amount mariculture in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy and Technology Development zone	islands	184.63	265.06	380.53
Huidong County	Pinghai	304.62	437.32	627.83
	Renshan	134.79	193.51	277.80
	Subtotal	439.41	630.83	905.64
Longgang District	Kuichong	10.86	14.59	19.58
	Dapeng	8.63	17.35	34.87
	Nanao	32.82	37.41	42.64
	Subtotal	52.32	69.34	97.08
Total		676.36	965.23	1383.25

Table I-17 Prediction results of PO_4^- discharge amount mariculture in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy and Technology Development zone	islands	175.64	252.15	362.00
Huidong County	Pinghai	289.79	416.03	597.26
	Renshan	128.22	184.08	264.27
	Subtotal	418.01	600.11	861.53
Longgang District	Kuichong	10.33	13.88	18.63
	Dapeng	8.21	16.50	33.17
	Nanao	31.22	35.59	40.56
	Subtotal	49.77	65.97	92.36
Total		643.42	918.23	1315.89

Table I-18 Prediction results of CODcr discharge amount from livestock and poultry breeding in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	390.70	510.63	667.37
	Central Region	574.28	750.56	980.96
	Harbor Region	78.45	102.54	134.01
	Petrochemical Industry Region	134.94	176.36	230.50
	Xiachong	390.70	510.63	667.37
	Subtotal	1569.08	2050.72	2680.21
Huidong County	Pinghai	814.17	1064.09	1390.72
	Renshan	729.85	953.88	1246.69
	Subtotal	1544.02	2017.97	2637.41
Longgang District	Kuichong	5.38	7.13	9.45
	Dapeng	7.28	9.65	12.79
	Nanao	7.15	9.48	12.57
	Subtotal	19.81	26.26	34.81
Total		3132.91	4094.95	5352.43

Table I-19 Prediction results of NH_3-N discharge amount from livestock and poultry breeding in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	31.62	41.32	54.01
	Central Region	46.48	60.74	79.39
	Harbor Region	6.35	8.30	10.85
	Petrochemical Industry Region	10.92	14.27	18.65
	Xiachong	31.62	41.32	54.01
	Subtotal	126.98	165.96	216.90
Huidong County	Pinghai	65.89	86.11	112.55
	Renshan	59.06	77.20	100.89
	Subtotal	124.95	163.31	213.44
Longgang District	Kuichong	0.44	0.58	0.76
	Dapeng	0.59	0.78	1.03
	Nanao	0.58	0.77	1.02
	Subtotal	1.60	2.12	2.82
Total		253.54	331.39	433.16

Table I-20 Prediction results of PO_4^- discharge amount from livestock and poultry breeding in planning period (Benchmark year: 2007) (Unit: t/a)

Administrative Districts	Subdistricts	2010	2015	2020
Daya Bay Economy And Technology Development Zone	Western Region	5.35	6.99	9.13
	Central Region	7.86	10.27	13.43
	Harbor Region	1.07	1.40	1.83
	Petrochemical Industry Region	1.85	2.41	3.15
	Xiachong	5.35	6.99	9.13
	Subtotal	21.48	28.07	36.69
Huidong County	Pinghai	11.14	14.56	19.04
	Renshan	9.99	13.06	17.06
	Subtotal	21.13	27.62	36.10
Longgang District	Kuichong	0.07	0.10	0.13
	Dapeng	0.10	0.13	0.18
	Nanao	0.10	0.13	0.17
	Subtotal	0.27	0.36	0.48
Total		42.88	56.05	73.26

Appendix II

Table II-1 Water quality variables of RCA (Fitzpatrick, 2004)

Water quality variable	Description
SAL	Salinity (ppt)
PHYT1	Phytoplankton carbon - winter assemblage (mg C l^{-1})
PHYT2	Phytoplankton carbon - summer assemblage (mg C l^{-1})
PHYT3	Phytoplankton carbon - fall assemblage (mg C l^{-1})
RPOP	Refractory particulate organic phosphorus (mg P l^{-1})
LPOP	Labile particulate organic phosphorus (mg P l^{-1})
RDOP	Refractory dissolved organic phosphorus (mg P l^{-1})
LDOP	Labile dissolved organic phosphorus (mg P l^{-1})
PO_4^-	Dissolved inorganic phosphorus (mg P l^{-1})
RPON	Refractory particulate organic nitrogen (mg N l^{-1})
LPON	Labile particulate organic nitrogen (mg N l^{-1})
RDON	Refractory dissolved organic nitrogen (mg N l^{-1})
LDON	Labile dissolved organic nitrogen (mg N l^{-1})
NH_4^+	Ammonia nitrogen(mg N l^{-1})
$NO_2^- + NO_3^-$	Nitrite + nitrate nitrogen (mg N l^{-1})
SiU	Biogenic silica- unavailable (mg Si l^{-1})
SiT	Available silica (mg Si l^{-1})
RPOC	Refractory particulate organic carbon(mg C l^{-1})
LPOC	Labile particulate organic carbon (mg C l^{-1})
RDOC	Refractory dissolved organic carbon (mg C l^{-1})
LDOC	Labile dissolved organic carbon (mg C l^{-1})
ExDOC	Algal exudates dissolved organic carbon (mg C l^{-1})
RePOC	Reactive particulate organic carbon(mg C l^{-1})
ReDOC	Reactive dissolved organic carbon (mg C l^{-1})
COD	Chemical oxygen demand (mg O_2 l^{-1})
DO	Dissolved oxygen (mg O_2 l^{-1})

Table II-2 Phytoplankton growth equations of RCA (Fitzpatrick, 2004)

Variable/ reaction term	Description/ equation
H	Water column depth or thickness of the water cell or segment (m)
T	Temperature (°C)
SSC	Suspended sand concentration (mg SS l^{-1})
POM	Particular organic matter concentration (mg l^{-1})
$Chla$	Ambient phytoplankton population as chlorophyll (ug l^{-1})
I_o	Incident light intensity at the segment surface (ly day^{-1})
Phytoplankton kinetics	——
Reaction rate	$S_p = (G_p - D_p)\ \mathrm{PHYT}$
Growth rate	$G_p = G_{pmax} \cdot G_T(\mathrm{T}) \cdot G_I(\mathrm{I}) \cdot G_N(\mathrm{N})$
Nutrient Uptake	$G_N(N) = Min\left(\frac{DIN}{K_{mN}}, \frac{DIP}{K_{mP}}, \frac{Si}{K_{mSi} + Si}\right)$
Light attenuation	$G_I(I) = \frac{e}{k_e H}\left[\exp\left(\frac{-I_O}{I_S} e^{k_e H}\right) - \exp\frac{-I_O(t)}{I_S}\right]$
Optimum Temperature Version	$G_{P\max(T)} = G_{P\max} e^{-\beta_1 (T - T_{opt})^2}$ $G_{P\max(T)} = G_{P\max} e^{-\beta_2 (T_{opt} - T)^2}$
Total extinction coefficient	$K_e = 0.052SSC + 0.174POM + 0.031a_{cchl}PHYT$
Total loss rate	$D_P = K_{PR}(\mathrm{T}) + K_{sP} + K_{grz}(\mathrm{T})$
Algal Respiration	$K_{PR}(T) = K_{PR}\theta_{PR}^{T-20}$
Algal Settling	$K_{SP} = \left[\frac{V_{sPb}}{H} + \frac{V_{sPn}}{H} \cdot (1 - G_N(N))\right] \cdot \theta_{base}^{T-20}$
Zooplankton grazing	$K_{grz}(T) = K_{grz}\theta_{grz}^{T-20}$

Table II- 3 Nitrogen reaction rates (Fitzpatrick, 2004)

Variable	Rate equation
Refractory particulate organic nitrogen	$S_{RPON} = a_{NC} \cdot f_{RPON} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT$ $-K_{RPON} \cdot \theta_{RPON}^{T-20} \cdot RPON \cdot \frac{PHYT}{K_{mPc} + PHYT} - \frac{V_{sRPON}}{H} \cdot RPON$
Labil particulate organic nitrogen	$S_{LPON} = a_{NC} \cdot f_{LPON} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT$ $-K_{LPON} \cdot \theta_{LPON}^{T-20} \cdot LPON \cdot \frac{PHYT}{K_{mPc} + PHYT} - \frac{V_{sLPON}}{H} \cdot LPON$
Labile particulate organic nitrogen	$S_{RDON} = a_{NC} \cdot f_{RDON} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT$ $+K_{RPON} \cdot \theta_{RPON}^{T-20} \cdot RPON \cdot \frac{PHYT}{K_{mPc} + PHYT}$ $-K_{RDON} \cdot \theta_{RDON}^{T-20} \cdot RDON \cdot \frac{PHYT}{K_{mPc} + PHYT}$
Refractory dissolved organic nitrogen	$S_{LDON} = a_{NC} \cdot f_{LDON} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT$ $+K_{LPON} \cdot \theta_{LPON}^{T-20} \cdot LPON \cdot \frac{PHYT}{K_{mPc} + PHYT}$ $-K_{LDON} \cdot \theta_{LDON}^{T-20} \cdot LDON \cdot \frac{PHYT}{K_{mPc} + PHYT}$
Labile dissolved organic nitrogen	$S_{NH4} = a_{NC} \cdot f_{NH4} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT +$ $(K_{RDON} \cdot \theta_{RDON}^{T-20} \cdot RDON + K_{LDON} \cdot \theta_{LDON}^{T-20} \cdot LDON)$ $\cdot \frac{PHYT}{K_{mPc} + PHYT} - a_{NC} \cdot a_{NH4} \cdot (1 - f_{ExDOC}) \cdot G_P \cdot PHYT$ $-K_{NH4} \cdot \theta_{NH4}^{T-20} \cdot NH4 \cdot \frac{DO}{K_{nitr} + DO}$
Ammonia nitrogen	$S_{NO23} = K_{NH4} \cdot \theta_{NH4}^{T-20} \cdot NH4 \cdot \frac{DO}{K_{nitr} + DO}$ $-a_{NC} \cdot (1 - a_{NH4}) \cdot (1 - f_{ExDOC}) \cdot G_P \cdot PHYT$ $-K_{NO23} \cdot \theta_{NO23}^{T-20} \cdot \frac{K_{NO3}}{K_{NO3} + DO}$

Table II-4 Phosphorus reaction rates (Fitzpatrick, 2004)

Variable	Rate equation
Refractory particulate organic phosphorus	$S_{RPOP} = a_{PC} \cdot f_{RPOP} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT - K_{RPOP} \cdot \theta_{RPOP}^{T-20} \cdot RPOP \cdot \frac{PHYT}{K_{mPc} + PHYT} - \frac{V_{RPOP}}{H} \cdot RPOP$
Labile particulate organic phosphorus	$S_{LPOP} = a_{PC} \cdot f_{LPOP} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT - K_{LPOP} \cdot \theta_{LPOP}^{T-20} \cdot LPOP \cdot \frac{PHYT}{K_{mPc} + PHYT} - \frac{V_{LPOP}}{H} \cdot LPOP$
Refractory dissolved organic phosphorus	$S_{RDOP} = a_{PC} \cdot f_{RDOP} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT + K_{RPOP} \cdot \theta_{RPOP}^{T-20} \cdot RPOP \cdot \frac{PHYT}{K_{mPc} + PHYT} - K_{RDOP} \cdot \theta_{RDOP}^{T-20} \cdot RDOP \cdot \frac{PHYT}{K_{mPc} + PHYT}$
Labile dissolved organic phosphorus	$S_{LDOP} = a_{PC} \cdot f_{LDOP} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT + K_{LPOP} \cdot \theta_{LPOP}^{T-20} \cdot LPOP \cdot \frac{PHYT}{K_{mPc} + PHYT} - K_{LDOP} \cdot \theta_{LDOP}^{T-20} \cdot LDOP \cdot \frac{PHYT}{K_{mPc} + PHYT}$
Dissolved inorganic phosphorus	$S_{PO4} = a_{PC} \cdot f_{PO4} \cdot (K_{PR}(T) + K_{grz}(T)) \cdot PHYT + (K_{RDOP} \cdot \theta_{RDOP}^{T-20} \cdot RDOP + K_{LDOP} \cdot \theta_{LDOP}^{T-20} \cdot LDOP) \cdot \frac{PHYT}{K_{mPc} + PHYT} - a_{PC} \cdot (1 - f_{ExDOC}) \cdot G_P \cdot PHYT$

Table II-5 Silica reaction rates (Fitzpatrick, 2004)

Variable	Rate equation
Biogenic silica-unavailable	$S_{BSi} = (K_{PR}(T) + K_{grz}(T)) \cdot PHYT - K_{BSi} \cdot \theta_{BSi}^{T-20} \cdot \frac{PHYT}{K_{mPc} + PHYT} - \frac{V_{sBSi}}{H} \cdot BSi$
Available silica	$S_{Si} = K_{BSi} \cdot \theta_{BSi}^{T-20} \cdot BSi \cdot \frac{PHYT}{K_{mPc} + PHYT} - (1 - f_{ExDOC}) \cdot a_{SC} \cdot G_P \cdot PHYT$

Table II- 6 Carbon reaction rates (Fitzpatrick, 2004)

Variable	Rate equation
Refractory particulate organic carbon	$S_{RPOC} = f_{RPOC} \cdot K_{grz}(T) \cdot PHYT - K_{RPOC} \cdot \theta_{RPOC}^{T-20} \cdot RPOC \cdot \frac{PHYT}{K_{mPc} + PHYT} - \frac{V_{sRPOC}}{H} \cdot RPOC$
Labile particulate organic carbon	$S_{LPOC} = f_{LPOC} \cdot K_{grz}(T) \cdot PHYT - K_{LPOC} \cdot \theta_{LPOC}^{T-20} \cdot LPOC \cdot \frac{PHYT}{K_{mPc} + PHYT} - \frac{V_{sLPOC}}{H} \cdot LPOC$
Refractory dissolved organic carbon	$S_{RDOC} = f_{RDOC} \cdot K_{grz}(T) \cdot PHYT + K_{RPOC} \cdot \theta_{RPOC}^{T-20} \cdot RPOC \cdot \frac{PHYT}{K_{mPc} + PHYT} - K_{RDOC} \cdot \theta_{RDOC}^{T-20} \cdot RDOC \cdot \frac{PHYT}{K_{mPc} + PHYT} \cdot \frac{DO}{K_{DO} + DO}$
Labile dissolved organic carbon	$S_{LDOC} = f_{LDOC} \cdot K_{grz}(T) \cdot PHYT + K_{LPOC} \cdot \theta_{LPOC}^{T-20} \cdot LPOC \cdot \frac{PHYT}{K_{mPc} + PHYT} - K_{LDOC} \cdot \theta_{LDOC}^{T-20} \cdot LDOC \cdot \frac{PHYT}{K_{mPc} + PHYT} \cdot \frac{DO}{K_{DO} + DO}$
Algal exudates dissolved organic carbon	$S_{ExDOC} = f_{ExDOC} \cdot G_P \cdot PHYT - K_{ExDOC} \cdot \theta_{ExDOC}^{T-20} \cdot ExDOC \cdot \frac{PHYT}{K_{mPc} + PHYT} \cdot \frac{DO}{K_{DO} + DO}$
Reactive particulate organic carbon	$S_{\mathrm{Re}POC} = -K_{\mathrm{Re}POC} \cdot \theta_{\mathrm{Re}POC}^{T-20} \cdot \mathrm{Re}POC \cdot \frac{PHYT}{K_{mPc} + PHYT} - \min\left[V_{24\max}, V_{24\min} + (V_{24\max} - V_{24\min})\left(\frac{\mathrm{Re}POC}{C_{ref}}\right)^{\beta}\right] \cdot \mathrm{Re}POC$
Reactive dissolved organic carbon	$S_{\mathrm{Re}DOC} = K_{\mathrm{Re}POC} \cdot \theta_{\mathrm{Re}POC}^{T-20} \cdot \mathrm{Re}POC \cdot \frac{PHYT}{K_{mPc} + PHYT} - K_{\mathrm{Re}DOC} \cdot \theta_{\mathrm{Re}DOC}^{T-20} \cdot \mathrm{Re}DOC \cdot \frac{PHYT}{K_{mPc} + PHYT} \cdot \frac{DO}{K_{DO} + DO} \cdot \frac{\mathrm{Re}DOC}{K_{mLDOC} + \mathrm{Re}DOC}$

Table II-7 Chemical oxygen demand reaction rates (Fitzpatrick, 2004)

Variable	Rate equation
Chemical oxygen demand	$S_{COD} = K_{COD} \cdot \theta_{COD}^{T-20} \cdot \frac{PHYT}{K_{mPc} + PHYT} \cdot \frac{DO}{K_{DO_{COD}} + DO}$

Table II-8 Dissolved oxygen reaction rates (Fitzpatrick, 2004)

Variable	Rate equation
Saturation concentration of Dissolved oxygen	$C_S = \exp[-139.34411 + 1.575701 \cdot 10^5 \cdot T^{-1} - 6.642308 \cdot 10^7 \cdot T^{-2} + 1.243800 \cdot 10^{10} \cdot T^{-3} - 8.621949 \cdot 10^{11} \cdot T^{-3} - 8.621949 \cdot 10^{11} \cdot T^{-4} - S_a (1.7674 \cdot 10^{-2} - 10.754 \cdot T^{-1} + 2140.7 \cdot T^{-2})]$
Dissolved oxygen	$S_{DO} = a_{OC} \cdot a_{NH4} \cdot G_P \cdot PHYT + a_{NO3C} \cdot (1 - a_{NH4}) \cdot G_p \cdot PHYT + K_a \cdot \theta_a^{T-20} \cdot (DO_{sat} - DO) - a_{OC} \cdot K_{PR}(T) \cdot PHYT - 2 \cdot a_{ON} \cdot K_{NH4} \cdot \theta_{NH4}^{T-20} \cdot NH4 \cdot \frac{DO}{K_{nitr} + DO} - a_{OC} \cdot [K_{RDOC1} \cdot \theta_{RDOC1}^{T-20} \cdot RDOC + K_{LDOC1} \cdot \theta_{LDOC1}^{T-20} \cdot LDOC \cdot \frac{LDOC}{K_{mLDOC} + LDOC} + K_{\mathrm{Re}DOC1} \cdot \theta_{\mathrm{Re}DOC1}^{T-20} \cdot \mathrm{Re}DOC \cdot \frac{\mathrm{Re}DOC}{K_{mLDOC} + \mathrm{Re}DOC} + K_{ExDOC1} \cdot \theta_{ExDOC1}^{T-20} \cdot ExDOC \cdot \frac{ExDOC}{K_{mLDOC} + ExDOC}] \cdot \frac{PHYT}{K_{mPc} + PHYT} \cdot \frac{DO}{K_{DO} + DO} - K_{COD} \cdot \theta_{COD}^{T-20} \cdot COD \cdot \frac{PHYT}{K_{mPc} + PHYT} \cdot \frac{DO}{K_{DO_{COD}} + DO}$

Table II-9 Parameter value of phytoplankton growth (Daya Bay project, 2009)

Variable	Description	Value	Unit
G_{pmax}	Maximum specific growth rate at T_{opt}	2.0	day^{-1}
I_S	The saturating light intensity	250.0	$ly\ day^{-1}$
T_{opt}	Temperature optimum	25.0	^oC
β_1	Shaping parameter(lower than optimum temperature)	0.005	None
β_2	Shaping parameter(higher than optimum temperature)	0.005	None
K_{PR}	Respiration rate	0.1	day^{-1}
K_{grz}	Loss due to zooplankton grazing	0.08	day^{-1}
K_{mN}	Half-Saturation constant for nitrogen	10	$ug\ l^{-1}$
K_{mP}	Half-Saturation constant for phosphorus	1	$ug\ l^{-1}$
K_{mSi}	Half-Saturation constant for silica	2	$ug\ l^{-1}$
K_{mPc}	Half-Saturation constant for phytoplankton	1.0	$mg\ C\ l^{-1}$
θ_{base}	Temperature coefficient of algal settling	1.029	None
θ_{PR}	Temperature coefficient of algal respiration	1.051	None
θ_{grz}	Temperature coefficient of zooplankton grazing	1.10	None
a_{NC}	Nitrogen/Carbon Ratio	0.25	None
a_{PC}	Phosphorus/Carbon Ratio	0.025	None
a_{SC}	Silica/Carbon Ratio	0.05	None
a_{cchl}	Carbon/Chlorophyll Ratio	30	None

Table II-10 Parameter value of nitrogen cycling (Daya Bay project, 2009)

Variable	Description	Value	Unit
f_{RPON}	Fraction of respired and grazed algal nitrogen recycled to the RPON pool	0.30	None
f_{RDON}	Fraction of respired and grazed algal nitrogen recycled to the RDON pool	0.15	None
f_{LPON}	Fraction of respired and grazed algal nitrogen recycled to the LPOD pool	0.15	None
f_{LDON}	Fraction of respired and grazed algal nitrogen recycled to the LDON pool	0.15	None
f_{NH4}	Fraction of respired and grazed algal nitrogen recycled to the NH4 pool	0.25	None
K_{RPON}	RPON hydrolysis rate at 20^{o}C	0.008	day^{-1}
K_{RDON}	RDON mineralization rate at 20^{o}C	0.009	day^{-1}
K_{LPON}	LPON hydrolysis rate at 20^{o}C	0.06	day^{-1}
K_{LDON}	LDON mineralization rate at 20^{o}C	0.09	day^{-1}
θ_{RPON}	Temperature coefficient of RPON hydrolysis	1.08	None
θ_{RDON}	Temperature coefficient of RDON mineralization	1.08	None
θ_{LPON}	Temperature coefficient of LPON hydrolysis	1.08	None
θ_{LDON}	Temperature coefficient of LDON mineralization	1.08	None
V_{sRPON}	RPON settling rate	0.5	m day^{-1}
V_{sLPON}	LPON settling rate	0.5	m day^{-1}
K_{NH4}	Nitrification rate	0.08	day^{-1}
θ_{NH4}	Temperature coefficient of nitrification	1.045	None
K_{nitr}	Half saturation constant for oxygen limitation	1.0	mg O_2 l^{-1}
K_{NO23}	Denitrification rate at 20^{o}C	0.09	day^{-1}
K_{NO3}	Michaelis constant for Denitrification	0.1	mg O_2 l^{-1}

Table II-11 Parameter value of phosphorus cycling (Daya Bay project, 2009)

Variable	Description	Value	Unit
f_{RPOP}	Fraction of respired and grazed algal phosphorus recycled to the RPOP pool	0.25	None
f_{RDOP}	Fraction of respired and grazed algal phosphorus recycled to the RDOP pool	0.15	None
f_{LPOP}	Fraction of respired and grazed algal phosphorus recycled to the LPOP pool	0.15	None
f_{LDOP}	Fraction of respired and grazed algal phosphorus recycled to the LDOP pool	0.15	None
f_{PO4}	Fraction of respired and grazed algal phosphorus recycled to the PO4 pool	0.30	None
K_{RPOP}	RPOP hydrolysis rate at 20^{o}C	0.008	day^{-1}
K_{RDOP}	RDOP mineralization rate at 20^{o}C	0.01	day^{-1}
K_{LPOP}	LPOP hydrolysis rate at 20^{o}C	0.09	day^{-1}
K_{LDOP}	LDOP mineralization rate at 20^{o}C	0.1	day^{-1}
θ_{RPOP}	Temperature coefficient of RPOP hydrolysis	1.08	None
θ_{RDOP}	Temperature coefficient of RDOP mineralization	1.08	None
θ_{LPOP}	Temperature coefficient of LPOP hydrolysis	1.08	None
θ_{LDOP}	Temperature coefficient of LDOP mineralization	1.08	None
V_{sRPOP}	RPOP settling rate	0.5	m day^{-1}
V_{sLPOP}	LPOP settling rate	0.5	m day^{-1}

Table II-12 Parameter value of silica cycling (Daya Bay project, 2009)

Variable	Description	Value	Unit
K_{BSi}	Biogenic silica mineralization rate 20^{o}C	0.10	day^{-1}
θ_{BSi}	Temperature coefficient of biogenic silica mineralization	1.08	None
V_{sBSi}	Biogenic silica settling rate	0.5	m day^{-1}

Table II-13 Parameter value of carbon cycling (Daya Bay project, 2009)

Variable	Description	Value	Unit
f_{ExPP}	Fraction of primary productivity going to the algal exudates DOC pool	0.10	None
f_{LPOC}	Fraction of grazed organic carbon recycle to the LPOC pool	0.35	None
f_{LDOC}	Fraction of grazed organic carbon recycle to the LDOC pool	0.15	None
f_{RPOC}	Fraction of grazed organic carbon recycle to the RPOC pool	0.35	None
f_{RDOC}	Fraction of grazed organic carbon recycle to the RDOC pool	0.15	None
K_{RPOC}	RPOC hydrolysis rate at 20^{o}C	0.008	day^{-1}
K_{RDOC}	RDOC mineralization rate at 20^{o}C	0.009	day^{-1}
K_{LPOC}	LPOC hydrolysis rate at 20^{o}C	0.08	day^{-1}
K_{LDOC}	LDOC mineralization rate at 20^{o}C	0.10	day^{-1}
θ_{RPOC}	Temperature coefficient of RPOC hydrolysis	1.08	None
θ_{RDOC}	Temperature coefficient of RDOC mineralization	1.08	None
θ_{LPOC}	Temperature coefficient of LPOC hydrolysis	1.08	None
θ_{LDOC}	Temperature coefficient of LDOC mineralization	1.08	None
V_{sRPOC}	RPOC settling rate	0.5	m day^{-1}
V_{sLPOC}	LPOC settling rate	0.5	m day^{-1}
K_{ExDOC}	Oxidation rate of ExDOC	0.1	day^{-1}
K_{ReDOC}	Oxidation rate of ReDOC	0.25	day^{-1}
K_{RePOC}	Mineralization rate of RePOC	0.1	day^{-1}
θ_{ExDOC}	Temperature coefficient of ExDOC mineralization	1.08	None
$\theta_{\mathrm{Re}DOC}$	Temperature coefficient of ReDOC hydrolysis	1.047	None
$\theta_{\mathrm{Re}POC}$	Temperature coefficient of RePOC mineralization	1.08	None
K_{DO}	Half saturation for oxygen limitation	0.2	mg O_2 l^{-1}
K_{mLDOC}	Michaelis constant for LDOC	0.1	mg C l^{-1}
V_{24min}	Minimum RePOC settling rate	0.5	m day^{-1}
V_{24max}	Enhanced RePOC settling rate (due to floculation)	25	m day^{-1}
C_{Ref}	Reference (or normalizing term) of RePOC	10	mg C day^{-1}
β	Power function of RePOC	1.2	None

Table II-14 Parameter value of COD reaction (Daya Bay project, 2009)

Variable	Description	Value	Unit
K_{COD}	Oxidation rate in COD reaction	0.08	day^{-1}
θ_{COD}	Temperature coefficient of COD reaction	1.08	None
$K_{DO_{COD}}$	Half saturation for oxygen limitation in COD reaction	0.2	$mg\ O_2\ l^{-1}$

Table II-15 Parameter value of dissolved oxygen cycling(Daya Bay project, 2009)

Variable	Description	Value	Unit
a_{OC}	Oxygen to carbon ratio	32/12	mgO_2/mgC
a_{ON}	Oxygen to nitrogen ratio	32/14	mgO_2/mgN
a_{NO3C}	Oxygen to carbon ratio for nitrate uptake	$\frac{48}{14}a_{NC}$	mgO_2/mgC
θ_a	Temperature coefficient of reaeration	1.024	None
K_L	Oxygen transfer coefficient	1.05	$m\ day^{-1}$

Appendix III

Table III-1 Setting of wastewater outfalls for the catchment basin of Daya Bay

Number of wastewater Outfalls	Longitude	Latitude	Number of Wastewater Outfalls	Longitude	Latitude
1	114.49432	22.64846	31	114.6189	22.43752
2	114.51625	22.68416	32	114.61355	22.63366
3	114.52233	22.67463	33	114.62246	22.51464
4	114.52635	22.67463	34	114.61198	22.7554
5	114.5284	22.70667	35	114.63144	22.59018
6	114.50003	22.57509	36	114.64066	22.47166
7	114.50912	22.54611	37	114.64931	22.66689
8	114.51144	22.59533	38	114.68466	22.37534
9	114.53862	22.71617	39	114.65221	22.77117
10	114.52107	22.55679	40	114.67678	22.7577
11	114.52128	22.55972	41	114.69173	22.79193
12	114.52147	22.56266	42	114.73323	22.52377
13	114.52489	22.55947	43	114.72427	22.59602
14	114.52509	22.56244	44	114.74036	22.60826
15	114.52613	22.59219	45	114.73246	22.66495
16	114.54627	22.65182	46	114.7442	22.64146
17	114.52622	22.47389	47	114.72168	22.79342
18	114.53613	22.56482	48	114.76308	22.59651
19	114.54427	22.59492	49	114.74826	22.70032
20	114.5552	22.72882	50	114.74217	22.73856
21	114.5587	22.60398	51	114.79745	22.59904
22	114.56799	22.73512	52	114.82517	22.5998
23	114.57318	22.69007	53	114.86668	22.54036
24	114.5741	22.49202	54	114.7823	22.76761
25	114.57642	22.61991	55	114.89147	22.5743
26	114.5789	22.54752	56	114.90556	22.55362
27	114.58411	22.63903	57	114.77811	22.82714
28	114.58376	22.74161	58	114.79036	22.82679
29	114.59364	22.6548	59	114.81039	22.81593
30	114.60479	22.53222	60	114.82448	22.79153

Table III-2：Environmental capacity calculation results of Daya Bay in terms of COD_{Mn}, DIN and PO_4^-

Number of wastewater Outfalls	COD_{Mn}（t/a）	DIN（t/a）	PO_4^-（t/a）
1	141.00	12.31	1.28
2	216.94	18.85	2.00
3	161.05	13.86	1.41
4	837.00	73.01	7.80
5	219.56	19.88	1.46
6	422.83	42.71	3.21
7	232.73	22.80	1.76
8	207.80	20.43	1.58
9	207.80	20.43	1.58
10	0.00	0.00	0.00
11	1216.38	121.87	8.96
12	0.00	0.00	0.00
13	545.89	49.92	3.63
14	0.00	0.00	0.00
15	331.22	31.75	2.30
16	308.66	27.05	2.82
17	1582.10	139.46	15.16
18	736.87	70.06	5.37
19	797.26	79.63	5.89
20	94.07	9.44	0.71
21	644.06	63.40	4.82
22	370.30	36.71	2.72
23	2577.25	240.90	17.24
24	871.81	76.64	8.37
25	841.82	77.20	5.84
26	1808.02	164.91	17.26
27	1179.57	105.30	11.59
28	336.52	33.83	2.54
29	3514.69	314.86	33.80
30	525.93	47.44	4.93
31	4640.84	379.47	29.19
32	996.29	72.66	4.63
33	5192.09	450.37	49.07
34	194.40	19.54	1.47
35	2577.85	205.32	15.74
36	4134.68	336.05	25.84
37	3458.87	304.78	24.23
38	5925.93	487.58	37.51
39	253.23	21.89	2.06

-Table III-2 continued

Number of wastewater Outfalls	COD_{Mn}（t/a）	DIN（t/a）	PO_4^-（t/a）
40	1020.95	89.67	9.35
41	192.38	16.09	1.76
42	4035.03	306.46	25.54
43	15355.19	1237.63	86.16
44	2141.67	194.35	13.69
45	1389.57	117.05	13.50
46	241.38	21.62	1.57
47	89.99	7.53	0.82
48	237.96	20.50	2.38
49	221.85	18.69	2.05
50	687.61	57.49	6.27
51	2177.84	189.07	22.32
52	1069.80	93.52	11.20
53	14712.49	1117.38	93.11
54	514.98	42.59	4.45
55	1268.63	96.32	8.02
56	8973.25	681.52	56.79
57	268.12	21.80	2.18
58	392.37	32.09	3.21
59	140.36	11.48	1.15
60	100.61	8.23	0.82
Sum	103535.34	8593.39	732.11

Table III-3: Environmental capacity calculation results of Daya Bay in terms of CODcr, NH_3-N and PO_4^-

Number of wastewater Outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
1	380.70	6.77	1.28
2	585.74	10.37	2.00
3	434.84	7.62	1.41
4	2259.90	40.16	7.80
5	592.81	10.93	1.46
6	1141.64	23.49	3.21
7	628.37	12.54	1.76
8	561.06	11.24	1.58
9	561.06	11.24	1.58
10	0.00	0.00	0.00
11	3284.23	67.03	8.96
12	0.00	0.00	0.00
13	1473.90	27.46	3.63
14	0.00	0.00	0.00
15	894.29	17.46	2.30
16	833.38	14.88	2.82
17	4271.67	76.70	15.16
18	1989.55	38.53	5.37
19	2152.60	43.80	5.89
20	253.99	5.19	0.71
21	1738.96	34.87	4.82
22	999.81	20.19	2.72
23	6958.58	132.50	17.24
24	2353.89	42.15	8.37
25	2272.91	42.46	5.84
26	4881.65	90.70	17.26
27	3184.84	57.92	11.59
28	908.60	18.61	2.54
29	9489.66	173.17	33.80
30	1420.01	26.09	4.93
31	12530.27	208.71	29.19
32	2689.98	39.96	4.63
33	14018.64	247.70	49.07
34	524.88	10.75	1.47
35	6960.20	112.93	15.74
36	11163.64	184.83	25.84
37	9338.95	167.63	24.23
38	16000.01	268.17	37.51
39	683.72	12.04	2.06

-Table III-3 continued

Number of wastewater Outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
40	2756.57	49.32	9.35
41	519.43	8.85	1.76
42	10894.58	168.55	25.54
43	41459.01	680.70	86.16
44	5782.51	106.89	13.69
45	3751.84	64.38	13.50
46	651.73	11.89	1.57
47	242.97	4.14	0.82
48	642.49	11.28	2.38
49	599.00	10.28	2.05
50	1856.55	31.62	6.27
51	5880.17	103.99	22.32
52	2888.46	51.44	11.20
53	39723.72	614.56	93.11
54	1390.45	23.42	4.45
55	3425.30	52.98	8.02
56	24227.78	374.84	56.79
57	723.92	11.99	2.18
58	1059.40	17.65	3.21
59	378.97	6.31	1.15
60	271.65	4.53	0.82
Sum	279545.42	4726.36	732.11

Table III-4: Allocation results for Daya Bay Economy and Technology Development Zone

New number of Wastewater outfalls	Old Number of Wastewater outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
DY1	2	585.74	10.37	2.00
DY2	3	434.84	7.62	1.41
DY3	4	2259.90	40.16	7.80
DY4	5	592.81	10.93	1.46
DY5	9	561.06	11.24	1.58
DY6	23	6958.58	132.50	17.24
DY7	20	253.99	5.19	0.71
DY8	22	999.81	20.19	2.72
DY9	28	908.60	18.61	2.54
DY10	34	524.88	10.75	1.47
DY11	39	683.72	12.04	2.06
DY12	40	2756.57	49.32	9.35
DY13	41	519.43	8.85	1.76
DY14	37	9338.95	167.63	24.23
DY15	32	2689.98	39.96	4.63
DY16	35	6960.20	112.93	15.74
DY17	36	11163.64	184.83	25.84
DY18	31	12530.27	208.71	29.19
DY19	43	41459.01	680.70	86.16
DY20	38	16000.01	268.17	37.51
Sum		118181.97	2000.67	275.40

Table III-5: Allocation results for Huidong County

New number of Wastewater outfalls	Old Number of Wastewater outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
HD1	47	242.97	4.14	0.82
HD2	57	723.92	11.99	2.18
HD3	58	1059.40	17.65	3.21
HD4	59	378.97	6.31	1.15
HD5	60	271.65	4.53	0.82
HD6	54	1390.45	23.42	4.45
HD7	50	1856.55	31.62	6.27
HD8	49	599.00	10.28	2.05
HD9	45	3751.84	64.38	13.50
HD10	46	651.73	11.89	1.57
HD11	44	5782.51	106.89	13.69
HD12	42	10894.58	168.55	25.54
HD13	48	642.49	11.28	2.38
HD14	51	5880.17	103.99	22.32
HD15	52	2888.46	51.44	11.20
HD16	55	3425.30	52.98	8.02
HD17	56	24227.78	374.84	56.79
HD18	53	39723.72	614.56	93.11
Sum		104391.48	1670.73	269.07

Table III-6: Allocation results for Longgang District

New number of Wastewater outfalls	Old Number of Wastewater outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
SZ1	1	380.70	6.77	1.28
SZ2	16	833.38	14.88	2.82
SZ3	29	9489.66	173.17	33.80
SZ4	27	3184.84	57.92	11.59
SZ5	25	2272.91	42.46	5.84
SZ6	21	1738.96	34.87	4.82
SZ7	19	2152.60	43.80	5.89
SZ8	15	894.29	17.46	2.30
SZ9	8	561.06	11.24	1.58
SZ10	6	1141.64	23.49	3.21
SZ11	7	628.37	12.54	1.76
SZ12	10	0.00	0.00	0.00
SZ13	11	3284.23	67.03	8.96
SZ14	12	0.00	0.00	0.00
SZ15	13	1473.90	27.46	3.63
SZ16	14	0.00	0.00	0.00
SZ17	18	1989.55	38.53	5.37
SZ18	26	4881.65	90.70	17.26
SZ19	30	1420.01	26.09	4.93
SZ20	33	14018.64	247.70	49.07
SZ21	24	2353.89	42.15	8.37
SZ22	17	4271.67	76.70	15.16
Sum		56971.97	1054.96	187.64

Table III-7: Preliminary allocation results for subdistricts of Daya Bay Economy and Technology Development Zone

Allocation objects	No. of wastewater outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
Western Region + Central Region + Harbor Region	DY1	585.74	10.37	2.00
	DY4	592.81	10.93	1.46
	DY5	561.06	11.24	1.58
	DY6	6958.58	132.50	17.24
	DY7	253.99	5.19	0.71
	DY8	999.81	20.19	2.72
	Subtotal	9951.98	190.42	25.71
Petrochemical industry Region	DY9	908.60	18.61	2.54
	DY10	524.88	10.75	1.47
	DY14	9338.95	167.63	24.23
	DY19	41459.01	680.70	86.16
	DY20	16000.01	268.17	37.51
	Subtotal	68231.46	1145.85	151.91
Xiachong	DY11	683.72	12.04	2.06
	DY12	2756.57	49.32	9.35
	DY13	519.43	8.85	1.76
	Subtotal	3959.71	70.21	13.17
Islands	DY2	434.84	7.62	1.41
	DY3	2259.90	40.16	7.80
	DY15	2689.98	39.96	4.63
	DY16	6960.20	112.93	15.74
	DY17	11163.64	184.83	25.84
	DY18	12530.27	208.71	29.19
	subtotal	36038.82	594.20	84.61
Total		118181.97	2000.67	275.40

Table III-8: Allocation results for subdistricts of Huidong County

Allocation objects	No. of wastewater outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
Renshan Town	HD1	242.97	4.14	0.82
	HD2	723.92	11.99	2.18
	HD3	1059.40	17.65	3.21
	HD4	378.97	6.31	1.15
	HD5	271.65	4.53	0.82
	Subtotal	2676.92	44.62	8.18
Pinghai Town	HD6	1390.45	23.42	4.45
	HD7	1856.55	31.62	6.27
	HD8	599.00	10.28	2.05
	HD9	3751.84	64.38	13.50
	HD10	651.73	11.89	1.57
	HD11	5782.51	106.89	13.69
	HD12	10894.58	168.55	25.54
	HD13	642.49	11.28	2.38
	HD14	5880.17	103.99	22.32
	HD15	2888.46	51.44	11.20
	HD16	3425.30	52.98	8.02
	HD17	24227.78	374.84	56.79
	HD18	39723.72	614.56	93.11
	Subtotal	101714.56	1626.11	260.89
Total		104391.48	1670.73	269.07

Table III-9: Allocation results for subdistricts of Longgang District

Allocation objects	No. of wastewater outfalls	CODcr（t/a）	NH_3-N（t/a）	PO_4^-（t/a）
Kuichong Subdistrict	SZ1	380.70	6.77	1.28
	SZ2	833.38	14.88	2.82
	Subtotal	1214.08	21.65	4.10
Dapeng Subdistrict	SZ3	9489.66	173.17	33.80
	SZ4	3184.84	57.92	11.59
	SZ5	2272.91	42.46	5.84
	SZ6	1738.96	34.87	4.82
	SZ7	2152.60	43.80	5.89
	SZ8	894.29	17.46	2.30
	SZ9	561.06	11.24	1.58
	SZ10	1141.64	23.49	3.21
	Subtotal	21435.98	404.40	69.03
Nanao Subdistrict	SZ11	628.37	12.54	1.76
	SZ12	0.00	0.00	0.00
	SZ13	3284.23	67.03	8.96
	SZ14	0.00	0.00	0.00
	SZ15	1473.90	27.46	3.63
	SZ16	0.00	0.00	0.00
	SZ17	1989.55	38.53	5.37
	SZ18	4881.65	90.70	17.26
	SZ19	1420.01	26.09	4.93
	SZ20	14018.64	247.70	49.07
	SZ21	2353.89	42.15	8.37
	SZ22	4271.67	76.70	15.16
	Subtotal	34321.91	628.91	114.51
Total		56971.97	1054.96	187.64

Table III-10: Available environmental capacity for each districts of Daya Bay

Administrative Districts	Subdistricts	Available natural Environmental capacity (t/a)		
		CODcr	NH_3-N	PO_4^-
Daya Bay Economy And Technology Development Zone	Western Region	3337.46	67.30	9.71
	Central Region	5339.06	100.24	13.49
	Harbor Region	1275.46	22.87	2.50
	Petrochemical Industry Region	52231.45	877.68	114.40
	Xiachong	3959.71	70.21	13.17
	Islands	36038.82	594.20	84.61
	Subtotal	102181.96	1732.51	237.89
Huidong County	Renshan	2676.92	44.62	8.18
	Pinghai	77436.78	1251.27	204.10
	Subtotal	80113.70	1295.89	212.28
Longgang District	Kongchong	1214.08	21.65	4.10
	Dapeng	21435.98	404.40	69.03
	Nanao	34321.91	628.91	114.51
	Subtotal	56971.97	1054.96	187.64
Total		239267.62	4083.36	637.81