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INTEGRATED CATCHMENT MANAGEMENT OF DEEP BAY, HONG KONG

C. S. W. Kueh and H. K. Chui

Environmental Protection Department, Hong Kong Government, Hong Kong

ABSTRACT

Deep Bay contains one of the most important wetlands in southern China. It is located at the border of Hong Kong and the Shenzhen Special Economic Zone (SEZ). Over 50,000 birds rely on this wetland as a breeding, feeding, resting and refuelling station in winter. The Deep Bay catchment is also one of Asia's fastest developing areas. Its population has doubled since 1984. The rapid population increase and economic development have exerted considerable pressure on the wetland environment. Efforts have been made to reduce the pollution loads by both the Hong Kong and Shenzhen Governments to protect this ecologically important wetland. Through the implementation of a series of environmental programmes, including: sewerage master plans, the livestock waste control scheme, and enforcement of the Water Pollution Control Ordinance, the pollution loads arising from Hong Kong decreased from 125,000 to 45,000 kgBOD_5/day between 1988 and 1994 and are expected to further reduce to around 3,000 kgBOD_5/day by the year 2000. To protect the wetland community while promoting sustainable development in the catchment, Hong Kong initiated a study in 1995 to develop a mathematical model for the bay and a water quality management strategy for the future. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

KEYWORDS

Deep Bay; integrated catchment management; pollution reduction; sustainable development; wetland.

INTRODUCTION

Deep Bay is a semi-enclosed bay of predominantly estuarine water and inter-tidal mud flats. It is located at the border of Hong Kong and the Shenzhen Special Economic Zone (SEZ) in the Guangdong province of China (Fig. 1). Situated to the east of the Pearl River Estuary, Deep Bay has a length of 17 km and a width varying from 4 km to 8 km, forming a total area of about 11,500 hectares. The seabed of Deep Bay is relatively flat with an average depth of 2.9 m at mean sea level.

Deep Bay contains a wetland of internationally recognized importance and one of the largest mangrove communities in southern China. Covering an area of 380 hectares, the wetland is highly fertile with an annual productivity of more than 12 tonnes dry weight per hectare (Young and Melville 1993). This supports a diverse faunal community including arboreal, benthic, surface dwelling and pelagic organisms amongst which a dozen invertebrate species (crabs, worms, snails, etc.) are new to science. It also supports over 250 species of birds, especially waterfowls and migratory birds, which rely on the wetland as a breeding, feeding, resting and refuelling station in winter. More than 50,000 birds, of which around 80% are migrants and visitors, have been recorded in Deep Bay's largest mangrove marshes, the Mai Po Marshes Nature

Reserve, in a single day. These include at least 12 globally threatened species, e.g. Black-faced Spoonbill (*Palatea minor*), Saunders' Gull (*Larus saundersi*), Asiatic Dowitcher (*Limnodromus semipalmatus*) and Spotted Greenshank (*Tringa guttifer*). Due to its ecological importance, Mai Po is listed as a Wetland of International Importance especially as Waterfowl Habitat under the Ramsar Convention (Ramsar Site). In addition, Deep Bay has 600 hectares of oyster culture ground. Fishing, pond fish culture and shrimp culture are important activities in Deep Bay.

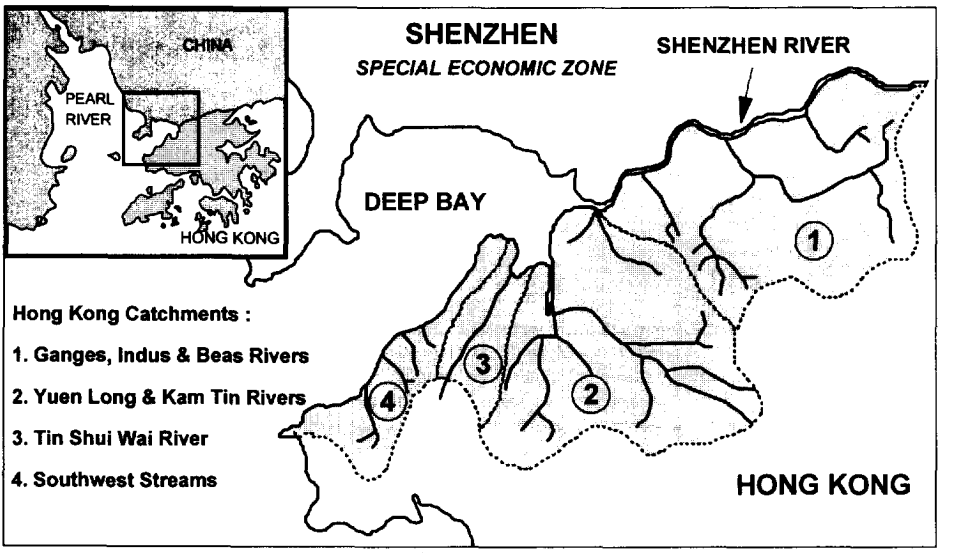

Figure 1. The Deep Bay catchment.

As a result of the rapid economic growth in southern China and large volume of cross-border trade between Hong Kong and Guangdong province, the Deep Bay catchment has been transformed from a rural, agricultural land into a new megapolis in the last 15 years. Between 1984 and 1993, population increased from 0.5 to 1.2 million in the Shenzhen SEZ and from 0.3 to 0.5 million in the Hong Kong catchment. The rapid population increase and industrial development have exerted considerable pressure on the wetland environment. Most of the rivers and streams in the Deep Bay catchment are grossly contaminated with waste matter from livestock farms, industrial effluents, and domestic discharges from unsewered villages. Water in the inner Deep Bay is high in organic, inorganic and bacterial pollutants. Toxic algal blooms have occurred in the bay (Zhang *et al.* 1994) and oysters growing in the area are contaminated with disease-causing microorganisms (Kueh 1992) and trace metals (Phillips *et al.* 1982). Since 1988, a series of measures have been taken to reduce pollution loads from major sources, improve both inland and marine water quality, and preserve natural habitats in Deep Bay. This paper presents an overview of the water pollution problems and actions taken to tackle these problems while maintaining sustainable development in the catchment.

DEEP BAY MANAGEMENT PLAN

Recognizing its ecological importance, Deep Bay was identified by Hong Kong and Guangdong as the highest priority area requiring protective conservation action. The first target was to control the pollution loads and to restore water quality in the Shenzhen River which drains into Deep Bay.

Serving as a boundary between Shenzhen SEZ and Hong Kong, the Shenzhen River is about 28 km in length, covering a catchment area of 300 km^2. Of this area, 190 km^2 is on the north bank and 110 km^2 on the south bank of the river, under the management of the Shenzhen SEZ and Hong Kong Governments, respectively. The water quality of Shenzhen River was good before the 1970s. However, rapid development

has resulted in a serious deterioration of the condition of the river. Since 1982, the Shenzhen River has been jointly monitored by both Governments and a Management Plan for Shenzhen River Pollution Control was subsequently developed in 1988. The plan aimed at gradually improving the water quality and aesthetic appearance of the river by reducing its pollution loading and restoring water quality by the year 2000.

In 1992, the Pollution Control Management Plan was extended to cover the whole Deep Bay catchment. A set of joint Environmental Quality Objectives was set as a preliminary long term goal to be achieved for the water in Deep Bay. The objectives are to be refined in the future as detailed information on the hydrology and assimilative capacity of Deep Bay becomes available. In order to effectively control pollutants entering Deep Bay, the need to study the dispersion characteristics of pollutants within the bay and to determine its assimilative capacity was identified at that time.

Pollution abatement measures have been carried out by both Hong Kong and Shenzhen. Whilst Shenzhen intended to reduce pollution loads by treating part of its wastewater by secondary treatment and exporting the rest of the wastewater out of the Deep Bay catchment (Huang *et al.* 1988), Hong Kong implemented a series of environmental programmes including a livestock waste control scheme, enforcement of the Water Pollution Control Ordinance, and sewerage master plans (SMPs). In addition, Hong Kong also established a "Zero Discharge Policy" as a long term target which, through stringent control of development plans, aimed at preventing any substantial additional pollution load entering Deep Bay.

Apart from implementing these pollution load reduction programmes, Hong Kong also initiated a series of actions to protect ecologically sensitive sites in Deep Bay from deterioration due to development and human disturbance (Fig. 2). The first action was taken in 1975 with the declaration of the Mai Po Marshes as a Restricted Area under the Wild Animals Protection Ordinance to keep disturbance to a minimum. Six Sites of Special Scientific Interest (SSSI) were also established in recognition of their unique flora and fauna. In 1988, Hong Kong further established two buffer zones around Inner Deep Bay to ensure that land use in the area was compatible with the ecological sensitivity of the sites. No new development is allowed in Buffer Zone 1 unless it is required to support the conservation of the area's natural features and scenic qualities, while no new development in Buffer Zone 2 will be allowed if it has any significant environmental impact on Inner Deep Bay. There is also a plan to extend the Mai Po Restricted Area to cover the inter-tidal mudflats so that the disturbance by human activities such as fishing can be kept to a minimum.

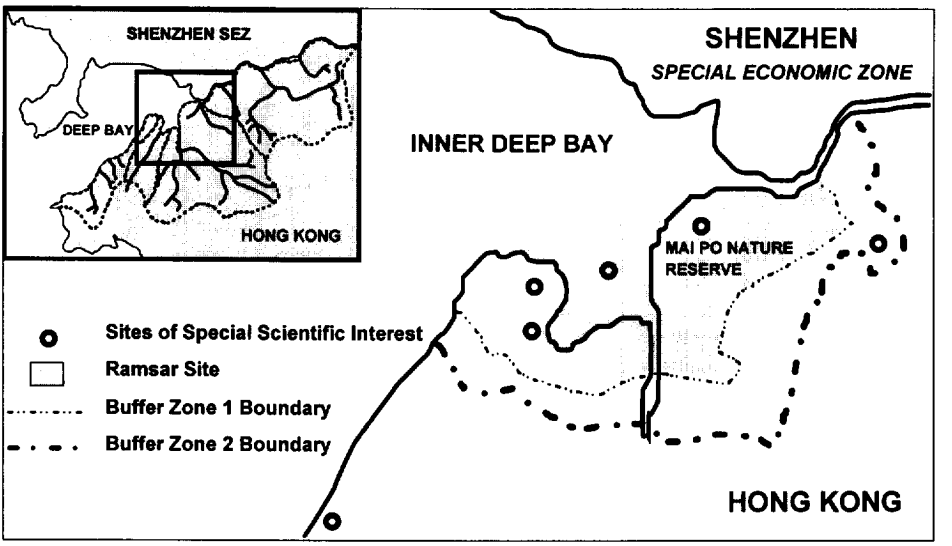

Figure 2. Ecologically sensitive areas in Deep Bay.

CURRENT WATER QUALITY

Marine water

Deep Bay is strongly influenced by the flow from the Pearl River and summer monsoon rain with characteristic fluctuations in temperature (18-29°C), salinity (10-32 $^{o}/_{oo}$) and suspended solid levels (1-25 mg/L) (EPD 1994a). Deep Bay can be divided into inner and outer zones. The current water quality in the Inner Deep Bay, which receives river flows from Shenzhen, Yuen Long, Kam Tin and their tributaries is very poor. Levels of total nitrogen, total phosphorus, suspended solids and chlorophyll-a are highest amongst Hong Kong's marine waters. With an annual mean DO level of 62% saturation at the surface, the dissolved oxygen level of Inner Deep Bay is also the lowest in the territory, with the exception of grossly polluted typhoon shelters. The BOD_5 level averaged 1.5 mg/L and NH_4-N averaged 1.32 mg/L in 1993 (Table 1). Toxic plankton blooms are known to have occurred in the bay. During a red tide incident in February 1986, 50% of the oysters cultured were wiped out (Zhang *et al.* 1994). Water in Inner Deep Bay where many oyster culture rafts are located has a high faecal bacterial count. Studies carried out between 1993 and 1994 show that *E. coli* in the oyster tissues and sediments in the inner bay averaged 10^4 per 100 g representing a 10 fold increase from that in the ambient water (Ho and Tam 1995). A number of pathogenic organisms including *Salmonella, Vibrio parahaemolyticus, Vibrio cholerae (non-O1),* and *Vibrio fulnificus* (Kueh 1992; Ho and Tam 1995) have been detected in the oysters at a level which can be a health risk if they are eaten undercooked. Consumption of oysters and other shellfish in winter months has long been suspected to be linked with outbreaks of hepatitis A during this period. Work to detect hepatitis A virus in oyster tissues is in progress.

Bottom sediments of inner Deep Bay are anoxic and heavily contaminated with toxic metals, in particular zinc (>200 mg/kg dry solids), chromium (50-80 mg/kg) and copper (>65 mg/kg) (EPD 1994a). These may be attributed to the discharges from electroplating, electronics and dyeing industries mostly located in the urban areas. Toxic metals have also been detected in the oyster issues which are a possible health risk to the public (Phillips *et al.* 1982).

Table 1. Water quality in the Deep Bay catchment

Location	DO (mg/L)	BOD_5 (mg/L)	NH_4-N (mg/L)	*E.coli** per 100mL
Marine Waters				
Inner Deep Bay	5.8	1.5	1.32	730
Outer Deep Bay	6.7	0.7	0.15	160
Rivers				
Ganges River	3.3	68	12	$4x10^6$
Beas River	1.4	47	7	$8x10^6$
Indus River	1.8	13	4	$2x10^6$
Yuen Long River	2.3	110	17	n.a.**
Kam Tin River	1.1	44	15	n.a.**
Tin Shui Wai River	4.4	17	2	$2x10^7$
Southwest Streams	6.2	28	3	n.a.**

All values are average of monthly samples in 1993 (EPD 1994a,b).
* *E.coli* is expressed as geometric means.
** n.a. - not available.

Rivers and streams

The Shenzhen River has deteriorated to such a stage that it affects the residents living along its banks. A large part of the river is turbid and smelly. The lower estuarine reach typically has a DO level of 0.7 mg/L at

low tide and 1.0 mg/L at high tide. Its tributaries, including the Rivers Ganges, Beas and Indus on the Hong Kong side and Shawan, Buji Rivers on the Shenzhen side, are also foul, smelly and devoid of aquatic life. Most rivers in the Deep Bay catchment are heavily contaminated with organic wastes with an annual mean BOD_5 in the range of 13-110 mg/L and NH_4-N in the range of 2-17 mg/L (Table 1). Three of the seven rivers and streams had an annual DO level of less than 2 mg/L. *E. coli* counts of the river water are generally between 10^6 and 10^7 per 100 mL, not dissimilar to that of settled domestic sewage. Using a water quality index developed by the Netherlands Ministry of Transport and Public Works, based on DO, BOD_5 and NH_4-N, all six major rivers within the Hong Kong catchment are rated as "bad" to "very bad". Pristine water can still be found in the upstream Ganges River and in a few minor streams outside the urban areas. Although a slight improvement has been detected in some parts of the rivers in the last few years, the overall inland water quality in the Deep Bay catchment remains very poor and in need of urgent improvement.

Ecology in the Mai Po Marshes Nature Reserve has been shown to be adversely impacted by pollution from the Deep Bay rivers. An extensive study carried out between 1990 and 1991 (Chiu 1992) indicates that organic pollutants in the water and sediment have depleted the oxygen level to such an extent that the survival of sensitive species in the mangroves has been affected. The population of the native shrimp, *Exopalaemon styliferus*, diminishes with pollution loading. Algae and mangrove leaf litter, as well as herbivores consuming these leaves have also been shown to contain high concentration of trace metals.

REDUCTION OF POLLUTION LOADS

Deterioration of water quality in Deep Bay and contamination of sediments as a result of human activities poses major threats to the ecologically sensitive areas and the beneficial uses of the water. The problem is aggravated by the increasing changes in land use and development pressure in the catchment. In order to arrest the deteriorating trend, steps have been taken by Hong Kong in identifying major pollution sources, prioritizing environmental targets, and formulating an action plan comprising various pollution load reduction programmes since 1988.

The total organic and nitrogen loads from the Hong Kong catchment to Deep Bay in 1988 were estimated to be 125,000 kgBOD_5/day and 37,000 kgN/day, respectively. Of this around 85% came from over 0.5 million pigs and 16 million poultry in the catchment, the untreated wastewater of which was discharged directly into the receiving waters. The rest of the pollution load was contributed by industrial discharges, expedient sewer connections in the urban areas, domestic discharges from village houses, and effluent discharges from Government Sewage Treatment Works (STWs).

Livestock waste control scheme

As the first major environmental programme implemented in Deep Bay, Hong Kong developed a livestock waste control scheme under the Waste Disposal Ordinance to reduce the pollution load arising from the livestock farms. Under the scheme, farmers were required to provide treatment for the livestock wastes and meet the effluent standard. To assist farmers to install the treatment facilities, technical guidance was provided as well as financial assistance in the form of Capital Grant and Loan. Treatment methods such as dry muck-out, wet muck-out and pig-on-litter were introduced to the farmers at the Takwuling Demonstration Farm. To those farmers who chose to wind up their livestock rearing business, ex-gratia payments were offered.

In the course of implementation of the livestock waste control scheme, the BOD_5 load arising from livestock wastes was reduced by 65% between 1988 and 1994. It is expected that almost all the pollution load from livestock rearing activities in the Deep Bay catchment will be eliminated by the end of the century.

Water pollution control ordinance

Deep Bay was declared as a Water Control Zone under the Water Pollution Control Ordinance in 1990. Since then, over 75% of the industrial discharges and expedient connections have been brought under control. Under the Ordinance, all waste discharges into the bay are required to receive at least secondary

treatment unless they are discharged to foul sewers leading to a Government STW. Stringent discharge standards have been established according to the volume of the discharge and the beneficial uses of the receiving water (EPD 1991). In addition, waste dischargers are also required to install proper sewers and rectify any expedient connections identified. Village houses operating septic tanks should comply with specific guidelines. If public sewers are provided nearby, villagers can be required under the Water Pollution Control Ordinance to make connection to these sewers.

Sewerage master plans

The main purpose of implementing sewerage master plans (SMPs) in the Deep Bay catchment is to provide adequate sewerage facilities for both urban and rural areas based on the current and projected growth and development plan. This involves evaluating the capability of the existing sewerage, upgrading and rectifying inappropriate sewerage and sewage treatment facilities, and providing new sewerage to remote villages. Two SMPs have been implemented since 1992: the North District SMP covering the south of Shenzhen River, and the Yuen Long and Kam Tin SMP covering the rest of the Deep Bay catchment.

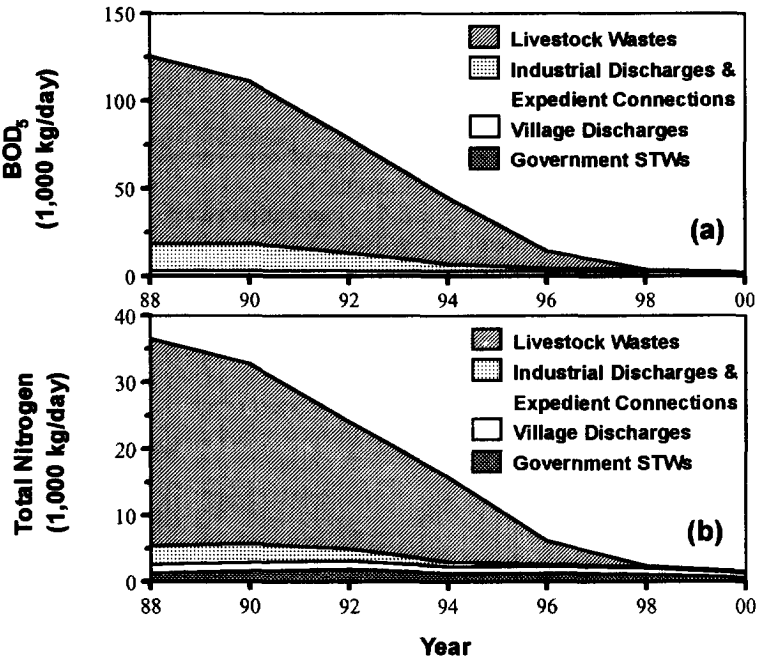

Figure 3. Reduction of pollution loads to Deep Bay from the Hong Kong catchment. (a) BOD_5, (b) Total Nitrogen.

In view of the rapid population growth in new towns and housing estates, priority has been given to the upgrading of sewerage and provision of trunk sewers to major property developments. Expedient connections in existing urban areas are being rectified as a priority action. On the other hand, as the pollution load from village type developments in the rural areas is comparatively small (< 2%), provision of sewerage and sewage treatment facilities to the remote villages is given a lower priority and its implementation will be extended beyond the year 2000. A guidance note (EPD 1992) concerning on-site sewage treatment using the septic tank/soakaway systems was therefore provided for these villages in the interim.

Although the organic loading derived from the Government STW is small (< 1%) as compared with other pollution sources (Fig. 3a), their effluent is an important source of nitrogen loads to Deep Bay (Fig. 3b). This will be especially so after the removal of livestock pollution in 1998. To reduce the impact of this pollution

source, effluent from Yuen Long STW will be transported out of Deep Bay by an effluent export scheme under the Yuen Long and Kam Tin SMP. Another Government treatment works, the Shek Wu Hui STW, on the other hand, will be upgraded to provide tertiary treatment including nitrification/denitrification under the North District SMP. In addition, the Shek Wu Hui STW will also be upgraded with disinfection facilities to reduce bacterial loads to Deep Bay.

Results of the environmental programmes

Traditionally, pollution in the Deep Bay catchments has been dominated by livestock farm wastes. By the end of this century, over 100,000 kgBOD_5/day, 30,000 kgN/day (Fig. 3a and b) and $5x10^{16}$ *E.coli*/day from this source will be removed due to the implementation of the livestock waste control scheme. This is equivalent to a reduction of 85% of BOD_5 and nitrogen loads, and 92% of *E.coli* load in the Hong Kong catchment.

The aforesaid environmental programmes will result in a total BOD_5 reduction of around 120,000 kg/day in 2000 as compared with that in 1988. The ultimate BOD_5 loading by then is expected to be around 3,000 kg/day (Fig. 3a). Further reduction of BOD_5 load will come from the sewerage provision and connection programmes to the rural areas after the year 2000.

Reduction of nitrogen load to Deep Bay from the Hong Kong catchment is shown in Fig. 3b. By the year 2000, the nitrogen load will be around 2,000 kgN/day as compared to the loading of 37,000 kgN/day in 1988. In terms of bacterial pollution, there will be a 99% reduction of the total *E.coli* load through implementation of all the major environmental programmes.

THE REGIONAL WATER QUALITY MANAGEMENT STRATEGY STUDY

Although a series of measures have been initiated to reduce pollution in Deep Bay, the effect of diffuse sources and pollution loads from Shenzhen SEZ to Deep Bay is not well understood. To cater for the sustainable development in the region whilst protecting the ecologically sensitive wetland in Deep Bay, there is a need to formulate strategic options for managing the water quality in the catchment. As the hydrography of Deep Bay is complicated by its shallow nature and the influence of the Pearl River Estuary, it is necessary to obtain a detailed understanding of the hydraulic, chemical, and biological processes within the bay. It is also essential to develop a mathematical model for quantifying its assimilative capacity and establishing a regional strategy for future developments. Hence, Hong Kong has initiated a Regional Water Quality Management Strategy Study in 1995, to be completed in three years, to:

- determine the current and future flow, pollution loading (both point and non-point sources) and water quality regime in the Deep Bay;
- determine the capacity of Deep Bay to assimilate nutrients and other potentially polluting materials, and to review the Water Quality Objectives originally set for Deep Bay;
- establish future strategies to achieve and maintain the Water Quality Objectives proposed; and
- assess the likely effects on water quality as a result of land use changes and pollution from development projects.

CONCLUSIONS

Effective steps need to be taken urgently to control water pollution and preserve Deep Bay's natural habitat. To protect this ecologically sensitive wetland whilst maintaining sustainable development in the Deep Bay catchment, Hong Kong has implemented a series of pollution abatement programmes to reduce pollution loads into the bay. These programmes include the livestock waste control scheme, enforcement of the Water Pollution Control Ordinance, and implementation of the sewerage master plans. The organic pollution load

arising from Hong Kong in the year 2000 will be 2% of the load in 1988. In terms of nitrogen and bacterial loads, around 95% and 99% reduction will also be achieved, respectively. Whether the resultant pollution load will be sufficient to achieve the environmental quality standards set and what management strategy is required to maintain these standards will be assessed in a modelling study to be carried out shortly.

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