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Chapter 22

The Application of Constructed Wetlands for Water Quality Improvement in the Deep Bay Catchment of Hong Kong

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Abstract. A mosaic of natural and man-made wetland habitats can be found in the northwestern New Territories of the Hong Kong SAR, supporting a high diversity of fauna and flora. The Inner Deep Bay mudflats is the core area of the Deep Bay wetland ecosystem, which provides feeding grounds for the tens of thousands of migratory waterbirds that annually stop-off in Hong Kong. Due to the rapid urbanization and population growth of the Deep Bay catchment, the water quality of Deep Bay is poor and consistently beyond the set objective. In order to protect the water environment and thus the wetland ecosystem of Deep Bay, and allow its assimilative capacity to be met in the long term, the pollution load entering the Bay needs to be significantly reduced. To achieve this, the Shenzhen SEZ and Hong Kong SAR Governments have formulated a joint implementation program to tackle Deep Bay's water quality problems. Stringent requirements for developments within the Deep Bay catchment have also been established. Developments in areas soon, or unlikely ever, to be connected to the public sewer have to provide effective onsite sewage treatment facilities and further measures to offset the residual pollution load from the facilities during the interim, or the life of the development. This is to achieve the requirement of no net increase in pollution loading into Deep Bay. The idea of using constructed wetlands to polish effluent from treatment plants or polluted streams in order to balance the net increase of pollution load is commonly adopted in planning proposals. So far a number of such proposals have been endorsed and some developments in the Deep Bay area are described. The effectiveness of constructed wetlands for water quality improvement in Hong Kong still needs to be demonstrated.

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22.1. Introduction

Constructed wetlands are man-made complexes consisting of different types of substrate, emergent and/or submerged vegetation, wildlife and water that simulate natural wetlands to treat wastewater. The processes of biological degradation, filtration, sedimentation and absorption result in significant reduction of suspended solids and organic pollutants. Such constructed wetlands are in widespread use in the USA and are becoming common in Europe, Australia and parts of Asia and Africa (Bastian & Hammer, 1993; Cooper & Green, 1995; Urbanc-Bercic & Bulc, 1995; Cooper et al., 1996). Interest has also grown in making use of wetland processes to treat urban and agricultural stormwater runoff (Raisin & Mitchell, 1995; Cooper et al., 1996). However, there is limited data and experience in Hong Kong on using constructed wetland for water improvement, apart from a mini setup at the Kadoorie Farm and Botanic Garden to demonstrate the function of constructed wetlands on treating wastewater from a livestock source. In the recent years, the approach of using constructed wetland has been widely proposed by development projects within the Deep Bay catchment in response to the stringent pollution control requirement imposed in Deep Bay for protecting the ecological integrity of that site (Town Planning Board, 1999). This chapter reviews the status and strategy of a few ongoing projects on using constructed wetland to achieve the planning requirements.

22.2. Deep Bay Catchment

Deep Bay is a large shallow semi-enclosed bay located in the northwestern New Territories of Hong Kong. It is fed by water from the Pearl River Estuary and several rivers around the bay (Fig. 1). The total surface area of the Bay is approximately 112 km, with a length of about 15 km and an average depth of 3 m. The total catchment area of the Bay covers about 535 km^2, of which 51% lies on the Shenzhen side and 49% lies in the New Territories of Hong Kong (Environmental Protection Department, 1998). The Shenzhen River flows from the northeast to southwest into Deep Bay and forms the boundary between Hong Kong and Shenzhen.

The Deep Bay catchment comprises many high-valued ecological sites, especially around Inner Deep Bay. On the Hong Kong side of this site, different natural and man-made wetlands provide a wide range of habitats to support a high diversity of biota. Habitats including the mudflats, mangroves, traditional shrimp ponds (*gei wai*), inundated marshlands and extensive man-made fishponds in these areas are recognized to have high ecological values, and form a complex wetland

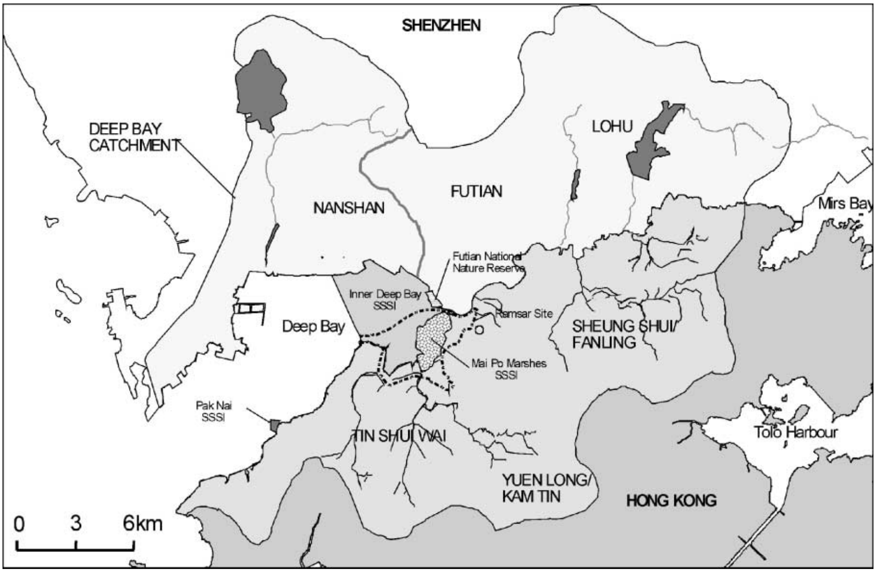

Figure 1: Delineation of the Deep Bay catchment and the distribution of the major sensitive sites around Deep Bay.

ecosystem in Inner Deep Bay (Planning Department, 1997). The wetlands within and surrounding the Mai Po Nature Reserve are an especially important roosting and feeding ground for ten of thousands of migratory birds and variety of local species. A 1,500 ha area of the Mai Po Marshes, Inner Deep Bay and surrounding fishponds were listed as a "Wetland of International Importance" (Ramsar Site) in 1995. According to the SSSI registration and the latest review (Planning Department, 1999), there are a number of important ecological sensitive receivers around the coast of and at Deep Bay. These include the Inner Deep Bay Site of Special Scientific Interest (SSSI) (1986), Futian National Nature Reserve in Shenzhen, Mai Po Inner Deep Bay Ramsar Site (1995), Mai Po Marshes SSSI (1976), Mai Po village SSSI (1979), Tsim Bei Tsui SSSI (1985), Tsim Bei Tsui egretry SSSI (1989), Pak Nai SSSI (1980), seagrass and horseshoe crab habitats along the coast of Pak Nai, and mariculture subzone along the coast of Lau Fau Shan and Pak Nai (Fig. 1).

22.3. Strategies on Water Pollution Control in Deep Bay

Due to rapid urbanization and development around Deep Bay, substantial amounts of pollutants are carried from the urban, industrial and rural areas of Hong Kong and Shenzhen into Deep Bay. The water quality of the Bay is consistently poor, especially in Inner Deep Bay, although substantial efforts have been spent since the 1980s to reduce pollution (Environmental Protection Department, 2000). A comprehensive study using computer modeling, was conducted between 1995 and 1998 to assess the assimilative capacity of the Bay (Environmental Protection Department, 1998; Lee, 2000). The results of the study showed that the assimilative capacity of the Bay has been far exceeded, especially for a few important water quality parameters, e.g. oxygen demand, nitrogen, phosphorus and bacteria. Apart from the existing and planned effluent treatment and export schemes in both the Hong Kong and Shenzhen sides of the catchment, further reduction in the loads discharged from the substantial population and associated commercial, industrial and livestock rearing activities are required. Accordingly, further reviews were undertaken in 1999 by the governments of Hong Kong and Shenzhen to identify areas for further reduction. A joint implementation program was devised outlining steps to achieve the target of pollution reduction within the next 15 years (HKGEPLG, 1999).

In the meantime, the Hong Kong SAR Government's Planning Department has established a new strategy to tackle the increasing development pressure in the Deep Bay area, such as the low-density residential developments (Fig. 2). To avoid

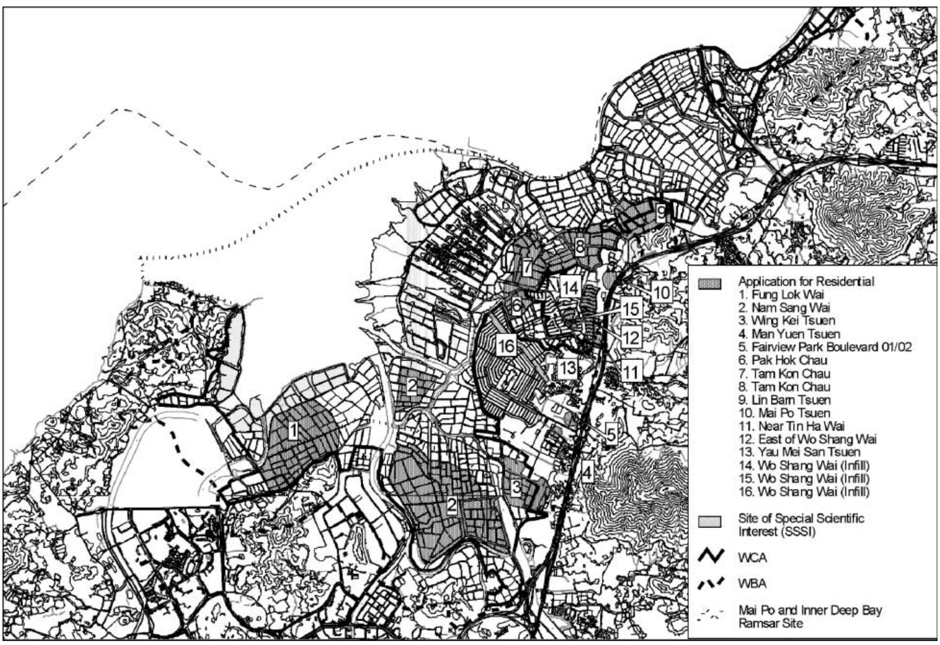

Figure 2: Delineation of the Ramsar site. Wetland conservation area (WCA) and wetland buffer area (WBA) and distribution of the residential proposals in the sensitive zone.

any adverse impact on the Deep Bay Wetland ecosystem, the Town Planning Board has designated the landward part of the Ramsar site and its surrounding continuous and adjoining fishponds, as a wetland conservation area (WCA). A strip of land about 500 m wide along the landward side of the WCA was further designated as a wetland buffer area (WBA) to protect the ecological integrity of the WCA (Town Planning Board, 1999) (Fig. 2). According to the planning guidelines, any developments within the WCA and WBA should fulfill the requirement of no net increase of pollution load to Deep Bay. To achieve this, mitigation measures have to be provided to offset any residual pollution loads from the development.

22.4. Application of Constructed Wetlands in the Deep Bay Catchment

22.4.1. Constructed Wetlands for Stormwater Runoff

Wetlands are transitional ecosystems that exist at the interface between aquatic and terrestrial systems. Because of their position in the landscape, they are frequently the default recipients of stormwater runoff. Increasing urbanization has led to large increase in the pollutant loads delivered to natural receiving waters. The use of constructed wetland for cleaning up stormwater runoff before discharging is widely adopted in order to protect the water environment (Raisin & Mitchell, 1995; Cooper et al., 1996; Godrej et al., 1999; IWA, 2000), but this arrangement is not common in Hong Kong. This is likely due to the limited resources for establishing constructed wetland and handling the issues of stormwater runoff in Hong Kong. Normally, standard practices are adopted to reduce the impact from stormwater runoff in urban or less sensitive areas, e.g. silt trap or grease trap. However, more stringent measures are necessary for developments within the Deep Bay catchment. This step is considered necessary as recent research has demonstrated that the heavy metal levels recorded in the feathers of the egrets breeding in colonies around Deep Bay were particularly high, especially for lead. Further additional input may cause biological impacts to the biota involved (Connell et al., 2000). To address this concern, one recent highway and bridge project has proposed the "control at sources strategy" to tackle the highway runoff problem (Highway Department, 2002). The proposed high frequency of road cleaning by vacuum sweeper is targeted to reduce pollutants accumulating on the bridge and risk of runoff into Deep Bay during storm events. The effectiveness of this measure will be monitored during the initial operation stage from around 2005.

In the 1990s, the large-scale Tin Shui Wai residential development in the northwest New Territories drew much attention from the public and green groups. The development site covered around 220 ha and would have a final total population of around 340,000 (Territory Development Department, 1997). The northeastern reach of the site was adjacent to the ecologically sensitive Ramsar Site (Fig. 3). Although the development would be connected to the public sewer, the potential impact of stormwater runoff was still a substantial environmental concern. To reduce the impact of stormwater runoff and avoid the interfacing problems between areas for people and conservation, the Tin Shui Wai development EIA recommended the creation of a constructed wetland to serve as a buffer to separate the Tin Shui Wai residential zone and the Ramsar Site. The proposed constructed wetlands, which covers 56 ha was aimed to provide opportunities for mitigation of wetland habitat loss due to the Tin Shui Wai development and for cleaning up part of the stormwater before it is discharged into Deep Bay. This constructed wetland then became the major part of the current Wetland Park project. Apart from having a function to improve water quality, the Wetland Park can also promote recreation, education and tourism (Agriculture, Fisheries and Conservation Department, 1999).

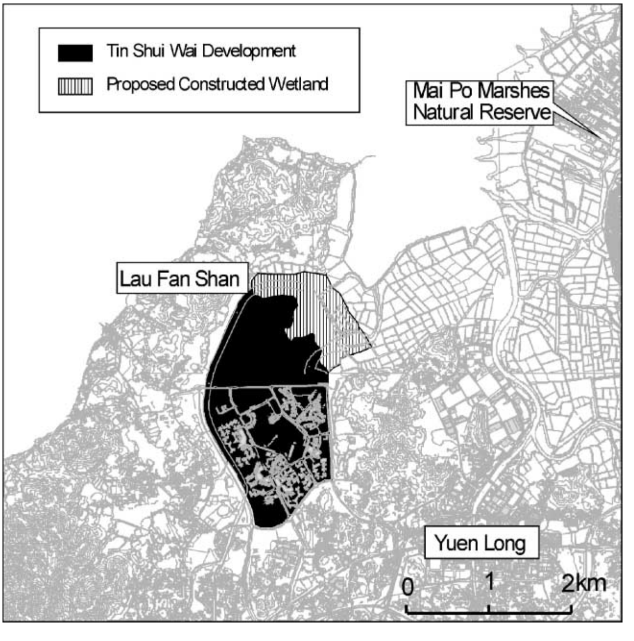

Figure 3: Location of the Tin Shui Wai development and the proposed constructed wetland.

To achieve the water improvement function, the Wetland Park incorporates a numbers of long channels with varying depths between 0.5 and 2.0 m and a series of shallow and deep water pools separated by weirs for flow control. A filter system composed of different type of wetland plants, e.g. reed bed and sedge, are integrated into the overall wetland design to provide a cleanup function for a portion of the stormwater flowing from the development area. Water quality monitoring at various locations within the constructed wetland is specified to monitor the treatment efficiency of the water circulation system. Apart from the general in situ parameters, ammonium-N, total phosphorous, biological oxygen demand, Chlorophyll-a and suspended solids will be monitored. After the first year of monitoring, the program will be reviewed to assess the effectiveness of the constructed wetland system for water improvement and the adequacy of the monitoring program. Some initial data have already collected and the system will soon be in operation.

22.4.2. Construction Wetlands for Polishing Treatment Plant Effluents and Stream Water

Development pressure in the northern New Territories is very high, especially from low-density residential developments which occur around the Deep Bay wetland area (Fig. 2). This area is largely rural and unsewered, although a trunk sewer is planned to be in operation around 2007. According to the Deep Bay planning guidelines, any developments that take place within this area before the trunk sewer is in place, will have to provide effective sewage treatment facilities and offsetting measures to achieve the requirement of no net increase of pollution load into Deep Bay. Generally, secondary treatment plus disinfection is the proposed treatment level, whilst the offsetting measures mainly include the proposal for reusing treated effluent for toilet flushing and gardening, pumping the equivalent amount of polluted stream water into the plant for treatment, and using constructed wetlands onsite or offsite to treat the effluents and/or water from the polluted streams. At the moment, many such residential proposals are either at the stage of planning, application process or pending approval, e.g. the developments at Nam Sang Wai and Fung Lok Wai. Due to the sluggish local investment market and economic downturn in recent years, many residential development projects are either on-hold or have been abandoned.

Apart from residential projects, one re-development project and one infrastructure project, respectively, are, however, approaching the stage of operation and detail design. These are the *Expansion of Kiosks at Lok Ma Chau Boundary Crossing (Boundary Crossing Project)* and *Sheung Shui to Lok Ma Chau Spurline (Spur Line Project)* (Fig. 4). Both of these projects lie within

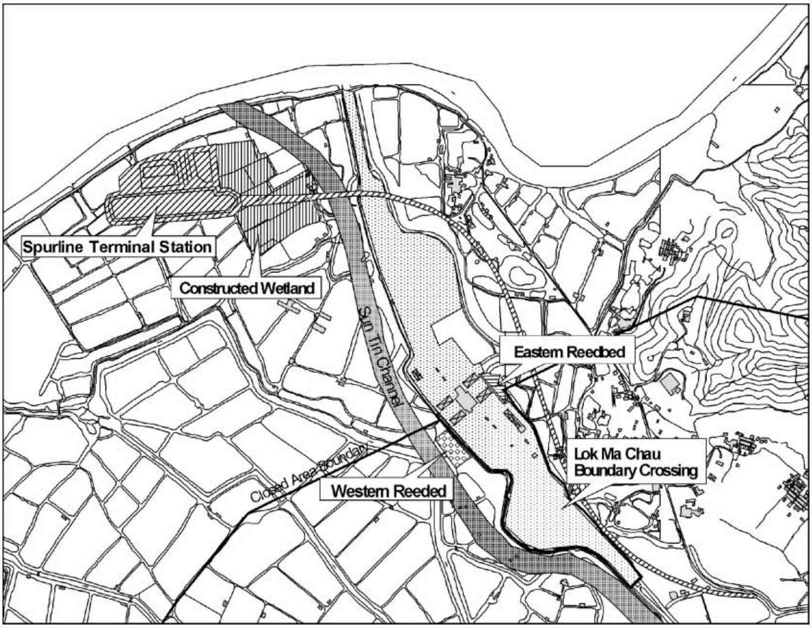

Figure 4: Location of the constructed wetlands proposed by the Lok Ma Chau Spur Line and boundary crossing projects.

the WCA and unsewered zone. Accordingly, they have to provide onsite sewage treatment facilities and fulfill the offsetting requirements. The offsetting plans of these two projects are briefly reported below:

Boundary Crossing Project. The Lok Ma Chau boundary crossing is one of the three crossings between Hong Kong and Mainland China. It was opened in 1989 with a total of 14 pairs of customs kiosks installed. The design capacity of the crossing is 1,000 vehicles per hour while the present peak traffic flow has risen to around 1,400–1,500 per hour, greatly exceeding the design capacity. With the increase in the freight and passenger traffic set to continue, it was proposed that 10 additional pairs of kiosks and other facilities be added to the crossing point (Architectural Services Department, 1999). This arrangement will directly affect the number of people crossing the border, and thus the amount of sewage production at the crossing. The original septic tank and soakaway system is insufficient to cater for the average of 25,000 passengers per day, with the sewage flow around 80 m^3/day. Accordingly, it was proposed that an onsite rotating biological contactor (RBC) sewage treatment plant be constructed to achieve the discharge standards (Table 1) (Environmental Protection Department, 1991), with

Table 1: Effluent standards of the related parameters for discharging into the "group B inland waters", which represent the beneficial use for irrigation.

Parameters	**Discharge standard based on effluent flow rate (m^3/day)**	
	≤200	**>1000 and ≤1500**
pH	6.5–8.5	6.5–8.5
BOD_5 (mg/l)	20	20
COD (mg/l)	80	80
Suspended solids (mg/l)	30	30
Ammonia nitrogen (mg/l)	5	5
Nitrate + nitrite (mg/l)	30	20
Total phosphorous (mg/l)	10	8
E. coli (count/100 ml)	100	100

the mitigation measures to offset the residual pollutant load that would be discharged into Deep Bay from the RBC treatment plant.

Two patches of constructed reedbeds are proposed for the offsetting plan (Kowloon-Canton Railway Corporation, 2000) (Fig. 4). The eastern reedbed will receive a constant flow of effluent from the RBC, whereas the western reedbed will treat water extracted from the nearby San Tin Channel as the external pollutant source for compensation of the load discharged from the RBC. As the residual load from the RBC can be calculated and the purification function of the reedbed can be estimated through regular monitoring at the input and output points, the effectiveness of the offsetting measures can thus be assessed. For example, according to the RBC design, the BOD_5 concentration in its effluent can achieve the level around 15 mg/l. According to the estimated daily sewage flow, the annual load from the RBC is thus around 1,116 kg, which needs to be offset by both the eastern and western reedbeds. Assuming the eastern reed bed achieves 50% removal of BOD_5 from the constant effluent from RBC, the western reed bed has to treat the remaining 50%, i.e. 583 kg/l BOD_5 via extracting enough water from the San Tin Channel to treat that equivalent amount of BOD_5.

Due to the lack of information on the general performance of constructed wetlands in Hong Kong, it is considered inappropriate to set the daily compliance of offsetting at this stage. Accordingly, project proponents are requested to achieve only the annual balance between the residual load from the RBC and removal by the reedbed system. BOD_5 is the parameter used to assess the effectiveness of the reedbed system for the offsetting, although other parameters will also be monitored on a regular basis (Table 2). The monitoring results and case review

Table 2: Parameters to be measured in water, sediment and plant samples collected from the constructed wetlands.

Parameters in water samples	
In situ	Flow rate, temperature, salinity, pH, turbidity, dissolved oxygen
Nutrient	BOD_5, suspended solids, total phosphorus, ammoniacal nitrogen, nitrite, nitrate, total Kjeldahl nitrogen, TOC, COD, *E. coli*
Metal	Cadmium, lead, copper, zinc, iron, arsenic
Parameters in sediment and plant samples	
Nutrient	Organic nitrogen, total Kjeldahl nitrogen, total nitrogen, organic phosphate, total phosphate
Metal	Cadmium, lead, copper, zinc, iron, arsenic

will provide a basis for formulating the offsetting compliance requirement in future. At present, the eastern reedbed is under construction.

Spur Line Project. This Spur Line Project consists of the construction and operation of a railway station at Lok Ma Chau, and railway alignment between Sheung Shui and Lok Ma Chau (Kowloon-Canton Railway Corporation, 2000) (Fig. 4). The project aims to relieve the congestion at Lo Wu Boundary Crossing. It was estimated that the peak flow of passengers to cross this new boundary crossing might reach around 20,000 passengers per hour. Including the approximately 1,100 staff at the Lok Ma Chau station, the estimated maximum daily sewage flow is around 1,228 m^3/day. As the Lok Ma Chau station lies within the WCA and unsewered area, the construction of a RBC treatment plant with a disinfection setup was proposed to achieve the discharged standards (Table 1). The effluents will be further polished by a 2 ha constructed reedbed. In the meantime, water from the San Tin Channel will be pumped to the reedbed for treatment in order to offset the residual pollution load from the treatment plant. This strategy is similar to that adopted at the nearby Boundary Crossing Project. Again, similar monitoring will be carried out during the operation phase to assess the effectiveness of the reedbed system. The Spur Line Project is now at the stage of detail design and construction. Its operation phase will begin around 2006.

22.5. Conclusion

The Deep Bay catchment has a high potential to promote the use of constructed wetlands for water improvement. With the benefit of less limitation on land resources, the constructed wetland can fit well into the original landscape that supports a wide range of wetlands. The current ongoing large-scale projects described above will help to collect useful information to verify the effectiveness of constructed wetland for water improvement in Hong Kong. If the results demonstrate that the approach of constructed wetland is viable and satisfactory, it will further help to improve the polluted water environment of Deep Bay.

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References

Agriculture, Fisheries and Conservation Department. (1999). *Hong Kong international wetland park and visitor center feasibility study*, Hong Kong SAR, China.

Architectural Services Department. (1999). *Expansion of kiosks and other facilities at Lok Ma Chau boundary crossing*, Hong Kong SAR, China, Vol. 1, Chapter 7.

Bastian, R. K., & Hammer, D. A. (1993). In: G. A. Moshiri (Ed.), *Constructed wetlands for water quality improvement* (pp. 59–68). Lewis, London.

Connell, D. W., Wong, B. S. F., Lam, P. K. S., Poon, K. F., Lam, M. H. W., Wu, R. S. S., Richardson, B. J., & Yen, Y. H. (2000). Risk of breeding success of ardeids by contaminants in Hong Kong: evidence from trace metals in feathers. *Ecotoxicology*, **11**, 49–59.

Cooper, P., & Green, G. (1995). Reed bed treatment systems for sewage treatment in the United Kingdom — the first 10 years' experience. *Water Science and Technology*, **32**, 3, 317–328.

Cooper, P. F., Job, G. D., Green, M. S., & Shutes, R. B. E. (1996). *Reed beds & constructed wetlands, for wastewater treatment*. WRC, Swindon, pp. 61–168.

Environmental Protection Department. (1991). *Technical memorandum standards for effluents discharged into drainage and sewage systems, inland and coastal waters*. Hong Kong SAR, China, p. 18.

Environmental Protection Department. (1998). *Deep Bay water quality regional control strategy study — final report*, Hong Kong SAR, China.

Environmental Protection Department. (2000). *Marine water quality in Hong Kong for 2000*, Hong Kong SAR, China.

Godrej, A. N., Grizzard, T., Kenel, P. P., Lampe, L. K., & Carleton, J. N. (1999). *Evaluating the use of constructed wetlands in urban areas*. Water Environment Research Foundation, USA.

Highway Department. (2002). *Shenzhen western corridor investigation and planning*, Vol. 1, Chapter 7, Hong Kong SAR, China.

HKGEPLG. (1999). *Deep Bay (Shenzhen Bay) water pollution control joint implementation plan*, Hong Kong SAR, China.

IWA. (2000). *Constructed wetlands for pollution control: processes, performance, design and operation*. IWA Publishing, England, p. 29.

Kowloon-Canton Railway Corporation. (2000). *Sheung Shui to Lok Ma Chau Spur Line environmental impact assessment*, Vol. 2, Chapter 6, Hong Kong SAR, China.

Lee, A. W. T. (2000). *Regional management of water quality of Deep Bay, Hong Kong, POLMET 2000*. Kuala Lumpur, Malaysia, pp. 20–23.

Planning Department. (1997). *Study on the ecological value of fish ponds in Deep Bay area, final report*, Chapter 6, Hong Kong SAR, China.

Planning Department. (1999). *Register of sites of special scientific interest (SSSIs)*, Hong Kong SAR, China.

Raisin, G. W., & Mitchell, D. S. (1995). The use of wetlands for the control of non-point source pollution. *Water Science and Technology*, **32**, 3, 177–186.

Territory Development Department. (1997). Tin Shui Wai development engineering investigations for development of areas 3, 30 & 31 of the development zone and the reserve zone, Vol. 1, Chapter 7, Hong Kong SAR, China.

Town Planning Board. (1999). *Town planning guidelines for application for developments within Deep Bay buffer zones under section 16 of the town planning ordinance. TPB PG-No. 12B (revised April 1999)*, Hong Kong SAR, China.

Urbanc-Bercic, O., & Bulc, T. (1995). Integrated constructed wetland for small communities. *Water Science and Technology*, **32**, 3, 41–48.