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Review of the Water Environment in Tolo Harbour: A Land-Locked Embayment in North-Eastern Hong Kong*

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Abstract: *Uncontrolled discharges of municipal sewage, agricultural wastes and industrial effluents in the past decades have upset the ecosystems, caused frequent occurrences of red tides, and resulted in a loss of inland and coastal amenity values of the land-locked embayment of Tolo Harbour and the related river systems. This paper provides a review of the established relevant legislations and sewage management facilities for environmental conservation, and the current status of water environment in the Tolo Harbour Water Control Zone.*

Keywords: *Hong Kong, land-locked estuarine embayment, Tolo Harbour, water environment conservation.*

1. Introduction

Tolo Harbour in the north-eastern territories of Hong Kong is a nearly land-locked estuary (Fig.1). The main waterbody of about 50 km^2 has a narrow opening of 1.3 km in width. In the past two decades, rapid developments of the nearby Shatin and Taipo New Towns with a 1-million population have caused the water area, length of the coastline, catchment area, and fresh water run-off to be significantly reduced. Until recently, large quantities of municipal sewage, agricultural wastes and cottage industrial effluents were discharged, without any treatment, into rivers and watercourses that flow into the Tolo Harbour (Chua *et al.*, 1994; 1995a; Environmental Protection Department, 1996). The oceanic tidal flushing rate in the almost land-locked embayment is very weak, resulting in a hydraulic residence time in the harbour of as long as 35 days (Morton and Wu, 1975; Trott, 1973; Chau and Abesser, 1958). Exogenous organic materials are decomposed and recycled within the embayment. Uncontrolled sewage and waste discharges in the past

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two decades have caused significant decrease in dissolved oxygen levels, upset the ecosystems, caused frequent occurrences of red tides and resulted in a loss of inland and coastal amenity values (Chua *et al.*, 1995b; Environmental Protection Department, 1996). The Tolo Harbour and Channel Water Control Zone were declared in 1982 and the relevant pollution control regulations in the zone were established and enforced in 1987.

2. Physical Environment

The main waterbody of Tolo Harbour is about 16 by 3 km and the Tolo Channel, the opening that leads into the Mirs Bay, has a maximum width of only 1.3 km (Morton and Wu, 1975). Tolo Harbour is relatively shallow with an average depth of 12 m, while the narrow Tolo Channel is deeper at about 20 m. The area north of Tolo Harbour is dominated by the Patsin Mountain Range, rising in most parts to 500 m and reaching a summit of over 600 m.

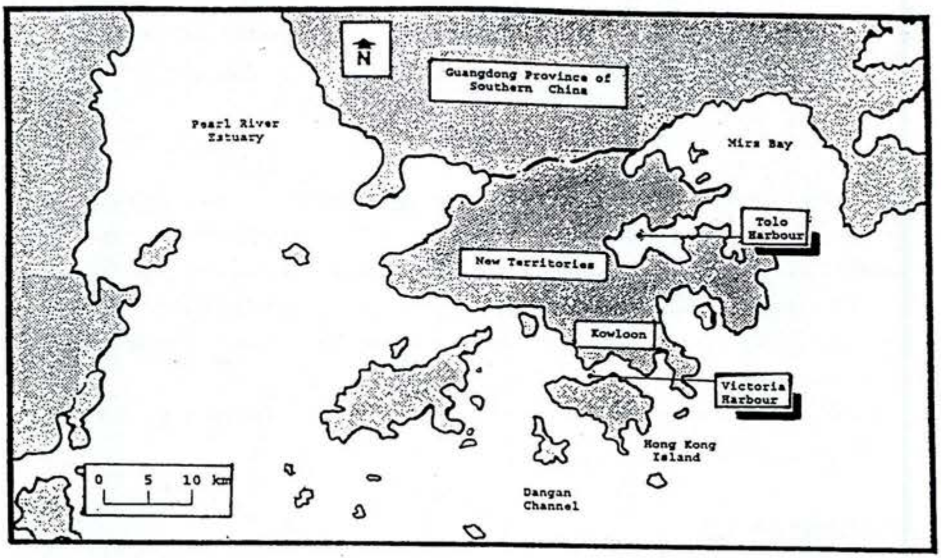

Fig. 1 Land-Locked estuarine Embayment of Tolo Harbour in North-Eastern Hong Kong

On the south of Tolo Harbour and Channel, the hilly terrain regains altitude, with an average of 600 m, and reaching 645 m at the Grassy Hill and 703 m at the Maon Mountain. The geological setting of Tolo Harbour area is primarily based on a sequence of metamorphosed sedimentary and volcanic rocks, intruded by granites (Addison, 1986). The granites are deeply weathered, but the area is one of hilly topography, giving rise to steep, flashy streams of soft, slightly acidic water. Superficial deposits of alluvium from narrow coastal lowlands give rise to an inter-tidal mangrove environment. Tolo Harbour has a subtropical monsoonal climate. It is affected by warm and moist tropical oceanic wind. The annual average air temperature is 22.8 degree centigrade. Monthly highest air temperature is over 28.6 degree centigrade, and monthly lowest air temperature is about 15 degree centigrade. Therefore, there is no distinct cold winter. The rainfall is concentrated in the summer, from May to September, which makes up 75 % of the total rainfall. The mean annual precipitation is between 1 900 and 2 200 mm, resulting in major run-off from the northern and southern hilly terrains into the Tolo Harbour (Trott, 1973).

On the other hand, on the relatively plain terrains on the west of Tolo Harbour connect three river systems, namely Shingmun, Lamtsuen and Taipo Rivers, within the catchment of the Water Control Zone (Fig.2). The catchment area of Shingmun River is 37 km^2, about one half of which is within water gathering grounds gazetted under the Waterworks Ordinance (Environmental Protection Department, 1994a). The 7-km main channel flows through the Shatin New Town and drains into the inner Tolo Harbour. The 50-km watercourse length includes three major tributaries, namely Tinsum, Siu Lek Yuen and Fotan. The catchment of Lamtsuen River covers 19 km^2, of which 16 km^2 fall within water gathering grounds. The flow of the 50-km stream courses is affected by drawing off of 1.5×107 tonnes of river water at the waterworks pumping station for sub-urban domestic uses annually. The catchment of Taipo River is relatively small, about 9 km^2. The Shatin and Taipo New Towns, with a total of 1-million population and immense commercio-industrial activities, are located amidst these river systems (Fig. 2).

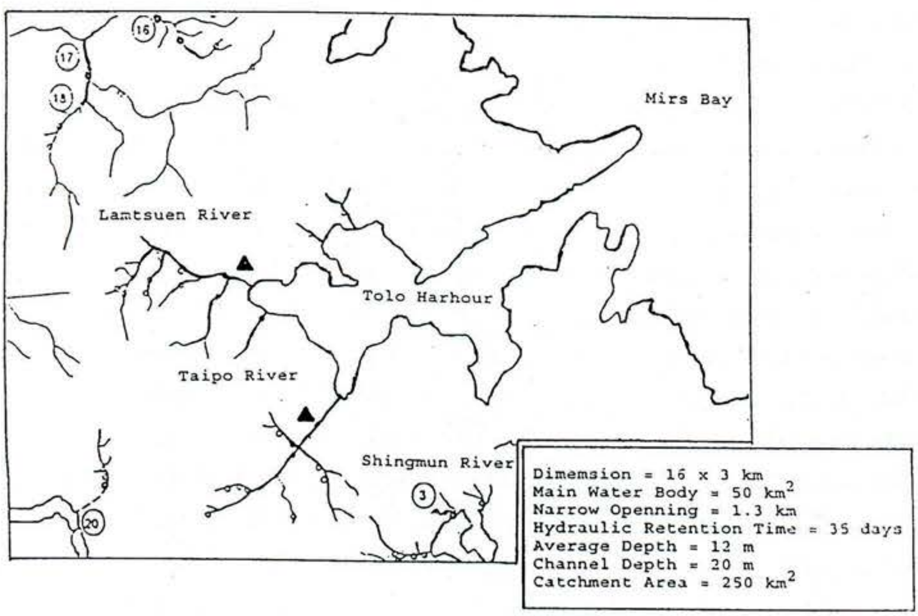

Fig. 2 Catchment of the Tolo Harbour Water Control Zone

3. Pollution Sources and Control

In the past 20 years, Taipo New Town has developed from a small market town of 25 000 into a new town with a population of 263 000, accommodating 1 260 ha of development area (Hong

Kong Cencus and Statistics Department, 1991). Most of the new town infrastructures are well in place. A further expansion of the Taipo Sewage Treatment Works is in progress to cater for the further developments in the town area and industrial estate. On the other hand, Shatin New Town is, to a large extent, completely developed. The down town area is already home to over half a million people.

The recent reclamation and development works at the Maon Mountain areas, completed in early 1994, added another 23 ha of urbanised area and residential occupancy is currently in the process.

In 1967, a large northern portion of Tolo Harbour was sealed off by a dam to form the 14 km^2 Plover Cove Reservoir in order to supply water to the developing new towns during those years. The reservoir and its associated catchwaters were completed in 1973. With the expansion of the new towns, water resources development in Tolo Harbour took a further step with the completion of the High Island reservoir in 1979. Urban development and reclamation of Tolo Harbour region has caused a dramatic physical impact on the water environment. The catchment area of Tolo Harbour has reduced by 68 % to only 5 000 ha, and freshwater run-off has reduced accordingly (Environmental Protection Department, 1991; 1994b). The water area has also reduced by 28 %. The length of the coastline has shortened from 139 to 109 km, which is equivalent to a reduction of 22 %. Most significantly, however, 42 % of the natural mangrove coastline has vanished. Most of these environmental changes occurred in the inner Tolo Harbour where the urban development was concentrated.

Urban development has also brought about severe sources of water pollution and created a major impact on the water quality of the poorly flushed embayment of Tolo Harbour and the related river systems. The main sources of pollution before the Eighties were (1) agricultural wastes from the livestock industries, (2) municipal sewage from domestic activities in the new towns, and (3) industrial effluents from the manufacturing and process industries.

The livestock industries concentrated on intensive rearing of pigs and poultries. In the past decades, waste disposal practices were, in almost all cases, highly polluting to the water environment. In 1980, the pig and chicken populations were 0.57 and 6.5 million respectively. The pig and poultry manure together contributed more than two-thirds of total putrescrble matter entering the river systems. About 50 % of the poultry manure was reused in vegetable farming, in fish ponds, and for the breeding of worms, and most of the remaining manure was dumped into streams. Unfortunately, little use can be made of pig manure, which was discharged by the pig farms into nearby stream courses. Chicken and pig manure were the main source of organic matters which caused oxygen depletion in the receiving waters, and was also a rich source of nitrogen, phosphorus and other nutrients which enhance eutrophication in the Tolo Harbour. The Waste Disposal (Livestock Waste) Regulations under the Waste Disposal Ordinance enacted and revised in the Ninties has put a ban on keeping livestocks in designated urban areas (Environmental Protection Department, 1996). This has introduced a scheme to licence livestock farms in order to regulate livestock keeping and to ensure effective controls over disposal of livestock wastes. The government has provided financial assistance for livestock farmers to install effective on-site waste treatment facilities.

In Shatin, after decades of uncontrolled discharges of sewage and wastes into the river systems, the municipal sewage and industrial effluents began to be treated by the Shatin Sewage Works in the early Eighties. The sewage works is a diffused air activated sludge plant, designed to include nitrification and denitrification. Stage 1 of the works was commissioned in 1982, and the stage 2 extensions were completed in 1986. The works was designed to serve a population of 500 000, with a total domestic and industrial flow of 200 000 tons·d^{-1} and a loading of 45 980 kg BODd^{-1}. Industrial effluents are controlled through the licensing procedures of the Water Pollution Control Ordinance which requires on-site pre-treatments. On the other hand, Taipo is served by two independent sewage works sharing the same site. Stage 1 of the works was a conventional activated sludge plant without nutrient removal. It was extended in stage 2, which provided nitrification and partial denitrification. The independent stage 3 works, designed to achieve 70 percent removal of nitrogen and 20 percent removal of phosphorus, was commissioned in 1986. The industrial pollutant sources, which are concentrated in Taipo Industrial Estate with 73 ha areas, are well managed. All trade effluents, after pre-treatments, are discharged via foul sewers to Taipo Sewage Works.

In the Eighties, the treated effluents from the sewage treatment works in Shatin and Taipo contributed heavy loads of nutrients to the Tolo Harbour. Both works were further modified in 1991 to significantly reduce nutrient loadings. However, another big point source of pollution in the Tolo Harbour was due to the discharge of alum sludge from the Shatin Water Treatment Works. This discharge has ceased with the completion of the sludge transfer system in 1991, which includes a pipeline that transfers the sludge to sludge treatment facilities in the Shatin Sewage Works. The treated sludge is then transported by tankers for marine disposal. Therefore, all major sources of pollution in the Tolo Harbour and Channel Water Control Zone were considered alleviated by 1991.

4. River Water Quality in Tolo Zone

Before the water environment legislations and sewage management facilities were established in the Eighties, the grossly polluted state of the river systems in the Tolo Harbour Zone was severe. The results of earlier studies in the Seventies showed that only 60 percent of the 200 km of water courses in this region, mostly in uninhabited areas, have acceptable water qualities. The other 24 percent were polluted, and the remaining 16 percent, mostly in the lowland areas, were heavily polluted. In 1981, the Environmental Protection Department completed a comprehensive survey of river and stream quality. A total of 21 rivers and their tributaries were investigated, and water samples were collected for the determination of the physical and chemical properties. Findings indicated that all the river systems in the Tolo Harbour Zone could be classified as "bad" and "very bad" according to the Water Quality Index (WQI) (Environmental Protection Department, 1996). Over the monitoring period, the BOD5 level averaged 60 mg·L^{-1} and ammonia nitrogen level averaged 6 mg·L^{-1}, indicating serious organic pollution.

The main tributaries of Shingmun River were polluted to various degrees (Environmental Protection Department, 1994a). Before 1991, Tinsum was mainly polluted by the alum sludge from the Shatin Water Treatment Works. Fotan Nullah was contaminated by sporadic discharges of industrial effluents from nearby multi-storey industrial buildings before 1987. Siu Lek Yuen was polluted by domestic sewage and livestock wastes disposal from the upper and middle reaches of the tributary before 1988.

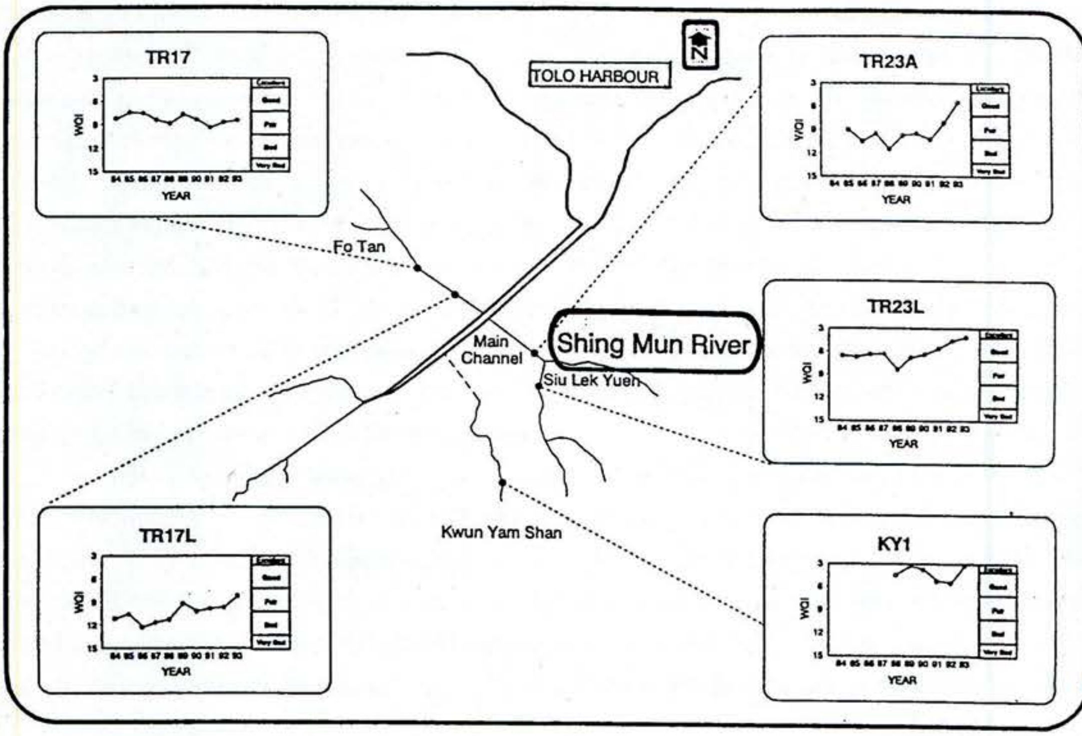

Fig. 3 Water Quality in Shingmun River

In the Ninties, there has been a progressive improvement of water quality in various sections of Shingmun River (Fig. 3) (Environmental Protection Department, 1994a). The water quality in the main channel of Shingmun River was graded as "fair" in 1991. Similar improvements were also reported at the lower Fotan Nullah. The water quality in the Fotan Nullah was "bad" in the dry season, but "fair" in the wet season due to diluting effects. Such improvements were attributed to enforcement actions under the Water Pollution Control Ordinance which was aimed at stopping unauthorized effluent discharges. The upper reaches of the Siu Lek Yuen that suffered from livestock waste pollution in the past had improved with the implementation of the livestock waste control scheme in 1988 prohibiting livestock rearing and disposal of livestock waste in the river catchment.

The Lamtsuen and Taipo Rivers were also showing similar progressive improvement in water quality in the Ninties due to the controlled disposal of livestock wastes and the removal of unsewered households.

5. Harbour Water Quality in Tolo Zone

The earliest published works by Chau and Abesser (1958) and Fung (1972) reported that average phosphate levels were 0.5μg.atoms· L^{-1} in the inner Tolo Harbour area, and was 0.39 μg.atom·L^{-1} at the centre of the Harbour over an 1-year period. The values for nitrates were 3.23 μg.atom·L^{-1} in inner Harbour and 2.90 μg.atom·L^{-1} at Harbour centre. These were close to normal base-line values for unpolluted estuarine conditions Chau (1962). Trott (1973) reported that water turbidity, pH, dissolved oxygen (DO) and nutrient levels were more significantly influenced by seasonal changes than by domestic discharges. Since 1972, the Public Works Department commenced a bi-monthly sampling programme. Severe oxygen depletion was observed in 1972, 1975 and 1977. Phosphate and nitrate levels were significantly higher than the base-line values (Fung, 1972). Mean concentrations of chlorophyll-*a* in the surface water of inner Tolo Harbour were higher by a factor of 6 than that in unpolluted waters.

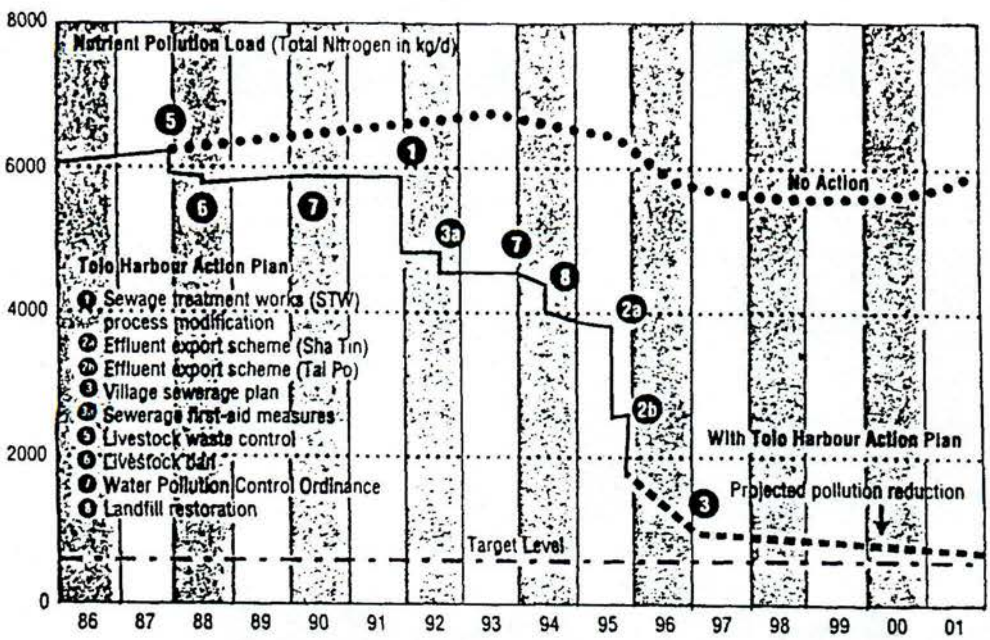

Fig. 4 Implementation and Environmental Effects of Tolo Harbour Action Plan

In mid Eighties, the Environmental Protection Department undertook a comprehensive review of the Tolo Harbour water quality. This review focused on the pollutant loadings generated in the catchment from a variety of sources, including treated and untreated municipal sewage, pig and chicken wastes, and trade effluents. It was concluded that the increase in pollutant loading during the period from 1976 to the end 1983 exceeded the receptive capacity of the Tolo waters. Several management options to reduce overall loading were considered. These options included (1) provision of sewerage systems for areas in which untreated human wastes were generated in the inner Tolo Harbour catchment, (2) redevelopment of rural villages for which sewerage provision was impractical, and (3) reduction of agricultural loading by implementation of animal waste collection services, on-site treatments, or relocation of farms away from the catchment area. In 1986, a Tolo Harbour Action Plan with eight components of action to restore the water quality was established (Environmental Protection Department, 1996). Figure 4 illustrates the Action Plan with projected increase in loading on Tolo Harbour and the improvement each stages of the Action Plan would achieve. The capital cost of the Action Plan is HK$ 1.6 billion.

Since the Eighties, more comprehensive monitoring programmes were conducted by the Environmental Protection Department. Monitoring data showed that the Tolo Harbour Action Plan has generally resulted in improved harbour water quality. There was an increased compliance rates with water quality objectives for surface chlorophyll-a after the implementation of the Action Plan (Fig. 5) (Environmental Protection Department, 1996).

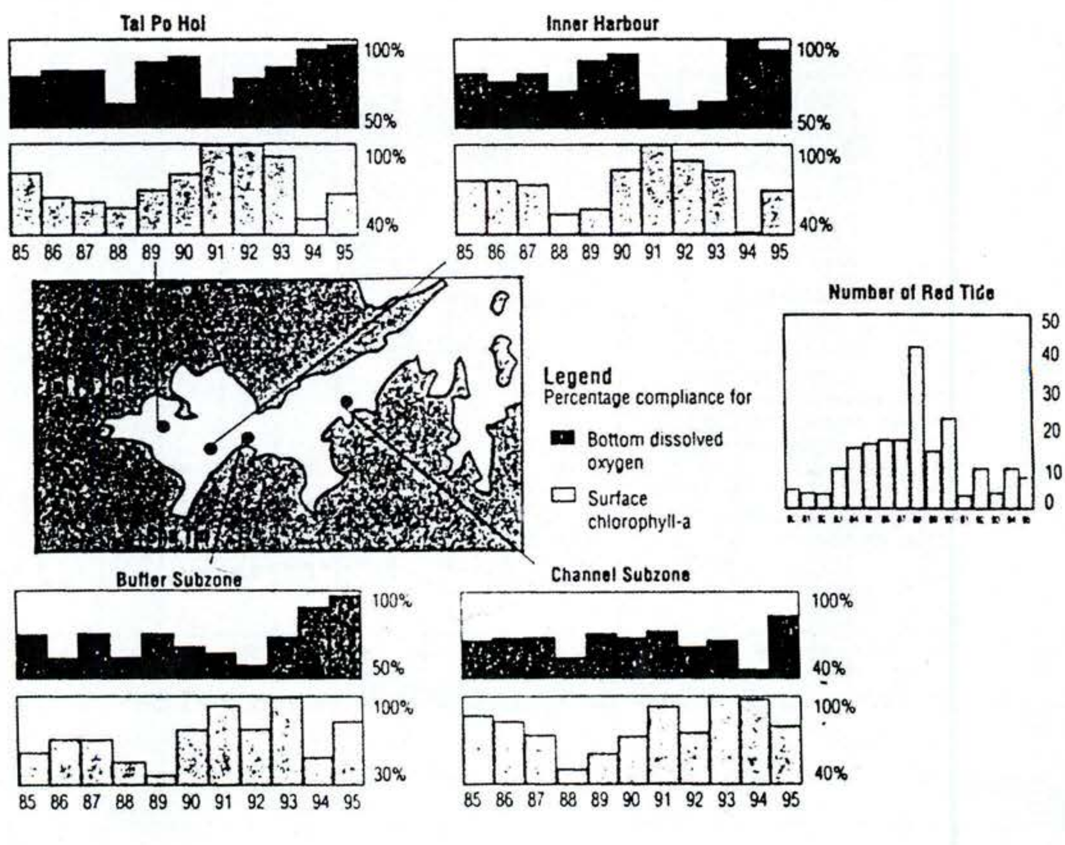

Fig. 5 Water Quality in Tolo Harbour

However, the improvements in bottom DO was not obvious because more time was needed for the contaminated sediments to recover. A declining trend of DO was observed until 1992 (Hong Kong Environmental Protection Department, 1992). Severe ecological and amenity problems occurred when the saturation of DO fell below 50 %.

Furthermore, despite the efforts on legislation enforcement and upgrading of sewage and waste management facilities in the river systems that flow into Tolo Harbour, the water quality in terms of nutrients also showed little improvement (Environmental Protection Department, 1994b). Phosphate levels averaged between 0.02 and 0.17 $mg \cdot L^{-1}$ and nitrate levels averaged between 0.01 and 0.61 $mg \cdot L^{-1}$. This could possibly be attributed to the fact that the sediments of the river systems and the harbour, which acted as sinks for pollutants during the decade before 1987, has turned into sources of pollutants to the overlying water. Release of polutants by sediments rendered the water quality remains poor even after a decade of effort to eliminate illegal discharges (Chua *et al.*, 1995c; Chua and Chung, 1997). The nutrients and other pollutants in the harbour were beginning to spread outward into the Mirs Bay (Bowler, 1985; Hodgkiss *et al.*, 1983; Stirling *et al.*, 1977; Holmes, 1988).

Excessive nutrients and organic pollutants have resulted in massive blooms of dinoflagellate algae which contain red, orange and yellow pigments. These microscopic organisms result in occurrence of red tides which causes intense deoxygenation of the water and physical clogging of fish gills. In the rapid socio-economic growth and industrialization in the 1980s, there has been drastic increase in occurrence of red tides in Tolo Harbour because it is poorly flushed by tidal currents and heavy discharge of untreated sewage effluents provide an abundant supply of nutrient (Fig. 5) (Hong Kong Environmental Protection Department, 1996). The number of red tides appears to have decreased after 1988. However, the algal blooms in the latter years were larger, covering much larger areas. These occurrences were caused by Noctiluca scintillans. When the algae drifted ashore, they created glutinous putrid slimes that fouled beaches and killed fish. In 1989, a toxic red tide was first discovered. Toxins accumulated in shellfish, which resulted in poisoning when consumed. Paralytic Shellfish Poisoning (PSP) toxin levels as high as 13 500 $mu \cdot kg^{-1}$ were recorded.

In addition, Escherichia coli counts were also high, revealing the presence of illegal sewage discharges. The sediment metal contamination was also very high, particularly with regard to copper pollution that comes from the printed circuit board industry. The concentration of copper often exceeds 400 $mg \cdot kg^{1}$ TDS. Filter-feeding shellfish, such as the green-lipped mussels (*Perna viridis*), in Tolo Harbour waters were found to accumulate metals, algal toxins and microorganisms from the water as they feed (Hodgkiss, 1992). These substances accumulated in the shellfish bivalves and tissues, and enter the human food chain. Recent works have shown that levels of accumulated cadmium, chromium, zinc, lead, silver and copper are elevated and in some cases, approaching permitted levels. Furthermore, increasing number of shellfish samples show contamination by pathogenic bacteria and viruses. Ninety percent of the Hong Kong population is sero positive by age 50 for water transmitted Hepatitis A, which is related to consumption of microbially contaminated shellfish. This figure is twice as high as the average for other cities throughout the world.

To further reduce the nutrients and organic loads in Tolo Harbour, the treated sewage effluents from the sewage treatment works are being piped to other less sensitive waters, namely Victoria Harbour, where it can be more satisfactorily diluted through tidal flows. This project works comprised sewage pumping stations, rising mains, submarine pipelines and sewer tunnel, of 3.2 m in diameter and 7.5 km in length. Stage 1 of the works between Shatin and Victoria harbour was completed in the end of 1994 and included the construction of the sewer tunnel. Stage 2 of the works between Taipo and Shatin was completed in the mid 1995, and included the construction of a 1-m diameter, 6-km long, steel rising main buried under the seabed of Tolo Harbour.

6. Conclusion

Uncontrolled discharges of municipal sewage, agricultural wastes and industrial effluents have upset the ecosystems, caused frequent occurrences of red tides and bioaccumulation of pollutants in seafood, and resulted in a loss of inland and coastal amenity values of the land-locked embayment of Tolo Harbour and the related river systems. The Tolo Harbour has become one of the most severely polluted coastal water bodies in Hong Kong. After a decade of efforts in establishing and enforcing water pollution control legislations and upgrading wastewater treatment facilities, the current status of water environment in the Tolo Harbour Water Control Zone shows smaller improvement than expected. Many of the water quality objectives are still not met. Decline in water quality in certain areas has continued, and is spreading outward into the Mirs Bay. This was attributed to the fact that the sediments of the river systems and the harbour, which acted as sinks for pollutants during the decade before 1987, has turned into sources of pollutants to the overlying water. Release of polutants by sediments rendered the water quality remains poor even after a decade of effort to eliminate illegal discharges. Seiment rehabilitation by dredging may be required as a further remedial option.

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