Peter Whiteside, Kwok-choi Ng and Wai-ping Lee

Management of Contaminated Mud in Hong Kong

Abstract

Marine sediments in Hong Kong, polluted by industrial and domestic wastes, have to be dredged for reclamation foundations and navigational purposes. Using concentrations of seven metallic elements, the Environmental Protection Department categorises the sediments as suitable for open sea disposal or as requiring contained marine disposal. Since late 1992, special pits dredged 15m below the seabed in a sheltered area of 5m water depth have been used for the disposal of the contaminated material. The pits are filled to within 3m of the seabed and then capped in three stages: 1m of sand, 2m of clean mud, and finally, after the pit infill has consolidated, a further 1-2m of clean mud. The latter is soon recolonised by benthic fauna.

Approximately $10Mm^3$ of contaminated mud have already been disposed of in a series of small pits. The total cost of the facility amounts to about US$7/$m^3$. Although most dredging of the contaminated mud has been by grab, and most disposal by bottom-dumping barges, an increasing use of trailer dredgers is expected. A 24-hour on-site management team directs and supervises the in-coming vessels and there is a comprehensive programme of environmental and ecological monitoring covering sediment, water, biota and ecotoxicology.
No adverse trends have been identified. A larger, empty sand borrow pit, extending about 35m below seabed, is now under study for future disposal. The whole disposal strategy has been reviewed using the London Convention's 1995 Dredged Material Assessment Framework and has been found acceptable.

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Introduction

Although for some years now Hong Kong has been implementing controlling legislation to reduce water pollution at source, the marine sediments close to developed areas of the territory are still contaminated by past pollution. Over many decades, both domestic and industrially polluted wastes have found their way via foulwater sewers, stormwater drains and watercourses, into Hong Kong's marine environment. Extensive field sampling and laboratory testing, particularly since 1991, have revealed large amounts of metallic pollutants associated with industrial processes such as electro-plating, and most recent testing has added organic pollutants to the list.

Concentrations tend to be highest around submarine outfall pipes where particulate pollutants have sedimented and where soluble pollutants have adhered to the fine particles in the seabed sediment. Once on the seabed, pollutants have been mixed into the sediment by ships' anchors, commonly to depths of up to 3m and occasionally more. An estimated $30Mm^3$ of this contaminated mud will have required disposal between 1991 and the year 2000 as part of Hong Kong's programme of port, airport and urban developments (Figure 1).

Pollution control policy in Hong Kong is developed and implemented by the Environmental Protection Department (EPD). In the late 1980s, when detailed planning started for the major programme of reclamations, EPD moved to establish criteria for characterising levels of contamination of the seabed sediments which would have to be dredged as part of the reclamations and associated navigational improvements. Hong Kong's "Dumping at Sea Ordinance", originally stemming from UK legislation, follows the London Convention (LC) in implementing measures for the avoidance of marine pollution. Because China is also a signatory, this situation will not change after the 1997 handover to Chinese sovereignty.

Unlike many countries, such as the USA, Hong Kong's "baseline" for the purposes of the LC is the highwater mark. All dredging activities, even those inland but within tidally affected freshwater drainage channels, are covered by the same legislation. In 1989, EPD adopted some interim guidelines for categorisation of severely contaminated dredged material in the northwest part of the territory.

In 1991, EPD replaced these guidelines with a set of criteria which have since been used to differentiate between dredged material suitable for open sea disposal and dredged material which is not (Table I).
In common with a number of other countries, notably in Europe, these criteria are based on levels of certain heavy metals. Sediments are classified as contaminated if they fail the criteria for one or more metals.

In parallel with the introduction of the 1991 contamination criteria, the government decided that if highly contaminated seabed mud had to be dredged then it would be best disposed of by placing it in seabed pits and capping with inert materials.
A potentially suitable seabed pit already existed at that time as a result of sand extraction for a new town development and so in April 1992, disposal experiments using uncontaminated mud were conducted in this exhausted marine borrow pit to determine whether it would be suitable for the disposal of contaminated mud.

Trailer dredger *Geopotes IX* which was employed on uncontaminated mud dredging for the new airport project was used for the trial (Figure 2). Both simple bottom dumping and pumping of the mud back down the suction pipe were tried but measurements indicated that the combination of 20m water depth and the relatively strong tidal currents resulted in sediment losses of about 6% when measured 300m downstream (Binnie, 1993). This was regarded as unacceptable and it was decided that an area of shallower water with relatively weak tidal currents was required.

Figure 1 shows the overall bathymetry in Hong Kong, and in particular, the areas of shallow seabed (<10m). Most of Hong Kong's storm weather is associated with intense tropical cyclones called typhoons, coming generally from a southeasterly to southerly direction. The shallow area selected in 1992 (East Sha Chau; Figure 1) is not only sheltered from these storms but also has relatively low tidal currents.
Unlike the area of the trial dump, however, there were no pre-existing pits at that time and so pits had to be specially dredged for the disposal of the contaminated mud. The East Sha Chau area (Brand *et al.,* 1994) has a water depth of about 5m and is adjacent to Hong Kong's new airport at Chek Lap Kok (Figure 3).

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Table I. Hong Kong's criteria for open sea disposal of dredged material.

Metal	Cd	Cr	Cu	Hg	Ni	Pb	Zn
ppm dry wt	<1.5	<80	<65	<1.0	<40	<75	<200

Note: Test results to be rounded off to the same significant figures as used in the table.

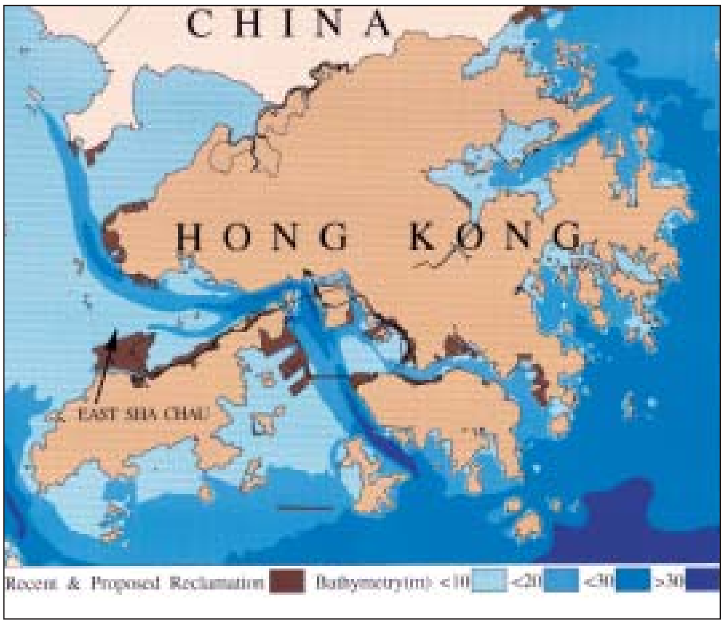

Figure 1. Bathymetric map of Hong Kong showing recent and proposed reclamations and the location of the East Sha Chau contaminated mud disposal area.

Figure 2. The Geopotes IX performed the disposal experiments using uncontaminated mud.

DESIGN OF THE DISPOSAL PITS

The pit and cap design centred around calculations of the potential for contaminated sediment in an uncapped pit to be remobilised by storm-induced bed shear stresses, and also the potential for the erosion of the completed cap of a pit. It was concluded that, if the highest contaminated mud level was 9m below sea level, the possibility of remobilisation of contaminated sediment was acceptably low, and if the pit cap was at least two metres thick the risk of complete erosion of a cap was negligible. In addition, seismic boomer surveys of the Holocene sediments in the area suggested that the maximum depth of natural scour of the seabed during the last several thousand years was about 1m, and so this thickness of mud cap should not be eroded even under extreme storm events not experienced for the 150 years during which records have been kept in Hong Kong. It was also important to preclude the possibility of burrowing organisms reaching the contaminated mud, which is commonly less than 0.5m thick.

The final cap design (Figure 4), took account of the requirements discussed above and also practical considerations mostly related to construction. The cap comprises a nominal 1m thick layer of sand which sinks differentially into the surface of the contaminated mud to densify the surface layer and, importantly, provides a valuable marker horizon for later coring of the completed caps. The second and most important part of the capping, is the nominal 2m thick layer of clean (i.e. uncontaminated) mud. The third part of the capping takes place about 1 year later, after the pit infill has consolidated, and it involves placing a further layer of clean mud 1 to 2m thick to bring the upper surface of the cap up to the same level as the surrounding seabed. The resulting 3 to 4m thick layer of clean mud provides a permanent barrier over the contaminated mud and isolates it from any future contact with the marine environment.

The pits are dredged as deep as can readily be achieved, which means in practice that they are dredged to the base of the soft post-glacial marine deposits, commonly about 15m below the seabed. Most of the pit dredging has been by grab dredger with pit sides excavated at about 1 in 6. After the first Contaminated Mud Pit (CMP I), the size of subsequent pits was decreased to provide an added measure of safety by reducing the surface area of contaminated mud that might at any time be exposed to turbulent water conditions which occur during some typhoons.

Since late 1992, a total of about $10Mm^3$ of contaminated mud has been disposed of in the series of CMPs. Figure 5 shows in graphical form the progressive formation and filling of different CMPs together with the anticipated volumes requiring disposal up to about the year 2002 when contaminated mud disposal is estimated to have reduced to less than $0.5Mm^3$ a year.

Although most of the contaminated mud has been dredged from government projects and disposed of in CMPs operated by the government, private projects with small volumes of contaminated mud needing disposal are also permitted to use the government CMPs. These private projects pay a fee, currently set at HK$55.4 (about US$7), which is calculated to reflect the actual cost of forming, operating, capping and

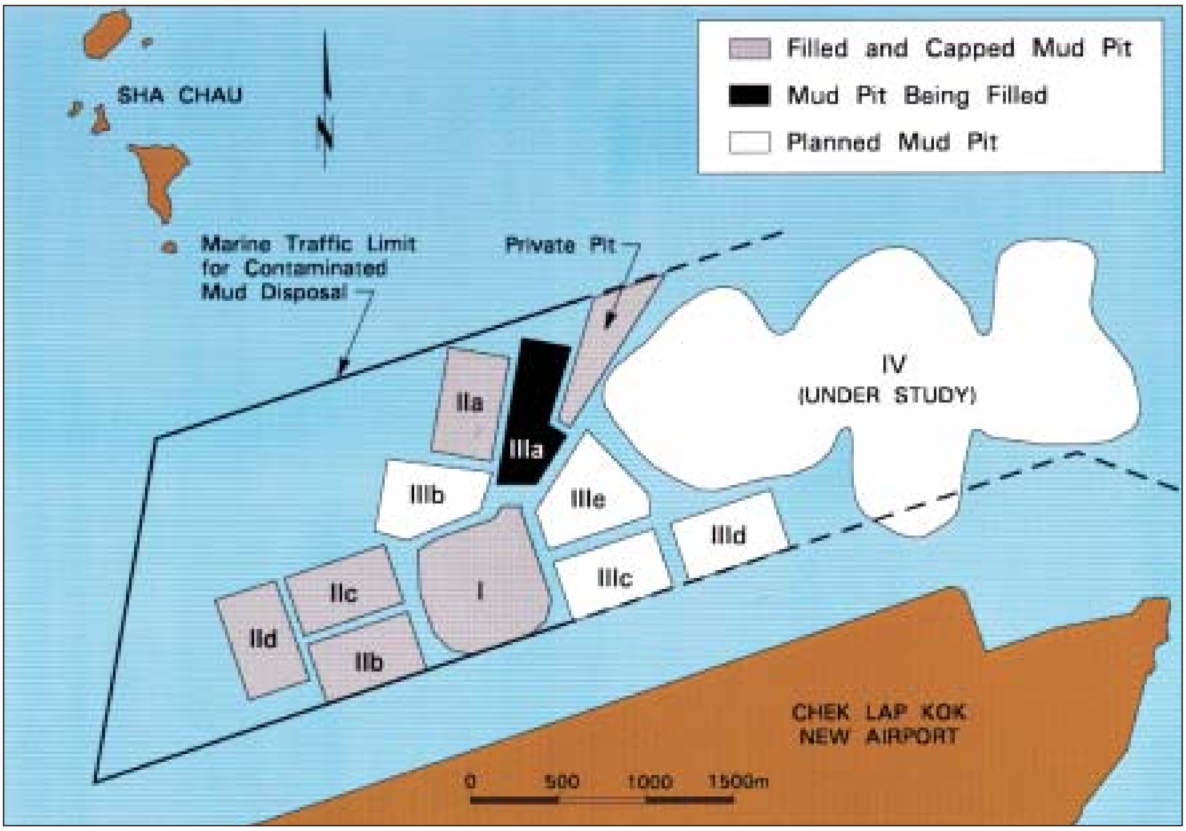

Figure 3. Layout and status of the contaminated mud disposal pits at East Sha Chau.

monitoring the facility. In addition, one private project with a large volume of contaminated mud requiring disposal has been permitted to form and fill its own pit at East Sha Chau following the same basic design (The Dock & Harbour Authority, 1996).

Dredging of the Contaminated Mud

Dredging Methods

The mud disposed of in the government CMPs has been dredged by grab and transported and placed by 750 to 1,000m^3 hopper barges. There have been three main reasons for the use of grab dredging of the contaminated mud:

– Grabs have been better suited to the shallow, near-shore and often constricted locations where most of the dredging has taken place.
– Hydraulically-dredged mud has a lower bulk density than grab-dredged mud and because the caps of the first few CMPs were formed using grab-dredged mud it was undesirable for the capping mud to have a higher density than the underlying contaminated mud.
– Most of the experience to date, and particularly the environmental monitoring data which showed no adverse impact, was based on the disposal of grab-dredged contaminated mud.

The private company referred to above, preferred to use a trailer dredger to dredge the contaminated mud and in order to demonstrate the environmental acceptability of using the trailer to place the mud in its CMP, it undertook a special monitored trial. This trial demonstrated losses no greater than from dumping grab-dredged mud and so the company was permitted to form, fill and cap its own pit.
The trailer dredger used for the work, the *Krankeloon,* has a submersed pump on the suction pipe giving relatively high hopper densities of about 1.4Mg/m^3 and has a split hull for dumping (Figure 6). The relatively high hopper density was an important factor in reducing losses during placement of the mud. Its relatively shallow draught also enabled it to operate in the East Sha Chau area. Because the capping mud was also trailer-dredged, there was no problem of a high density capping material sinking into a lower density contaminated material.

The environmental benefits of dredging contaminated mud by suction dredgers as opposed to dredging it by open grabs have not gone unnoticed in Hong Kong. Although closed grabs are used, this is not yet standard practice. Because of the need to dredge contaminated mud in busy shipping fairways where stationary plant is not feasible, more trailer-dredging will be used in the future.

Figure 4. Schematic section through a contaminated mud pit showing details of the capping layers.

Contamination Levels in Dredged Material

The sampling and testing programme has shown that some of the mud deposited in the CMPs is actually within the criteria for open-sea disposal – this is probably due to two factors.

Firstly, fifty metres is the average separation of the site investigation boreholes used to characterise the mud to be dredged but the actual contamination levels can vary on a smaller scale. When broad areas are classified for dredging purposes a conservative approach is adopted and this inevitably results in some uncontaminated mud being classified as contaminated.
Secondly, the grab-dredging process is not sufficiently discriminating to enable precise dredging of contaminated layers and this results in dredging of both contaminated and uncontaminated mud. Both these factors result in lower average concentrations of contaminants in the barge.

To address these points, the cost-effectiveness of the present borehole spacing is being reviewed and techniques of environmental and more precise dredging are being studied. Because dilution is philosophically not an acceptable solution to disposal of contaminants, post-dredging reclassification for open sea disposal is not permissible.

Placing and Investigating the Caps

With the exception of the private pit mentioned above, the formation of the caps up to early 1996 has used barges to place the sand and the mud, with the latter being grab-dredged. Each pit is divided into a grid of 30m by 30m cells. A split-hopper barge load of 1,000m^3 of sand is first deposited as evenly as possible over each grid cell by moving the partially open barge gradually over the area. The nominal 2m thick mud cap is then formed by placing two 1m thick layers of mud using similar procedures as for the sand layer. Because of the greater ease of hydraulic placing of mud, this method will be employed for mud cap placement henceforth and this will remove one of the objections to using trailer dredgers for placing of the contaminated mud as discussed above.

Six-metre long vibrocore samples are regularly taken from completed caps to inspect the cap structure and to provide samples from the top two metres for chemical testing. As may be expected, there are variations, particularly in the thickness of sand which is dependent on the construction technique and on the extent to which the sand penetrated the contaminated mud. Nevertheless, chemical testing of the cap samples has shown that the contaminants are being successfully contained.
In addition to ordinary bathymetric surveys during construction, Chirp seismic profiling is also used to provide a construction record (Evans & Woods, 1994; Selby & Foley, 1995). To help quality control, profiles are run before capping starts, again after the sand layer has been placed, and then again after placing the mud layer. The sand, which has different acoustic impedance from the mud, shows up as a useful marker horizon. When calibrated with vibrocore data, the Chirp profiling is able to show details of the cap structure to a depth resolution of about ±200mm.

To provide an overall perspective of the East Sha Chau area, the seabed in and around the CMPs is surveyed annually by 500kHz Side Scan Sonar and high resolution 180kHz Swath Bathymetry. These surveys provide information on consolidation settlement of the infilled pits and on any erosion which might have been caused by tidal scour or storms.

On-site Management

In July 1993, a 24-hour on-site management team was established to provide close monitoring and control of the disposal operations. Located on a barge moored outside, but near the active disposal pit, this team registers incoming barges and supervises filling and capping. In order to achieve as even a filling as possible, incoming barges are progressively directed to different parts of each pit.
In an attempt to limit dispersion of plumes formed during dumping, a silt curtain has been deployed between two anchored barges so that incoming barges can approach the disposal point from the upstream side and then dump in what is effectively a confined area. This practice was instituted in 1993 at a time when there was great public concern for what was then a very new and unproven operation. Because there are now three years of detailed environmental

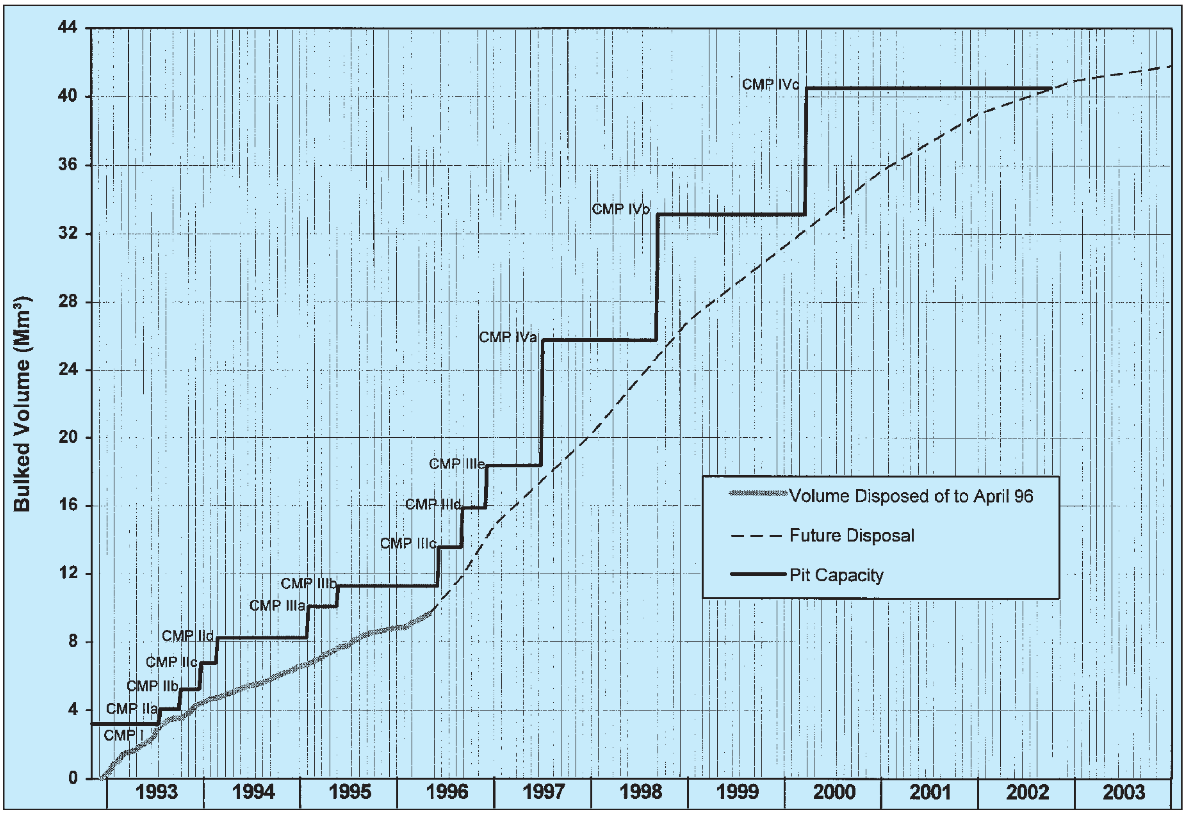

Figure 5. Graph showing the rate of filling of contaminated mud pits (CMPs) and the estimated future disposal volume.

and ecological monitoring to show that the operation is not having any noticeable environmental impact, and because on-site observations indicate that the curtain gives little, if any, additional confinement, its use will be discontinued for a trial period.

In early 1995, surveys were undertaken using the backscatter intensity from an Acoustic Doppler Current Profiler to quantify the sediment losses during dumping and it was estimated that where disposal takes place near the edge of the pit at peak tidal flow, losses of suspended sediment outside the disposal pit ranged from 1.2% to 3.1%. During slack current conditions, losses were negligible (Dredging Research Limited, 1995).

Inaccurate dumping outside the designated disposal pits was an occasional difficulty when CMP I was in operation, but this problem has been eliminated by the on-site supervision which started with CMP II. As an additional control, all licensed barges carry a sealed, automatic self-monitoring device that registers the barge position every five minutes and records the coordinates and time of the actual disposal.

ENVIRONMENTAL ASPECTS

Environmental Impact Assessment

Since the start of the disposal operations environmental concerns have been high among fishermen, environmental groups and the general public. Concerns were greatest in 1992 when disposal operations started but they have progressively reduced since then as the success of the operation has been demonstrated. The likely environmental impacts of the disposal arrangements at the East Sha Chau facility were assessed and are recorded in two reports finalised in March 1993 (Premchitt & Evans, 1993, CES & Binnie, 1993). Both reports were made public and were endorsed by the non-government environmental advisory committee.

In 1995, the London Convention adopted the Dredged Material Assessment Framework (DMAF) which provides a more detailed and structured approach to management and disposal of dredged material than was used in 1992 (IMO, 1995). In particular the DMAF outlines procedures for material characterisation, disposal methods and disposal site selection. The East Sha Chau operations have now been subjected to the DMAF procedures, and it has been reaffirmed that contained marine disposal at East Sha Chau is the preferred disposal arrangement (EVS, 1996).

Environmental Monitoring Programme

Environmental monitoring of the East Sha Chau area commenced in October 1992 prior to the disposal of contaminated mud, and since then has evolved and developed into a very comprehensive programme of physical, chemical and ecological monitoring. Apart from continued monitoring while pits are being filled

Figure 6. The splithull trailer dredger Krankeloon proved environmentally acceptable for the work.

and capped, the environmental monitoring of the site will continue until at least two years after the completion of the last disposal and capping operations at East Sha Chau.

The environmental monitoring programme now covers sediment and water quality, aquatic biota and ecotoxicology. The monitoring, which is carried out independently of the disposal operations, is in two parts – cumulative impact monitoring and pit-specific compliance monitoring.

Cumulative monitoring is carried out to measure any long-term effects on the overall disposal area and it comprises regular monitoring of water quality, sediment quality, abundance and diversity of benthic macro-infauna, heavy metal loading in tissue of demersal biota (fish and invertebrates), and toxicity testing of sediment.

The compliance monitoring programme involves observation around each pit during its operational phase, and it includes regular testing of water and sediment quality, and analysis of dredged material disposed of in the pit. A separate, three-month investigation of regional differences in fish stocks and heavy metal levels in tissue was undertaken from March to May 1995 during which trawls of demersal biota (fish and invertebrates) were carried out at East Sha Chau and various reference stations around Hong Kong.

A significant factor with the interpretation of all the East Sha Chau monitoring results is that the area is affected by large seasonal and diurnal fluctuations in salinity and natural suspended sediment load discharging from the Pearl River, China's third largest river. These estuarine conditions are also characterised by marked seasonal variations in temperature.

Despite the difficulties of monitoring within this very variable background, the environmental monitoring programme has not identified any adverse trends in the parameters being monitored. It has been concluded that the disposal procedures and capping methods are achieving the objectives of minimal losses during disposal and effective isolation of the contaminants thereafter. The additional fisheries survey described above indicates that the taxonomic characteristics of the regional stations are similar to those at the East Sha Chau stations and, more importantly, the statistical comparison between the East Sha Chau stations and the regional stations has not indicated elevations in tissue metal concentration of fish from East Sha Chau.

Recolonisation of Capped Pits

The benthic ecosystem of Hong Kong's muddy seabed is dominated by generally small polychaete worms with occasional crustaceans, molluscs and other fauna. The polychaetes are by far the most numerous and their dominance as an early pioneering group typifies the naturally dynamic seabed environment.

The seabed is seasonally remobilised by tropical storms, and in the East Sha Chau area is also subjected to fluctuations in salinity between 4 ‰ and 28 ‰, temperature between 18 C and 33 C, and suspended sediment levels between 10mg/l and 500mg/l as a result of the discharge of the Pearl River. The soft bottom benthic community which regularly has to recover from such severe physical changes, is therefore adept at recolonising the substrate and re-establishing itself.

Studies completed so far, have demonstrated, as expected, that recolonisation of the soft mud used to form the CMP caps is taking place (EVS, 1996; SAIC, 1994; Binnie, 1995). Full recolonisation will only be possible after the final topping-up capping layers have been placed, and even for the first CMP this has only recently happened. Nevertheless, it is expected that after about two years, the finished caps will be effectively indistinguishable from the surrounding natural seabed. Although yet to be fully demonstrated, it is therefore expected that as the capping operations in each pit are completed, the East Sha Chau area will be returned to its original condition both in terms of sediment type and ecosystem.

Conclusions: Future Disposal of Contaminated Mud

As shown in Figure 5, it is estimated that the CMP III series of small pits will be full by mid-1997. In order to meet disposal needs after that, a disused sand borrow pit (Figure 3) originally used for dredging of sand fill for construction of the new airport is now being studied for use as CMP IV. Extending to about 35m below sea level, this pit is significantly deeper than the earlier CMPs because the sand extracted was alluvial sand beneath the post-glacial soft marine mud.

However, by adopting the same general approach but stopping disposal at a lower level, possibly -12m, it is anticipated that about 22Mm3 of contaminated mud can be disposed of in this pit, with a final cap thickness of about 9m. The pit is actually in three sections, and as shown in Figure 5, it is envisaged that filling would be in three stages. The environmental impact assessment and design for CMP IV are currently underway.

The local regulatory procedures, and in particular, the 1992 sediment contamination criteria, are now being reviewed and it is expected that an additional set of contamination criteria for very contaminated material will be developed. Organic contaminants and effects-based biological testing are expected to be included in the revised management framework for disposal of contaminated mud. This review is expected to be completed later in 1996 at which time non-marine disposal options will also be considered for highly contaminated mud.

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