Civil Engineering and Development Department

Agreement No. FM 01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong

Report on Assessment of Management Options

FINAL REPORT (Rev A)

Civil Engineering and Development Department

Agreement No. FM 01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong

Report on Assessment of Management Options

FINAL REPORT
(Rev A)

August 2008

This report takes into account the particular instructions and requirements of our client.
It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party

Ove Arup & Partners Hong Kong Ltd
Level 5, Festival Walk,
80 Tat Chee Avenue,
Kowloon Tong, Kowloon,
Hong Kong
Tel +852 2528 3031 Fax +852 2268 3970
www.arup.com

Job number 25042

Contents

1 Introduction

1.1 Background

Large areas of the seabed close to inhabited areas of Hong Kong are contaminated with heavy metals, organic pollutants and raw sewage. For developments proposed in the near shore areas it is often necessary to dredge and dispose of this material. Several strategies have been proposed in the past for the disposal and treatment of dredged sediments which until recently has included open sea disposal and/or disposal to one of the designated purpose dredged confined marine mud pits with prior treatment as necessary depending upon the level and nature of contaminants that may be found within the dredged sediments as determined from chemical and biological testing. The record shows that the mud pits, particularly the one at East Sha Chau, are approaching their capacity and therefore new strategies will need to be developed to manage any future sediment disposal demands. Government Policy to leave the sediment in place has assisted in this aim but a longer term strategy will need to be developed to cope with future demands.

1.2 Description of the Assignment

This Assignment will review the existing management options and investigate possible alternatives to manage the disposal of marine sediments in the future under the following three categories i) Non-removal ii) Ex-situ Treatment and iii) Disposal and beneficial re-use. Non-removal is expected to be the preferred strategy wherever possible and therefore particular emphasis will be given to this area in deriving suitable management options. The assignment will involve the undertaking of a thorough desktop study of the management options and techniques that are available worldwide for the treatment of contaminated sediments each of which will be compared against one another and assessed with due consideration to the conditions in Hong Kong in order to determine which are most viable for which further consideration will be given. The five most favourable options with the associated monitoring will be recommended for field trials. The implications of each proposed option on the environment, ecology, fisheries, costs and technological requirements will all be considered carefully in the selection and ranking of each option and the recommended site characteristics for the trials. For each disposal option careful consideration will be given to ways in which to improve current practice to reduce the environmental impact of the works and to make use of the material. Advice will be given on a suitable procurement strategy for the undertaking of the trials including the logistical arrangements and an estimate of the implementation programme.

1.3 Objectives of the Assignment

The objectives of this assignment are to:

1. conduct a desktop study of management options/techniques available worldwide for contaminated sediments;
2. assess, with due reference to Hong Kong conditions, the respective merits and demerits of the options for application in Hong Kong environment;
3. recommend the options for management of contaminated sediment in Hong Kong to be taken further; and
4. draw up recommendation for field trials including associated monitoring requirements and their implementation plans and cost estimates.

1.4 Scope of this Report

This Report on Assessment of Management Options contains the following:

1. Overview of Marine sediments in Hong Kong Water;

2. Current management options for contaminated sediments in Hong Kong;
3. Review of worldwide sediment management options and practices;
4. Development of Screening and Ranking System;
5. Assessment of each management options with due consideration to specific conditions in Hong Kong; and
6. Recommendation of five most favourable options.

1.5 Definition of "soil" and "sediment"

It should be noted that, in the context of the current report, the term "soil" will be used in the broader engineering sense to mean any naturally formed earth material or fill which can be broken down by hand into its constituent grains according to Geoguide 3 – Guide to Soil and Rock Descriptions (GEO, 1997). Under this definition and unless otherwise clarified, soils shall comprise both "soil" found on the surface of the earth and "sediment" deposited under water.

2 Marine Sediments in Hong Kong Water

2.1 General

Many inorganic and organic contaminants present in the water are associated with particulate matter, which eventually settles in the sea as sediment. Apart from being a sink for contaminants the sediment also supports a variety of biota. These are part of the food chain and thus a potential hazard to higher organisms including humans because of biomagnifications.

Routine monitoring of marine sediments is conducted biannually by EPD at 60 stations throughout Hong Kong. These sampling stations include 45 stations at the open waters and 15 stations at typhoon shelters. The marine sediment parameters measured includes physical and aggregate properties (e.g. particle size fractionation, electrochemical potential, total solids, total volatile solids), aggregate organic constituents (e.g. chemical oxygen demand. total carbon), nutrients and inorganic constituents (e.g. ammoniacal nitrogen, total Kjeldahl nitrogen, total phosphorus, total sulphide, total cyanide), metals and metalloids (e.g. arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc) and trace organic compounds (e.g. total PCBs, low molecular weight PAHs and high molecular weight PAHs). With reference to EPD's Publication "20 Years of Marine Water Quality Monitoring in Hong Kong", the summary statistics for sediment quality in various areas of Hong Kong are summarised in Figures 2.1 to 2.6.

Data on other organic contaminants are limited. Four baseline surveys were undertaken by ERM-Hong Kong, Ltd (ERM 1999a), commissioned by the Hong Kong Planning Department, to determine toxic organic concentrations in sediments in Hong Kong's coastal waters in 1998. The five organic compounds measured comprised Total Polychlorinated Biphenyls (PCB), Total Polycyclic Aromatic Hydrocarbons (PAH), Organochlorine pesticide, Total Dichlorodiphenyltrichloroethane (DDT) and the Organotinantifoulant, Tributyltin (TBT). The findings of the surveys are briefly described in Section 2.4. The details of the survey can be referred to the following link:

http://www.epd.gov.hk/epd/english/environmentinhk/eia_planning/sea2005/toxic_marine.htm

2.2 EPD's Sediment Monitoring Data

As in 2006, routine monitoring of marine sediments has been conducted biannually by Environmental Protection Department (EPD) at a total of 60 stations; with 45 of them in open waters while the remaining 15 stations in typhoon shelters. A number of parameters are measured including physical and aggregate properties (e.g. particle size fractionation, electrochemical potential, total solids, total volatile solids), aggregate organic constituents (e.g. chemical oxygen demand, total carbon), nutrients and inorganic constituents (e.g. ammonia nitrogen (NH4-N), total Kjeldahl nitrogen (TKN), total phosphorus, total sulphide, total cyanide), metals and metalloids (e.g. arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc) and trace organic compounds (e.g. total PCBs, low molecular weight PAHs and high molecular weight PAHs).

According to EPD's Marine Water Quality in Hong Kong 2006 (ref: http://www.epd.gov.hk/epd/english/environmentinhk/water/marine_quality/files/MarineReport2006.pdf), in Year 2002 – 2006, sediments in Victoria Harbour, Junk Bay and Tsuen Wan Bay had higher levels of heavy metals, in particular copper and silver. This was related to effluents from printed circuit board, electroplating industries and photo-developing business in the 60s and 80s before pollution control legislation was in place. Mercury in the sediments was generally low except at one station in the western harbour, which may be related to discharges from dental clinics and industries in the past. Among the trace organic pollutants, the levels of polychlorinated biphenyls (PCBs) in the marine sediments of HK were generally low, except for a few sites in Victoria Harbour. Eighteen congeners of PCBs were analysed and they were found to be below the reporting limits in over 90% of the sediment samples. Low and high molecular weight polyaromatic hydrocarbons (PAHs) in the marine sediments ere mostly below reporting limits, except at one station in western Victoria Harbour where an elevated level of high molecular PAHs was found. This may be related to the contamination from the old waste incineration facilities in Kennedy Town which was decommissioned in 1994.

2.3 Qualitative Review of Sediment Quality in Hong Kong

Sediments in Hong Kong are generally anaerobic. This is mainly due to domestic discharges to the waters and an excess of decaying organic matter from reduced compounds such as hydrogen sulphide (H_2S), elemental sulphur and ammonia (Murphy et al., 1999). These compounds can limit or promote the number and types of species found in sediments depending on the characteristics of the compound. The lack of benthos reduces the mixing of sediments and the flux of oxygen inside. The electrochemical potential is very low around Victoria Harbour. Redox will vary according to the chemical regime of the sediments, the DO levels of the water column, mixing processes in the water column and the ambient temperature, which will affect biochemical oxidation rates. As the redox decreases, the available electron acceptors shift from energy rich compounds like oxygen and nitrate to energy poor compounds like sulphate and carbon dioxide. The lack of energy rich compounds suppresses the rate of bioremediation (Murphy et al. 1999). Highly anaerobic areas are found mainly in Victoria Harbour and embayments where they are enclosed areas where waters are not free flowing. Many of the embayments have fish culture zones that are highly polluted because of the fish excreta and excessive feedstock, resulting in anoxic situations.

In summary, a qualitative review of sediment quality in various water control zones in Hong Kong is summarised below:-

- Tolo Harbour & Channel - Sediment is particularly anaerobic giving large negative Eh values resulting from sewage, mariculture industry and livestock waste. High levels of nutrients, in the form of total Kjeldahl nitrogen are recorded in sediments at one monitoring site in the Tolo Channel. Elevated levels of lead were also identified at two sites near to the outlets of drainage channels thought to contain lead washed out from atmospheric sources (e.g. vehicle exhausts).
- Southern - Elevated levels of PAHs have been detected at two monitoring sites in West Lamma Channel.
- Port Shelter - High levels of nutrients, in the form of total Kjeldahl nitrogen are recorded in sediment at one monitoring site in Inner Port Shelter.
- Junk Bay - Elevated levels of PAHs detected at the monitoring site in inner Junk Bay.
- Deep Bay - Two sites in Inner Deep Bay are found to have high levels of nutrient (total phosphorus) in the sediments; High levels of copper and zinc were identified between 1993 and 1997 in inner Deep Bay sediment; Elevated levels of PAHs were detected at two monitoring sites in inner Deep Bay.
- Mirs Bay - Anaerobic conditions (high negative Eh) were found in the sediments of the Starling Inlet and Crooked Island areas. High levels of nutrients, in the form of total Kjeldahl nitrogen were recorded in sediment at two sample sites at Crooked Island and one at Port Island. These are thought to have derived from organic pollutants from mariculture zones.
- North Western, Western Buffer & Eastern Buffer - The sediment in the North Western WCZ shows compliance with all the parameters except for Arsenic. This is due to the naturally occurrence of Arsenic in that area. For the Western Buffer WCZ, the Arsenic

concentrations are also relatively high. In addition, WS1 in Tsing Yi also shows silver concentration. This is probably due to the historical industrial discharge from the industrial premises. Other than Arsenic and Silver, the other parameters comply with the sediment quality criteria. For Eastern Buffer WCZ, there are non-compliances for Copper, Mercury and Silvers at Stations ES1 and ES4 which are probably affected by the historical industrial discharge from the industrial premises in Chai Wan and Jink Bay.

- Victoria Harbour - High negative Eh values in sediment principally from sewage, commercial and industrial discharges. Also, high levels of ammoniacal nitrogen and total sulphide in Victoria Harbour may result in further toxicity under these anaerobic conditions; Serious contamination of sediment with chromium and copper was found in Tsuen Wan Bay, Rambler Channel and Kwun Tong (also nickel and zinc). The likely source is waste effluents from textile, printed circuit board and electroplating industries. Elevated PAH levels at all monitoring stations were detected.

The vast majority of contaminated sediments will comprise very soft marine muds. Figure 2.7, as extracted from EPD's report on Marine Water Quality in Hong Kong in 2004 (see http://www.epd.gov.hk/epd/english/environmentinhk/water/marine_quality/mwq_report04.html), indicates that marine sediments throughout the Hong Kong waters are composed predominately of soils with particle size <63μm, that is fine grained soils (clay and silts). Contamination is expected to be confined, in most cases, to the uppermost 1 or 2 metres of the soil profile although results recently obtained suggest that in some areas it may extend to a depth of 3 metres. The sediment is characterised by very high water content, fines content (less than 2 microns) typically in excess of 75%-80% and very low shear strength. Such materials are easily dredged by a variety of methods and do not constitute a 'dredging problem'. Some of the sediments, particularly that found in nullahs and typhoon shelters, are highly organic with a very low bulk density and specific gravity.

2.4 Toxic Level in Hong Kong Marine Sediments

2.4.1 Total DichloroDiphenylTrichloroethane (DDT)

The spatial variation of Total DDT in sediments recorded in the "Environmental Baseline Survey Report: Toxic in Marine Sediments and Biota" (see http://www.epd.gov.hk/epd/SEA/eng/environmental_baseline_reports.html) and reported previously in Hong Kong are shown in Figure 2.8. Total DDT concentrations in sediments analysed were generally above the Interim Sediment Quality Value (ISQV)-Low value (i.e. 1.58 $\mu g\ kg^{-1}$ dry weight, Long et al 1995) and hence potentially harmful to benthic organisms. Sediment re-suspension may also provide a DDT exposure pathway to pelagic (i.e. water column) organisms.

2.4.2 Tributyltin (TBT)

EPD does not gather data on TBT in the routine monitoring of sediments in Hong Kong waters. Few data is therefore available regarding TBT contamination of local sediments. The spatial variation of TBT values in sediment recorded in the baseline study (ERM, 1999a) along with values reported previously in Hong Kong are presented on Figure 2.9.

The highest TBT concentrations are found in the proximity to the south of Tsing Yi where the upper concentrations recorded ranged from 81.8 - 107.0ug Sn kg^{-1}. These high TBT levels are probably associated with intensive shipping activity (TBT antifouling paints) and nearby shipbuilding and repair operations.

TBT concentrations recorded in previous studies (EMR, 1999b) at the East Sha Chau and East Lamma Channel are generally at 10ug Sn kg^{-1}.

Relatively high TBT concentrations were recorded in sediments from the typhoon shelters at Pak Sha Wan (Sai Kung), marinas at Marina Cove and Hebe Haven, Causeway Bay, and, at the Tiu Cham Wan fish culture zone (Sai Kung) where values between 0.9 and 1.7ug TBT kg^{-1} were reported.

TBT sediment concentrations in Causeway Bay Typhoon Shelter, Tsing Yi North, Aberdeen, Victoria Harbour and Hebe Haven were previously measured to have levels of 312.5, 1163.0, 74.0, 16.5 and 39.0ug Sn kg^{-1}, respectively (Aspinwall 1998).

2.4.3 Total Polychlorinated Biphenyls (PCBs)

To monitor the quality of marine sediments, the Environmental Protection Department (EPD) collects sediment samples from 60 monitoring stations and tests for over 60 physical and chemical parameters. The mean concentrations of polychlorinated biphenyls (PCBs) in marine sediments in 2002-2006 are illustrated in Figure 2.10.

The high prevalence of Total PCBs recorded in local species is indicative of both environmental persistence and possibly continuing inputs (e.g. from illegal dumping of PCB contaminated wastes). For example, Morton (1989) noted that in Hong Kong in the 1980's, over 3300 PCB-filled capacitors were either still in use or in storage.

2.4.4 Total Polycyclic Aromatic Hydrocarbons (PAHs)

EPD's sediment monitoring data also includes the testing for Low Molecular Weight Polycylic Aromatic Hydrocarbon (PAH) and High Molecular Weight PAH. According to the data for 2002-2006, most of the data comply with the Lower Chemical Exceedance Level under the ETWB TC(W)34/2002 - Management of Dredged/Excavated Sediment, except the High Molecular Weight PAH within the Victoria Harbour (VS6). According to EPD's Marine Water Quality in Hong Kong 2006, this may be related to the contamination from the old waste incineration facilities in Kennedy Town which was decommissioned in 1994.

2.4.5 Heavy Metals and Metalloids

According to EPD's sediment monitoring data 2002-2006, most of the sediment samples show general compliance with the Lower Chemical Exceedance Level under the ETWB TC(W)34/2002, although some of the samples at some locations exceed the criteria. Some observations are list below:

- For heavy metals tested (ie Cadmium, Chromium, Copper, Lead, mercury, Nickel, Silver and Zinc), it is observed that the areas affected by historical and existing industrial areas showed relatively higher concentrations. These areas include Tolo Harbour (TS2, TS3 and TS4), Jink Bay (JS2), Tsing Yi (WS21). Other than these industrial area, area in Deep Bay also experienced higher concentration in copper and zinc.
- For Arsenic which is metalloid, areas to the north of Chek Lap Kok, west of Tuen Mun and Deep Bay showed relatively higher concentrations. This is probably due to the natural variation in these areas.

2.5 Key Marine Ecological Resources Potentially Affected by Suspended Sediment

2.5.1 Recognised sites of conservation importance

There are four marine parks, one marine reserve, and two proposed marine parks in Hong Kong waters.

- Sha Chau and Lung Kwu Chau Marine Park: a protected area for the Chinese White Dolphin in North Lantau waters;
- Hoi Ha Wan Marine Park;
- Double Haven Marine Park;
- Tung Ping Chau Marine Park;
- Cape d'Aguilar Marine Reserve; and

- The proposed marine parks at southwestern Lantau and Soko Islands.

Sha Chau and Lung Kwu Chau Marine Park which was designated for the conservation of Chinese White Dolphin. Sha Chau and Lung Kwu Chau Marine Park, a marine area of 12 km^2 (1,200 hectares), lies adjacent to the Urmston Road shipping channel. It is the only marine park in Hong Kong western waters. The Marine Park was designated on 22 November 1996 with the primary objective of protecting Chinese White Dolphin and its habitat. Some human activities are controlled in the Marine Park in order to provide a safe haven for dolphins. Trawling is prohibited, and speed limits are placed on vessel traffic to decrease the risk of collisions. The boundary is demarcated by yellow light buoys deployed at the corners of the marine park. The landward boundary follows the high water mark along the coastline of the islands. The marine environment of Sha Chau and Lung Kwu Chau Marine Park is greatly influenced by the Pearl River freshwater run-off, with high organic loading and sediment loading. Marine organisms found in this region are adapted to a low salinity and high turbidity marine environment.

Other marine parks were also designated for conservation, recreation and education purposes, while the marine reserve was mainly for conservation and scientific researches.

Two Marine Parks were proposed at the waters off the southwest coast of Lantau and the waters around Soko Islands. A feasibility study was completed in 1999 (Tsang & Milicich 1999). One of the purposes of this marine park is for the protection of cetaceans, in particular Chinese White Dolphin which is abundant in West Lantau waters and Finless Porpoise which occurs in Southern Hong Kong waters.

2.5.2 Chinese White Dolphins

There are fifteen recorded cetacean species from Hong Kong waters although only two of these species, the Chinese White Dolphin (Sousa chinensis) and Finless porpoise (Neophocaena phocaenoides) are resident (Parsons et al., 1995).

Chinese White Dolphin is present throughout shallow (< 20 m) coastal waters of the Indo-pacific, from Australia and China in the east to South Africa in the west. Off the coast of south China, at least seven separate populations were identified from Guangxi up to the mouth of the Yangtze River, and all coincide with the presence of river mouths. One of these populations inhabits the Pearl River Estuary, with the population size has been estimated using line-transect methods to number at least 1,504 individuals (Jefferson & Hung 2004). The habitat range of this population includes part of the HKSAR waters. There is a great deal of seasonal fluctuation in the abundance of dolphins in different areas within their habitat ranges. Peak abundance in Hong Kong SAR occurs in the autumn and winter months, when there are about 200 dolphins within the SAR boundaries (Jefferson & Hung 2004). The low season is spring, when Hong Kong abundance declines to only about 80 individuals (Jefferson 2003; Jefferson & Hung 2004).

In Hong Kong, Chinese White Dolphins *Sousa chinensis* are concentrated in the more estuarine-influenced waters, i.e. the western waters of Hong Kong. Particularly, West and North Lantau waters are the most important ranges of dolphins within Hong Kong.

In North Lantau, highest numbers of sightings were recorded in Urmston Road, in particular the area between Pillar Point, Black Point, Lung Kwu Chau, and the north of north-east corner of Chek Lap Kok as well as the Brothers. West Lantau waters (the waters between Fan Lau to Tai O) are recently recognised as another areas with high dolphin sightings (AFCD 2006). Moreover, unspotted calves or unspotted juveniles of dolphins were more frequently sighted in West Lantau waters.

Chinese White Dolphin is frequently observed in association with fishing vessels on trawl, apparently feeding on fishes disturbed by or escaped from nets. The dolphins appear to shift their grounds within Hong Kong seasonally with the extent of river influence, moving farther south and east from the Pearl River during wet season, and farther into the estuary proper during dry season.

Breeding appears to occur throughout the entire year, but there is a peak in the occurrence of births between the months of March and August (Jefferson 2000; Jefferson 2004). This corresponds to an observed increase in apparent sexual and aerial behavior in the late summer and autumn months.

2.5.3 Finless Porpoise

Finless porpoise, *Neophocaena phocaenoides*, is another resident cetaceans in Hong Kong. Within Hong Kong Finless Porpoises occur in the waters to the south and east of Lantau Island, but have never been sighted north or west of Lantau. In addition, they occur in Hong Kong's eastern waters, south of Lamma Island, Hong Kong Island, and in the Po Toi, Ninepins, Sai Kung, and Mirs Bay areas (Parsons et al. 1995; Jefferson & Braulik 1999; Jefferson et al. 2002). While finless porpoises do not use the North Lantau area or the Pearl River Estuary immediately to the west of Hong Kong, they do occur in Mainland waters around the Aizhou Islands at the southern end of the Pearl River Estuary (e.g., Guishan and Dazhi Zhou Islands) (see Jefferson et al. 2002). Finless Porpoises occur in relatively high densities in the Aizhou Islands area, especially in summer months, when there are estimated to be about 150 porpoises in that area (Jefferson et al. 2002). Although the population size of finless porpoise in the Pearl River Estuary is not exactly known, based on the line transect analyses, it is estimated to have a minimum of 220 individuals. The actual population size of finless porpoise in the Pearl River Delta region is likely to be larger.

Finless porpoises favour the more open water that is less frequently inhabited by Chinese white dolphins, mainly to the east and south of the Pearl River Delta region. They feed at different water levels in areas of reefs and sandy substrates (see http://www.afcd.gov.hk/english/publications/publications_con/files/fin_executive_summary.doc). Breeding of finless porpoises is strongly seasonal; most calves are born from October to January even though some may give birth at other times of the year.

2.5.4 Corals

Corals in Hong Kong exhibit strong gradients in distribution, species diversity and abundance. Hard corals prefer clear oceanic water and are vulnerable. The geographical distribution of hard corals in Hong Kong is affected by the salinity of the water. Hard coral cover and diversity decrease from east to west, toward the influence of the Pearl River (Scott 1984). The estuarine environment of the northwestern waters was thought unsuitable for the existence of scleractinians (reef-building corals) (Scott 1984). A later study demonstrated that water quality, particularly elevated freshwater and suspended sediment levels which are characteristic of estuarine environment, prevent substantial hard coral growth (Hodgson and Yau 1997).

Urmston Road and the North Lantau waters are within the estuarine northwestern waters. In contrast to the oceanic eastern waters, northwestern waters are characterized by domination of gorgonian and soft corals. Soft corals, sea pens and gorgonian corals (sea fans) were also reported to be present throughout the northwestern waters (Mouchel 2002b, 2004).

AFCD commissioned intensive underwater surveys in 2001-2002 to survey corals in territorial waters. Results indicated that the coverage of corals in western waters in Hong Kong is very low (less than 5%, and usually < 1%, the lowest compared with other regions in Hong Kong). The "near-total or "complete absence" of reef-building hard corals was considered attributable to the high turbidity and low salinity.

2.5.5 Marine Benthic Communities

In a recent territory-wide benthic survey commissioned by AFCD (CCPC 2002), up-to-date information on the subtidal benthic communities, with respect to spatial distribution, abundance, and species composition, was collected at 120 sampling stations over the territorial waters of Hong Kong which were divided into 5 strata (regions).

Species richness, diversity and evenness indices are inter-related. A diversity index integrates two components: the total number of species (d) and the distribution of individuals among species, into a single number (H'). H' is usually high (e.g. >3 or 4) in environmentally undisturbed benthic communities, and low (e.g. <1) in highly disturbed communities (Gray 1989). Values for diversity, and evenness would be high, with H'>3 and J (evenness) >0.8 for a diverse community structure. In benthic habitats where organic matter is concentrated or dissolved oxygen is low, such values are low, with H'<2, and J<0.5.

The cephalochordate *Branchiostoma belcheri* is the only known benthic macrofauna species of conservation interest in Hong Kong (CCPC 2002). It was recorded in Hong Kong eastern waters and the waters to the south of Cheung Chau.

2.5.6 Fishing / Spawning Grounds

Fishing grounds cover most of the open waters in HK waters, except for shipping fairways and marine exclusion areas. Detailed data on HKSAR capture fisheries in the fisheries study area were taken from the results of Port Survey. Port Survey is the most comprehensive fisheries study in Hong Kong conduced by AFCD every few years, and recent data comes from Port Survey 96/97 and the latest Port Survey 2001-2002.

In Port Survey 96/97, Hong Kong waters were divided into fishing areas of various sizes and shapes, and these fishing areas were grouped into 12 sectors. As indicated in the AFCD's Port Survey 96/97, within HKSAR waters, the highest yields for local fisheries were mainly derived from the eastern and northeastern coasts, while the western waters were less productive.

More recent data were extracted from the latest Port Survey in 2001-2002. In this study a uniform grid of 720 ha cell size was overlaid on Hong Kong waters and the fisheries related information (e.g. production, vessel number, catch value) was presented in several categories.

Important spawning grounds of commercial fisheries species were identified in different areas within Hong Kong waters during a fisheries study in Hong Kong (ERM 1998), including the North Lantau waters at the Brothers and Lung Kwu Chau and southern Hong Kong waters.

2.5.7 Mariculture sites

The predominant type of mariculture in Hong Kong is marine fish culture, which involves rearing of marine fish from fry or fingerlings to marketable size in cages suspended from floating rafts usually in sheltered coastal areas. Common species under culture include green grouper, brown-spotted grouper, Russell's snapper, mangrove snapper, red snapper, cobia and pampano (see AFCD website: http://www.afcd.gov.hk/english/fisheries/fish_aqu/fish_aqu_mpo/fish_aqu_mpo.html).

Marine fish culture is protected and regulated by the Marine Fish Culture Ordinance (Cap. 353), which requires all marine fish culture activity to operate under licence in designated fish culture zones. Currently, there are 26 fish culture zones occupying a total sea area of 209 ha with 1,080 licensed operators. In 2006, the production from local marine fish culture was 1,488 tonnes (of value HK$89 million), constituting 7.9 % of the local live marine fish consumption (see AFCD website: http://www.afcd.gov.hk/english/fisheries/fish_aqu/fish_aqu_mpo/fish_aqu_mpo.html).

Water quality within Marine FCZs is regulated under the WPCO and its supporting regulations and statements. Within Fish Culture Subzones, the dissolved oxygen level should not be less than 5 mg l^{-1} for 90% of the sampling occasions during the year; values should be calculated as water column average (arithmetic mean of at least 3 measurements at 1 metre below surface, mid-depth and 1 metre above seabed). In addition, the concentration of dissolved oxygen should not be less than 2 mg l-1 per litre within 2 metres of the seabed for 90% of the sampling occasions during the year, and the annual geometric mean of *E. coli* should not exceed 610/100 ml.

Oyster farming is another type of mariculture in Hong Kong. Hong Kong's oyster farming operations occur in Deep Bay only. The oyster beds and rafts near Tsim Bei Tsui and Ha Pak Nai are also the only marine culture fisheries sites inside Deep Bay. In 2006, the production was 131 tonnes valued at $6 million (see AFCD website: http://www.afcd.gov.hk/english/fisheries/fish_aqu/fish_aqu_mpo/fish_aqu_mpo.html).

There are over 1,000 ha of mudflats within Deep Bay, with about 75% of them extend from Tsim Bei Tsui to Ha Pak Nai (747 ha) and are suitable for oyster farming (Arup 2002). About 176 ha were occupied by oyster cultch, scattered throughout the area but concentrated near Lau Fau Shan (ibid.). There are also about 258 oyster rafts in Deep Bay (ibid.).

Two species of oyster are cultured in Deep Bay: *Crassostrea gigas* and *C. rivularis*. Most of the oysters are cultivated from spat collected in Deep Bay itself or imported from other parts of the Pearl River Estuary. Oysters are grown to market size on cultch (or "cultch"), a fixed substrate embedded in the mud. A cultch may be a concrete post, concrete tile, concrete block or a stone. Recently the most common type of cultch is a bamboo stick coated with concrete. Cultches are inserted into the tidal mudflats or suspended from oyster rafts near the middle of the Bay.

Though they have no direct relation with the settlement and growth of oysters, the mudflats provide a substrate for the deployment of oyster cultch. Cultches on mudflats are rearranged 2 to 3 times a year to maintain the angle favouring oyster growth. The average diameter of each oyster cultch with oysters is about 0.2m. The spacing between rows of cultch in oyster beds is about 1m, and the spacing between two oyster cultch is about 0.3m. Normally it takes about three years for the oysters to mature to a marketable size.

In the subtidal zone, rafts are used for oyster cultivation. Most oyster rafts measure about 80 - 96 m^2, while some are smaller in size (about $24m^2$). Binnie (1984) reported a much larger size range, i.e. 84 to 110 m^2, for the rafts in mainland waters. The rafts are constructed of bamboo or wood poles with floats attached. Oysters are suspended from the rafts such that the oysters are above the seabed even during low tide. This system enhances the contact time period of oysters with the water and thus reduces the growth time in comparison with oysters on cultches in the intertidal zone.

3 Current Management Practices for Contaminated Sediments in Hong Kong

3.1 Management Practices for Contaminated Sediments

Since 1992, when Hong Kong began formal classification of contaminated mud and initiated disposal of it in purpose-dredged pits in the seabed at East of Sha Chau, Hong Kong's programme of contaminated dredged material management has continually evolved to incorporate enhanced engineering and environmental management techniques. Disposal procedures have been adopted to provide more accurate placement of material within the pit taking account of current speed and direction at the time of placement, and monitoring techniques such as sediment bioassays, risk assessment and statistical hypothesis testing have been adopted and continually updated. Hong Kong has also revised the sediment classification system to include sediment quality criteria for a large number of contaminants in parallel with bioassay testing.

3.2 Legislation and Guidelines

Relevant legislation and guidelines for disposal of contaminated sediments at marine disposal sites are listed below:

- Dumping at Sea Ordinance (Cap.466);
- Guidance Note No.1/2006 "Implementation of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972";
- PNAP 252 "Management Framework for Disposal of Dredged/Excavated Sediment";
- ETWB TC No. 34/2002 "Management of Dredged / Excavated Sediment"; and
- WBTC No. 12/2000 Fill Management.

The Dumping at Sea Ordinance is the principal statutory legislation to control dumping of sediment at sea. It safeguards the water quality and ecology of Hong Kong waters.

PNAP 252 provides information on the management framework for dredged/excavated sediment disposal under the Dumping at Sea Ordinance. It states the requirements for justifying the need for dredging and provides guidance on how to obtain information on the sediment, which can be used to support the permit application for the disposal. It also outlines the procedures for assessing sediment quality and explains the marine disposal arrangements for different sediment categories. The practice note applies to all private projects which involve the marine disposal of dredged/excavated sediment and whose dredging/excavation work for which mud dredging/excavation proposals have not yet been agreed by the Marine Fill Committee. Examples of projects include reclamation, construction of marinas and deep excavation for basement construction where the excavated sediment is of such quantity that marine disposal has to be adopted.

Similar to PNAP 252, ETWB TC(W) No. 34/2002 sets out the procedure for seeking approval to dredge/ excavate sediment and the management framework for marine disposal of such sediment. It covers the approval of dredging / excavation proposals and marine disposal of dredged / excavated sediment. It does not cover the use of dredged/excavated sediment to form land, but such dredging and reclamation works must satisfy the requirements of the EIAO. Applications for approval of dredging/excavation proposals and allocation of marine disposal space shall be made to the Secretary of Marine Fill Committee (MFC). This circular applies to Government and quasi-Government projects which involve the dredging/excavation and marine disposal of sediment. The allocation of sediment disposal space at sea will not be considered until the need for removal of the sediment has been satisfactorily demonstrated. The rationale for sediment removal must therefore be provided to the Secretary of MFC for agreement.

3.3 Characterisation of Sediments

The aforesaid practice note, PNAP 252, and technical circular, ETWB TC(W) No. 34/2002, provide guidelines for the classification of sediment based on their contaminant levels. Sediment quality criteria for classification include:

- Metals (cadmium, chromium, copper, mercury, nickel, lead, silver and zinc);
- Metalloid (arsenic); and
- Organic micro-pollutants (PAHs, PCBs and TBT).

Based on the criteria, the sediment is classified into Category L (low contamination level), Category M (medium contamination level) or Category H (high contamination level), as follows:

- **Category L** (Low severity) – Sediment with all contaminant levels not exceeding the Lower Chemical Exceedance Level (LCEL). The material must be dredged, transported and disposed of in a manner which minimizes the loss of contaminants either into solution or by resuspension.
- **Category M** (Moderate severity) – Sediment with any one or more contaminant levels exceeding the Lower Chemical Exceedance Level (LCEL) and none exceeding the Upper Chemical Exceedance Level (UCEL). The material must be dredged and transported with care, and must be effectively isolated from the environment upon final disposal unless appropriate biological tests demonstrate that the material will not adversely affect the marine environment.
- **Category H** (High severity) – Sediment with any one or more contaminant levels exceeding the Upper Chemical Exceedance Level (UCEL). The material must be dredged and transported with great care, and must be effectively isolated from the environment upon final disposal.

PNAP 252 and ETWB TC No. 34/2002 also stipulate a three-tiered screening for sediment assessment for determining the disposal options.

WBTC No. 12/2000 defines the responsibilities of MFC and Public Fill Committee (PFC). It also sets out the terms of reference and membership of the two committees and provides explanation on the management of fill resources, construction and demolition material, and dredged/excavated sediment disposal.

Table 3.2 – Sediment Quality Criteria (Classification under ETWBTCW No 34/2002)

Contaminants	LCEL[(a)]	UCEL[(b)]
Metals (mg kg^{-1} dry weight)		
Cd	1.5	4
Cr	80	160
Cu	65	110
Hg	0.5	1
Ni[(c)]	40	40
Pb	75	110
Silver (Ag)	1	2
Zinc (Zn)	200	270
Metalloid (mg kg^{-1} dry weight)		

Contaminants	LCEL[(a)]	UCEL[(b)]
Arsenic (As)	12	42
Organic-PAHs ($\mu g\ kg^{-1}$ dry weight)		
Low Molecular Weight (LMW) PAHs	550	3160
High Molecular Weight (HMW) PAHs	1700	9600
Organic-non-PAHs ($\mu g\ kg^{-1}$ dry weight)		
Total PCBs	23	180
Organometallics (μg TBT l^{-1} in interstitial water)		
Tributyltin [(c)]	0.15	0.15

Note:

(a) Lower Chemical Exceedance Level (LCEL)

(b) Upper Chemical Exceedance Level (UCEL)

(c) The contaminant level is considered to have exceeded the UCEL if it is greater than the value shown.

According to the Management Framework for Dredged/Excavated Sediment as stipulated in Appendix C of ETWB TCW No. 34/2002, the sediment to be disposed of will need to be categorized to the abovementioned Category L, M and H through a series of chemical and biological screening. The corresponding disposal methods will then be assigned based on the results of these tests as follows:

Type 1 – Open Sea Disposal

Type 1 – Open Sea Disposal (Dedicated Sites)

Type 2 – Confined Marine Disposal

Type 3 – Special Treatment/Disposal

3.4 Key Environmental Issues for Dumping Site

Sections 3.2 and 3.3 outline the guidance that applies to the characterisation of dredged sediment and defines three categories of sediment according to contaminant levels. This information is used as part of a wider assessment of the potential impacts of the dredging and disposal on the marine environment.

An important consideration when assessing potential environmental impact is the nature of the receiving environment, one aspect of which is the sediment quality in the receiving environment at the dredging and disposal sites. In order to describe existing sediment quality to inform impact assessment it is often necessary to undertake surveys of seabed sediments over a given area that has the potential to be influenced by the dredging and/or disposal activity.

One of the aims of such survey work is to describe how sediment quality varies throughout a survey area at the sediment survey and (within a proposed dredge area) with depth in the sediment. In particular, the survey will reveal how variable sediment quality may be across a survey area (i.e. identify 'hot spots' of contamination) and with depth. This information can then be used to inform how dredging (and dispersal of fine sediment) and disposal might impact on sediment quality in the surrounding area and (along with other investigations such as bioassay tests) whether any changes are likely to be significant for marine habitats and species. It is important to note that as well as contaminant levels, the physical, chemical and biological nature of the sediment (e.g. grain size, cohesiveness, organic matter content, toxicity etc.) needs to be assessed as changes in these parameters at a receiving environment can also have significant effects on the biological environment.

The overall objective should be on identifying and, where possible, quantifying risk to the environment. In this respect, the source of contamination (i.e. whether it is of natural or anthropogenic origin) is not of particular relevance. The key issue is how representative the quality of the dredged sediment is in relation to the receiving environment and how the risk to the marine environment might change when sediment is dredged or disposed of (e.g. by making contaminants more bioavailable). For example, a sediment quality survey of a proposed dredge area may reveal that a number of metals are present, but it may be that the concentration of these metals is comparable with the surrounding area and with a proposed disposal site.

3.5 Generation of Sediments

3.5.1 Avoidable

There are three main types of marine works that fall within this category:-

(1) general reclamation;

(2) to provide a suitable foundation for seawalls, drainage outfalls and other structures; and

(3) to provide protection system for submarine pipelines and utilities.

There may be room to introduce appropriate management options to reduce the demand for disposal of contaminated sediments and thus meet the need to protect the marine environment and the living resources which it supports.

3.5.2 Unavoidable

Where the water depth needs to be increased, e.g. for new shipping lanes, navigation channels and turning basin, anchorages, typhoon shelters, submerged structures (e.g. cross harbour tunnels), improved drainage in river channels and removal of siltation in harbours and fairways, there is no alternative to dredging in these cases.

3.6 Anticipated Quantities of Dredged / Excavated Sediments

The estimated quantities of dredged contaminated sediments between 2002 and 2006, supplied by CEDD, are summarised in Table 3.5.1.

Table 3.5.1 – Quantity of Dredged Contaminated Sediments between 2002 and 2006

Works/Year	Quantity of Dredged Contaminated Sediments (million m^3)				
	2002	2003	2004	2005	2006
Government Maintenance Works	1.074	0.294	0.472	0.625	0.199
Government Capital Works	0.504	0.250	0.962	0.044	0.055
Private Maintenance Works	0.774	0.060	0.000	0.126	0.354
Private Capital Works	3.983	0.249	0.028	0.075	0.049
Total	**6.33**	**0.85**	**1.46**	**0.87**	**0.66**

With reference to the CEDD's Fill Management Data, the forecast estimates of contaminated sediments from active and proposed projects which cover the period 2007-2014 are summarised in Table 3.5.2.

Table 3.5.2 – Forecast of Arisings of Contaminated Sediments (2007-2014)

Works / Year	Quantity of Contaminated Sediments (million m^3)							
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Government Maintenance Works	0.883	0.416	0.611	0.650	0.650	0.390	0.000	0.000
Government Capital Works	0.320	0.043	0.582	0.275	0.256	0.307	0.138	0.042
Private Maintenance Works	0.072	0.124	0.000	0.000	0.000	0.000	0.000	0.000
Private Capital Works	0.212	0.087	1.560	0.501	0.748	0.231	0.055	0.000
Total (yearly)	**1.487**	**0.671**	**2.753**	**1.425**	**1.654**	**0.928**	**0.193**	**0.042**

3.7 Current Mode of Operation for Different Management

3.7.1 Marine Disposal Options

Although non-dredge methods are encouraged for Hong Kong reclamation projects, dredging is sometimes required for seawall construction. Dredging is also necessary for certain works related to the maintenance of harbours, fairways, anchorages and drainage channels. The Environment, Transport and Works Bureau (ETWB) have promulgated a framework for the management of dredged/excavated sediment through the ETWB Technical Circular (Works) No. 34/2002. As stipulated in the circular, the method of disposing of dredged sediment depends on the level of contamination of the sediment as described in Section 2. Sediment disposal methods currently used in Hong Kong are as follows:

- Open Sea Disposal of Dredged Sediment

  Two open sea floor disposal areas at South Cheung Chau and East Ninepin and various empty marine borrow pits, shown in Figure 3.1, have been used for disposal of uncontaminated mud. A centralised management and monitoring scheme has been set up to provide overall control of the operations and environmental monitoring at all the uncontaminated mud disposal areas. This centralised scheme meets the new international standards for managing mud disposal facilities adopted by the London Convention, to which China is a signatory.

- Confined Disposal of Dredged Sediment at East Sha Chau

  Contaminated mud is disposed of at East Sha Chau in an environmentally acceptable manner. The mud pits, having a total disposal capacity of about 46 Mm^3 and the remaining capacity as in 2007 as 4.01 Mm^3. It is expected that the mud pits will provide sufficient disposal capacity for contaminated mud until around late 2010. Compliance environmental monitoring has been conducted since operation of the mud pits and will continue until 2 years after closure of all the pits to ensure that there is no adverse impact on the environment.

  A charging system has been implemented for private projects using the marine disposal areas. Private users are charged pro-rata for the cost of dredging, managing, capping of mud pits, and environmental monitoring of the disposal areas.

- Disposal at North of Brothers

  For Category M Sediment that passes the biological screening test, they could also be disposed at the dedicated site at North of the Brothers.

3.7.2 Land Disposal Options

Land disposal options have been adopted in Hong Kong mainly for the management of industrial waste. They have, however, seldom been used for the management of dredged contaminated sediments in the region. The only land disposal option that had been adopted in Hong Kong for management of contaminated sediments is the landfill disposal option, although land reclamation option has also been identified as a potential long-term disposal alternative for contaminated dredged material.

Technical limitations to the reclamation/landfill disposal option include uncertainties related to contaminant mobility, lack of knowledge of in site management requirements, possible uses of the land following reclamation, mechanical stability of contaminated dredged spoil disposal, and the length of time required to develop a land reclamation facility. Some of the environmental issues of this option include the potential movement of contaminants, and the potential increased risk to human health from closer proximity to the contaminants (i.e. greater risk of exposure), and the impacts to nearby water quantity from leachate and dewatering.

Although there had been some case records on the use of land disposal options for managing dredged contaminated sediments in Hong Kong, where small quantities of river sediment and excavated sediment were disposed of at landfill, various reports have considered land formation, or poldering, to be a potential long-term disposal option for dredged material (FMC, 1989; Whiteside et al,.1990) and potential sites include the southeastern shore of Deep Bay. Nonetheless, marine disposal at East Sha Chau has remained a more feasible and less problematic option for management of operations than land reclamation.

4 Review of Worldwide Non-removal Options & Practices for Sediment Management

4.1 General

Non-removal is the preferred strategy for sediment associated with maritime works in Hong Kong. This is only applicable to activities like general reclamation; foundations for seawalls, drainage outlets and other structures; protection system for submarine pipelines and utilities. The following describes the worldwide non-removal management options and practices to reduce the demand for disposal of contaminated sediments.

4.2 Leave the Sediments in Place (Monitored Natural Recovery)

4.2.1 General

Leaving the sediments in place is one of the handling approaches. If the conditions are appropriate, natural sedimentation will bury or contain the contaminants at their original location (USEPA 1993). This approach allows the contaminants to degrade under natural conditions.

This option is appropriate when the pollutant discharge source has been halted, and burial or dilution processes are rapid. This option may not be viable if the area will be developed in future (e.g. reclamation) and continuous monitoring of the recovery progress will be required.

4.2.2 Advantages

- Its key advantage is that it can minimize the risk from handling and disposal of the contaminated sediments. Regardless of the cost and the effectiveness of the treatment methods, the sediment removal involves dredging operations during which the suspended sediments, even if uncontaminated, is a source of concern.
- Re-suspended contaminated sediments may induce the release of the buried contaminants. This may lead to the release of more toxic substances under aerated condition during the dredging operation. The potential impacts on the benthic organisms include the loss of submerged aquatic vegetation, inhospitable area for crustaceans, mortality, reproduction decrease and slower growth of molluscs, the habitat of corals (e.g. reduce species diversity, less live coral, lower growth rates, decrease in calcification and slower rates of reef accretion) and the burial of hatching area for fish (Wilber et al. 2005).
- This method also avoids the generation of other environmental impacts of the by-products from treatments e.g. possible leachate from solidified sediment, space for disposal and noxious emissions from incineration.
- It is also the most economical option.

4.2.3 Disadvantages

- This method relies on natural process such as input of uncontaminated sediments and their integration with in-place contaminated material through dispersion, mixing, burial and biological degradation, thus requiring longer time to complete the process.
- Long term water quality monitoring programme is required.
- No development value for future land use.

4.2.4 Case Histories

James River in Virginia, USA (USEPA, 1993)

Kepone, a toxic insecticide and fungicide, entered the James River in Virginia, USA through effluent discharge from the manufacturer and contaminated the river sediment. Because of the high partition coefficient, the majority of kepone was found in the sediment. Since Kepone was banned from being manufactured and used in 1975, the kepone concentration in the surface sediment began to decrease significantly. The contaminants were diluted and buried by fresh sediment. Kepone concentrations in fish were found significantly reduced in 1983 and the restrictions on all commercial fishing were lifted.

4.2.5 Applicability in Hong Kong and Recommendations

The technical feasibility of this option is usually determined by the physical conditions of the site and the time available for natural burial and degradation of contaminated sediments. The method is not widely applicable in Hong Kong due to the slow natural recovery processes involved and the limited future development value associated with the site. The leave in place with monitored natural recovery option cannot usually be rely upon for Hong Kong situations and most Hong Kong reclamation projects, where contaminated sediments are to be "leave in place", requires some form of filling and ground treatment works to make the site suitable for future developments.

4.3 In-situ Treatment – Band drains with Surcharging

4.3.1 General

The use of preloading is one of the oldest and most commonly used methods for improvement of soft compressible soils. This method is usually used in combination with some form of vertical band drains to accelerate consolidation because the layers requiring treatment is often relatively impermeable and too thick for improvement to take place in the time available for treatment.

Earthfill mounds acting as a surcharge is the most commonly used method of preloading. However, this method is time consuming when small preloads are used. If large preloads are used large quantities of surcharge material has to be made available and moved about. High surcharges may also cause instability of the underlying clay which is usually soft and therefore staged construction of embankments needs to be carried out so that the shear strength improvement can take place before proceeding to the next lift of surcharging. The principle behind the surcharge method is to increase the total load in the soil which simultaneously increases the excess pore water pressure. As the pore water pressure dissipates, the effective stress in the soil will increase by the same amount as the pore pressure dissipation.

Preloading is effective on its own only for treating soils which are relatively thin. For thick deposits of soft soils it is usually necessary to accelerate the consolidation process by introducing vertical drainage. The vertical drains shorten the drainage path and often take advantage of the natural existence of horizontal layers of high permeability. In most soils the horizontal permeability is greater than the vertical permeability and cases of the horizontal permeability being an order of magnitude to several orders of magnitudes larger than the vertical permeability have been reported.

There are currently more than 50 types of band drains available in the market and each is usually installed by displacement methods. This means connecting them to a suitably shaped mandrel, which is then driven into the ground either dynamically or statically. Figure 4.1 shows a typical arrangement using a vibrator to drive the mandrel and photos of installation of band drains.

4.3.2 Advantages

- High permeability to permit rapid dissipation of pore water pressure.
- Sufficient flexibility to accept large vertical and lateral ground movement. A single drain should not act as a pile, inhibiting consolidation. It should have about the same stiffness as the surrounding soil mass.

- Continuity over its full length and a good hydraulic connection with the drainage blanket at ground level which acts as a hydraulic sink.
- An installation method that does not cause so much disturbance as to make the surrounding soil too impermeable for the drain to be effective.
- Ability to function over the required period, which may be for a few month up to two years.
- Adequate drain characteristics in changing conditions of stress, usually increasing stress.
- Filters that do not become clogged by the surrounding fine-grained soils.

4.3.3 Disadvantages / Limitations

- Surcharge fill may need to be placed in stages in order to gain sufficient foundation strength so that the risk of instability is mitigated. Usually a granular blanket will be placed over the site to form a working platform for the rigs.
- In deep holes, sand can arch across the tube and leave gaps beneath. There is risk of soil squeezing into a gap, making the drain discontinuous.
- There are still uncertainties regarding their mechanical, hydraulic and durability properties of some of the vertical drains. There is only limited international standard available. Prefabricated drains can deteriorate under bacteriological or chemical attack, above and below the water table. The discharge capacity of a filter was found to reduce by over 60% after installed in peat for 280days (BSI,2007).
- The ground is disturbed with the installation of the drain, but the magnitude of the effect is difficult to predict. It is largely controlled by the dimensions of the mandrel. In extreme circumstances the ground could relax around the filter, forcing it into the core channels and preventing water flow.
- As the clay compresses, the drains distort, folding and perhaps kinking, so reducing the discharge capacity.
- The thickness of sediments that can be treated effectively by this method will depend on the limiting depth of the band drain installation which is typically limited to maximum 30m.

4.3.4 Case Histories

Thick marine clay deposits underlying reclamation have been frequently treated with vertical drains and surcharged to reduce excessive differential settlement before construction of roads, runways and other structures.

<u>Changi Airport in Singapore (Choa 1985)</u>

At Changi Airport in Singapore, the second runway was treated in this manner. A pilot test was carried out to determine the most suitable drain spacing for the main works. A drain spacing of 2.5m square grids in areas where the marine clay is greater than 15m whereas a drain spacing of 3.2m square grids in areas where the marine clay is between 5m and 15m. A prefabricated band shaped drain (Geodrains) was used. In both cases, a surcharge of 4m of sand was used. For areas with less than 5m of marine clay a surcharge of 2.5m only was used. After six months, a further 2m to 3m of sand surcharge was found to be necessary for the deeper clay areas.

<u>Pok Oi Flyover, Hong Kong (Ying, February 1999)</u>

Pok Oi Flyover is located between the New Yuen Long Southern Bypass and Castle Peak Road. The works consist of two approach slip roads at the south side linking dual 4-span segmental bridges, which tie in with Route 3 approach roads at the north side, and the formation of 8m high earth embankment. Vertical drains were intentionally used to speed up the consolidation process. Prefabricated drains of 8m long were extended into the 6m thick alluvium layer.

Chek Lap Kok Airport, Hong Kong (Ying, February 1999)

The construction of Chek Lap Kok Airport involved reclamation of about 600ha of land from the sea with fill thickness up to 15m. The offshore site investigation revealed the presence of 6m to 8m soft marine mud. A test embankment, 10,000m^2 in plan and 200m offshore was constructed between 1981 and 1982 to access the construction problems and performance of vertical drains. This study has demonstrated the effectiveness of band drains in marine clay, at spacing of 1.5m and 3.0m.

Pak Shek Kok Reclamation, Hong Kong

Prefabricated band drains were used with surcharging for the Pak Shek Kok reclamation project to accelerate the consolidation of an 8.5m thick soft marine deposit layer underlying the site. The vertical drains were installed on a barge over the sea and arranged in triangular pattern at a centre to centre spacing of 1.5m. (http://www.cse.polyu.edu.hk/~civcal /wwwroot/reclamation/intro/default.htm)

Penny's Bay Reclamation, Hong Kong

Prefabricated vertical drains were used with surcharging at a discrete location of the Stage 1 Penny's Bay Reclamation, where the marine mud is partially dredged, to accommodate a water recreation facility. Over 9,400,000m of prefabricated vertical drains were also installed and used with surcharging for the Stage 2 Penny's Bay Reclamation, to accelerate the rate of consolidation of the left in-situ marine mud. (http://www.scottwilson.com.hk/Penny.pdf)

Projects in China (Chen et al 2004)

In China, since 1950s vertical drains with or without preloading have been extensively used to improve the soft foundation beneath various types of structures (e.g. road embankment, earth dams, dikes, wharfs, storage tanks, buildings and runway of airport). A typical case study associated with this improvement method is the construction of Wenzhou Airport, which is the fist airport built on a soft ground in China. Fabric cased sand drains with preloading were used to minimize the post-construction settlement, particularly on the runway of the airport.

Venetian Cotai Development, Macau

In Macau, the recently completed Venetian hotel and casino development in Parcel 1 adopted band drains with surcharging to improve the over 65 hectares of land at the Cotai site underlain by approximately 15m of highly compressible and soft marine deposits. The band drains were installed in a triangular pattern at 1.2m spacing and the 4 m high surcharge was maintained for a period of about 4 to 6months.

4.3.5 Applicability in Hong Kong and Recommendations

The limitation of mud dumping area and the environmental impacts of the dredging process have been great concerns in managing the disposal of sediment in Hong Kong. By the 1970's, the vertical drain technique was introduced in Hong Kong. In early 1980's, the field test at the replacement airport at Chek Lap Kok demonstrated that preloading with vertical drains was very effective in stabilising the soft marine deposits in Hong Kong, and the advantage of the drainage method was proved. Since then, prefabricated band drains have been widely used in reclamation in Hong Kong.

4.4 In-situ Treatment – Deep Cement Mixing (DCM)

4.4.1 General

The technique of Deep Cement Mixing has been developed since the 1970s in Japan. The volume of soil improved has reached 200Mm^3 to date. The method can be used to form sufficiently strengthened and less permeable cement-mixed soil body.

This method involves the formation of columns both in clay soils and sands using cement introduced and mixed at depth by drill casing fitted with mixing blades. A schematic diagram showing the plant on the drill barge and the mixing equipment used to form the cement–stabilised blocks is shown in Figure 4.2 where a group of eight drill units that can be operated to form blocks of stabilised clay. Table 4.4 lists out the installation data of deep cement mixing.

Table 4.4 – Installation Data of Deep Cement Mixing

Depth of Treatment	To 30m or more
Plan Area of Treatment Block	4.3 – 5.7m^3
Rate of Penetration	1 – 2 m/min
Rotation Speed during Penetration	20 – 30rpm
Rate of Withdrawal (mixing stage)	0.5 – 1.5 m/min
Rotation Speed during Withdrawal	40 – 60 rpm

The stabilisation mechanism generally involves the following chemical reaction processes:-

- Cement reacts with the pore water of soft clay to form a series of hydrates;
- Hydrates exchange ions with clay particles and form large conglomerates; and
- Clay particles react with the excess calcium ions from the hydration process and form non-soluble compounds.

The design of Deep Cement Mixing can be referred to J H Yin (2004).

4.4.2 Advantages

- By stabilising native soil using chemical additives, deep cement mixing does not require dredging and filling to form the foundation as in the conventional dredging method.
- The weight of treated soil is basically unchanged. Hence, no additional surcharge will be induced on the underlying soil strata.
- It is flexible in application because the amount of stabilizing agent and form of treatment can be adjusted to suit different soil properties and engineering requirements. Soft sediment can be improved to a required strength by setting a proper cement mixture rate, thus preventing consolidation settlements.
- The operation would not cause lateral displacement of the soil being treated and generate less noise and vibration, and less influence to the surrounding structures.
- A less permeable cement-mixed soil body can be achieved.

4.4.3 Disadvantages

- Its cost may be several times higher than that of a conventional dredging scheme.
- Stringent quality control and monitoring is required during the mixing process to ensure that the required strength is developed in the soil. It may be necessary to carry out field trials to obtain an optimal site-specific soil to cement ratio for practical application.
- The rotating blades of the deep cement mixing machine may not work properly for ground with obstruction like boulders.
- Investigations should be carried out to assess the possible environmental impacts associated with marine application of deep cement mixing and to determine if mitigation measures are necessary for a particular site.
- It does not work well in certain soils, notably those which have a high organic content and acidic soils (Suzuki, 1982).

- The quantity of spoils resulted may be large and require special treatment. It was reported by O'Rourke (2006) that, for a project at Fort Point Channel, Boston, the volume of spoils generated during the deep mixing procedures was about 50% - 60% of the volume of soil treated at each element.

4.4.4 Case Histories

Projects in Japan (W. T. Yeung & K. S. Tam, 2006)

The Dejima District Project demonstrated a seawall ground soil improvement work for a reclamation project in south Hiroshima Port, Japan between year 2003 and 2004. The seabed ground in the water area is composed of soft silt/clay; therefore it is necessary to improve the ground soil in order to maintain the stability of the seawall. The total volume of improved ground was estimated to be about 750,000m^3. In Japan, it is usual to employ the Cement Deep Mixing Method for improving the ground soil for the foundation of seawalls.

Subsequent to the seawall construction, the reclaimed area will be used for industrial waste disposal and there is a requirement to construct the improved ground and a sea wall, in order to block the spoiled water from percolating into the surrounding sea water. Cement Deep Mixing method would increase strength using cement churning without the risk to increase the permeability. An outline of two soil improvement vessels is shown in Figure 4.3.

The mixing tool penetrates into the seabed using revolving churning paddles at its tip. Standard penetration speed is 1 meter per minute, which is lowered to around 0.5m per minute when the anticipated depth is approached. The mixing tool's rotation is regulated to match with the rotation number of the mixing blades to the speed of penetration into the ground.

Generally when the deep cement mixing improvement vessel is on the sea, the slurry is not expelled during penetration but rather during withdrawal. This is in case work is stopped by a breakdown during drilling, in order to prevent inability to withdraw the pumping mechanism due to hardening of the cement. In contrast to on-land improvement, due to tidal fluctuations during maritime work, if the pumping mechanism is stopped and left idle, there is also danger of a heavy load being exerted on the vessel by the mixing tool's shaft.

The average improved strength of the deep cement mixed soil is about 6.6MPa, with a standard deviation of 2.4MPa, satisfying the design strength of 2.7MPa. The average permeability of the deep cement mixed soil is about $3x10^{-8}$cm/sec, also satisfying the requirement of $1x10^{-5}$cm/sec or below.

The typical unit price is about JY7,000 to JY9,000 per 1m^3 (not included in mobilisation and demobilisation fee) depending on the capacity of Deep Cement Mixing vessels.

An operational cost of around HK$0.65million per 24-hour-working day (including staff cost and fuel cost but excluding material cost) was reported for one of the largest deep cement mixing barge available in Japan which has eight mixing shafts and a mixing area of 5.75m^2. On the other hand, for a medium-class barge with a twin mixing shaft and a mixing area of 2.2m^2, an operational cost of about HK$0.10 million per 12-hour-working day (excluding both staff cost and material cost) was reported.

Projects in China (Chen et al 2004)

In China, the first deep mixing machine with double-shaft was developed in 1978. Thereafter, deep mixing method with cement has been extensively used to improve the soft ground in the east coastal region of China, including the cities of Tianjin, Shanghai, Nanjing, Hangzhou, Wenzhou, Xiamen etc. Two typical case studies with deep cement mixing can be found in the city of Wenzhou. The first one is the soil improvement project for the multi-storey buildings in 1980s. After the construction, a long-term monitoring of settlement (i.e. lasting about 8 years) was carried out on the buildings. The second case is the expanding project of Wenzhou airport. The soft ground beneath the expanding area was treated by deep cement mixing, rather than the fabric encased sand drains with preloading used for the original areas.

Projects in Hong Kong

Deep cement mixing has not been used in Hong Kong as a method of ground improvement in full scale. It has only been used in the temporary works for the Lantau and Airport Railway Cut and Cover Tunnel in Central. According to the method statement ref. 501/MS/05/003A (Aoki Corporation, 1995) retrieved from the GEO file GCI 3/6/40, a cofferdam was constructed using the soil mix wall technique to facilitate the dewatering and bottom-up excavation works for the tunnel construction. The 36m deep soil mix wall was constructed using an 850mm diameter multi-shaft auger at an estimated rate of approximately 4 linear m per day. The wall was reinforced with steel H-piles. Temporary anchors were also used in conjunction with the soil mix wall to support the excavation.

Recently, a full scale field trial has been proposed for the Further Development of Tseung Kwan O Project under Agreement No. CE 87/2001 to prove the suitability of the technique to treat soft marine clay during the reclamation (Maunsell, 2005). Following a discussion with the project office (PM/NTE) of CEDD the captioned trial will only likely be carried out in end of 2009 following the award of consultancy for design in end 2008 according to the latest programme.

Researches are also on-going in Hong Kong to understand the behaviour of treated soil and, in particular, Yin (1998), Yin and Lai (1998), Yin (2001a,b) and Yin (2004) reported test results and their interpretation of the properties and behaviour of cement mixed Hong Kong marine deposits. It is anticipated that the technique will be further developed with respect to the local conditions with more technical researches over the coming years.

4.4.5 Applicability in Hong Kong and Recommendations

For construction of seawalls, the leave in place option could be associated with ground improvement treatment. The soft marine mud underneath the foundation could be improved by the deep chemical mixing method to achieve an increase in the rate of consolidation and provide sufficient strength under the fill. Successful application of the deep cement mixing method requires a thorough understanding on the soil-cement behaviour. Despite the useful data given by Prof. Yin, as described in section 4.4.1, there is still currently limited information available in Hong Kong on the behaviour of improved marine deposits. Extensive laboratory tests using Japanese standards as reference may be necessary to establish the soil-cement behaviours for local marine sediments before the technique can be applied.

Despite its very high cost, this option could be considered for use if site-specific conditions otherwise favoured it.

4.5 In-situ Treatment – Vibro-replacement / Vibro-displacement Lime Piles

4.5.1 General

The Swedish method of forming lime columns is the introduction of quicklime by hollow stem auger at depth so that it will be mixed with soft, fine-grained soil as the auger is rotated and raised.

Soft, clayey soils are strengthened by mixing with lime, possibly being as much as 10 to 50 times stronger after a year. Column-like units of the soil-lime mixture reinforce the ground and may individually be capable of bearing loads of 50 – 100kN per m^2. In addition to the columns, the lateral pressures in the ground are increased by the volume increase of the column as the lime / soil mixture is introduced. The columns are designed to act no as weak piles but as a composite with the surrounding soil.

The lime column process uses quicklime in soft, fine-grained soils to form columns, piers or walls. The method was developed as an alternative to piles as foundations for houses founded on clays with shear strengths of about 10-20kN/m^2. The columns are about 0.5m in diameter and up to 15m deep. A hollow-stem auger with a special blade for mixing is drilled into the ground to the required depth. Figure 4.4 shows a schematic diagram and photos of formation of lime columns. Rotation is then reversed, so that soil is not lifted on the flights of the auger, and the tool is withdrawn slowly at about 25mm/revolution to ensure thorough mixing of lime and soil. During extraction, the lime pumped down the hollow stem by compressed air through a hole just above the auger blade to mix with the soil. To prevent clogging of the discharge point, very pure lime is used, with a maximum particle size of less than 0.2mm. Production is at the rate of up to 1m/minute, which can produce up to 50 columns/day.

Lime columns are appropriate for soils containing at least 20% of clay and the content of silt and clay should be at least 35%. The plasticity index should also be greater than 50%. Gypsum can be added to help stabilise organic soils with moisture contents of up to 180%. According to Holm et al (1983a), when gypsum is added to the lime, undrained strength can be three times that when lime is used alone. Lime columns are particularly effective where there is a high ground temperature, because the rate of hardening of the columns is faster. Alkaline soils are also advantageous.

4.5.2 Advantages

- It offers seismic stability by reducing soil liquefaction risk
- It enhances soil bearing capacity and slope stability
- It requires short mobilization and execution periods
- It can allow foundation construction to start almost immediately.
- It can allow flexibility in case of design changes.
- It can be used to treat almost the entire range of soil types.

4.5.3 Disadvantages / Limitations

- Its cost may be several times higher than that of a conventional dredging scheme.
- Stringent quality control and monitoring is required during the mixing process to ensure that the required strength is developed in the soil. It may be necessary to carry out field trials to obtain an optimal site-specific soil to lime ratio for practical application.
- The method cannot be used for ground with obstruction like boulders.
- Investigations should be carried out to assess the possible environmental impacts associated with marine application of lime column and to determine if mitigation measures are necessary for a particular site.
- Lime columns can act as drains, and their bearing capacity can decrease with time because of leaching by slightly acidic groundwater.
- The cross-sections of the columns can be non-uniform with depth, as a result of variations in chemical reaction. It can be cracked in layers at every 20-50mm and be weakest in the centre.

4.5.4 Case Histories

Runnymeade Commerical Project in Penang, Malaysia (Wong 2004)

Chemical lime pile ground treatment was adopted for the Runnymeade Commerical Project in Penang, Malaysia during 2000 and 2001. Lime piles with diameter of 400mm were installed at 1.7m spacing, in order to increase the strength and modulus of a soft clay layer, with depth of 8m. The soft clay layer was improved for a piled raft foundation system that was proposed for a 23-storey tower structure.

Shatin Race Course Field Trial, Hong Kong (Davies, J. A. G. & Jackson, J. A. 1987)

A field trial, comprising installation of lime columns at 1.5m to 2.0m centres with surcharging, was undertaken at Shatin Race Course to investigate its effectiveness in alleviating the long-term settlement problem at the site. It was concluded that, although on the positive side, local equipments had been developed which permit lime columns to be installed through fill to a depth of 20m, the field trial failed to reduce the settlement to an acceptable rate. This was due to the presence of a relatively thick layer of fill that was seen to be the main cause of the problem in addition to consolidation of soft clays.

4.5.5 Applicability in Hong Kong and Recommendations

Vibro-replacement/ vibro-displacement lime piles has never been adopted in full-scale in Hong Kong. However, this method is considered to be a technically feasible option for ground improvement in Hong Kong with similarities on techniques as compared to Deep Cement Mixing. Its successful application will however depend on the site-specific ground condition and the properties of the soils to be treated.

4.6 In-situ Treatment – Granular Pile (Stone Column and Sand Compaction Pile)

4.6.1 General

Granular pile generally comprises compacted sand or gravel inserted into the ground to treat soft cohesive soils. The term granular piles used in this report refer to both sand compaction pile and stone column. Granular piles generally have a diameter ranges from 0.6m to 1.0m. By constructing granular piles in a square, rectangular or triangular grid pattern, the ground is transformed into a composite mass of vertical, compacted granular cylinders with intervening soil. This method increases the average shear strength and decrease the compressibility of the treated soil. Since sand and gravel are good drainage materials, installation of granular piles in clayey soil also accelerates the dissipation of excess pore water pressure and hence the consolidation. Ground improvement by granular piles is judged to be a feasible method for seawall and breakwater construction on soft marine clay.

Various methods have been used globally for installation of granular piles, namely the vibro-replacement method and vibro-compozer method. Selection of installation methods usually depends on their proven applicability and availability of equipment in the locality. Vibro-replacement has been used widely to form stone columns to improve cohesive soils. The technique utilizes the vibroflot equipment for forming cylindrical holes in the soil. For marine application, stone columns are generally formed by penetrating the vibroflot to the desired depth and gravel is pumped through a supply duct to the bottom of vibroflot where the gravel is forced out by air pressure through a mud protection shield as the vibroflot is lifted. The vibroflot also compacts the gravel and displaces the gravel outwards, hence mobilizing the lateral resistance of the soil against the displaced gravel. Compaction is continued until the lateral resistance to the displacement of the soil by the gravel is fully developed. Figure 4.5 shows a schematic diagram and photos of installation of stone columns.

The vibro-compozer method, on the other hand, is popularised in Korea and Japan. The method has been used to form sand compaction piles for stabilising soft clays in the presence of high ground water level. The installation procedures generally involves driving a casing pipe to the desired depth using a heavy vertical vibratory hammer located at the tope of the pipe. The casing is filled with specified volume of sand and the casing is then repeatedly extracted and partially redriven using the vibratory hammer starting from the bottom. The process is repeated until a fully penetrating compacted granular pile is formed. Figure 4.6 shows a schematic diagram and photos of installation of sand compaction piles.

4.6.2 Advantages

- Granular piles share the external loads with the native soil in the form of a composite foundation, and hence the method effectively utilizes the original ground without dredging in principle.
- It immediately increases the rate of settlement of the soil in the presence of sand or gravel that acts as drainage material.
- It is flexible in application because the diameter and spacing of the Granular piles can be easily adjusted to suit different site conditions.

4.6.3 Disadvantages / Limitations

- The method is more costly than the conventional dredging method, although it may be cheaper than the deep cement mixing method.
- Granular piles in the form of stone column may not be feasible if the strength of the soil to be treated is too low, whilst sand compaction piles may not be applicable for soil with standard penetration test (SPT-N) value exceeding 15 to 25.
- Stringent quality control is required during the installation process as the integrity of the granular piles is crucial in the whole system.
- Installations of granular piles may cause lateral or upward soil displacement and result in heaving of the seabed. The extent should be investigated in the design.
- The soil in the vicinity of the granular piles may be disturbed to a certain extent during installation. The effect of strength reduction should be included in design.

4.6.4 Case Histories

Penny's Bay Reclamation, Hong Kong

In its first stone column project in Hong Kong, Intrafor HK, working in a joint venture, has successfully completed 100,000 m of stone columns at Penny's Bay, the location of the Disney Land HK (VSL 2003). The project team installed 78,000m^3 of stones and delivered 7,500 columns of 1m-diameter in February 2003, using the dry bottom feed method to a maximum depth of 19m. Meanwhile, 600,000m^3 of reclaimed sand was compacted above the head of the stone columns. Some 42Mm^3 of reclaimed sand had already been compacted with this method on another part of the site.

Deep Bay Link Southern Section, Hong Kong

Over 32,000m of stone column was installed for the Deep Bay Link Southern Section in Hong Kong. The total cost for the installation was approximately HK$5.2M, giving a unit cost of average HK$162/m.

San Tin Eastern Drainage Channel Project, Hong Kong (K. W. Lau and K.C. Lam, 2003)

Over 1,500 nos. of 0.8m to 1.2m stone columns were installed for the San Tin Eastern Drainage Channel Project in Hong Kong. The stone columns were arranged in a square or a triangular pattern at 1.8m to 2.5m centres and were constructed using a wet top-feeding process, in which the vibroflot penetrates into the ground by the combined effects of its own weight and the vibrating action of its eccentrically mounted motor.

Sand Compaction Pile at Kansai International Airport, Japan

Kansai International Airport, which opened in September 1994, is built on a giant artificial island measuring approximately 4,370 meter length, 1,250 meter width and 511 hectare gross area. For the offshore work, sand compaction pile is one of the ground improvement method adopted to create revetments containing an astonishing 178.3million cubic-meter of reclaimed soil. To prepare the completed site for construction, Sand Compaction Pile is also adopted to meet the stringent requirements for a variety of Airport Facilities, including Terminal Building, Apron, Control Tower, and Guidance Road.

Sand Compaction Pile in Korea

The sand compaction pile has been widely used in Korea as a ground improvement measures to stabilize soft seabed. Recent projects included the Pusan Harbor, Busan New Harbor, Pisol Temporary Whaf and Guje Pisol Marine Works etc. The compacted sand pile diameter generally ranges from 1.5m to 2.0m with a maximum penetration depth of 43m.

Sand Compaction Pile in Singapore

The sand compaction pile has been used recently as a soil improvement technique for reclamation works in Singapore. It has been employed in the Marina Bay/Tanjong Rhu reclamation, and is being implemented in the Singapore-Malaysia second link reclamation project in Tuas as well as the Port of Singapore Authority's third cargo terminal reclamation works off Pasir Panjang (ref: http://www.eng.nus.edu.sg/EResnews/9505/fhlee.html).

4.6.5 Applicability in Hong Kong and Recommendations

Granular pile in the form of stone column is considered to be a technically feasible option for ground improvement in Hong Kong. The method has been employed for a few projects in Hong Kong including the Penny's Bay Reclamation, Deep Bay Link and San Tin Drainage Channel Project. Nevertheless, it is recommended that sufficient implementation and verification with on-site trials should be carried out to ascertain their effectiveness with respect to the local environment and conditions before they can be readily applied in Hong Kong.

Granular pile in the form of sand compaction pile has been developed and widely used in Japan since 1950's as an effective improvement method for soft ground to improve stability and compressibility. The method is also widely used in Korea and is increasingly used in Singapore etc. As for stone column, sand compaction pile is considered to be a technically feasible option for ground improvement in Hong Kong. There has not been any record of past application of this method in Hong Kong and hence the implementation of a field trail could help to ascertain their effectiveness with respect to the local environment and conditions before they can be readily applied in Hong Kong.

4.7 In-situ Treatment – In-situ Capping

4.7.1 General

In-situ capping involves the placement of a covering or cap over an established layer of contaminated sediment. This covering seals the sediments physically and chemically, preventing pollutants from migrating into the surrounding water. The cap is composed of one or more layers of sand, silt, rock, or geotextile fabric. Soil layers can be dredged from a nonpolluted underwater location or collected at a site on-land.

In-situ capping does not transform these pollutants into harmless substances; however, the act of isolating them gives natural forces more time to break down the pollutants. The thickness of the cap depends on a variety of environmental factors, but it is normally from two to five feet thick.

As a single-step technology that requires no sediment removal, transport, or pretreatment, in-situ capping promises a less complex and costly approach to remediation.

In consideration of the cost and the effectiveness, in-situ capping is a potentially economical and effective approach for remediation of contaminated sediment. A number of sites have been remediated by in-situ capping operations worldwide. A layer of clean sediment covers the contaminated sediment so as to isolate the contaminants from the environment. This option is not viable if the area will be for navigation and require reclamation for future development.

The effectiveness of in-situ capping will depend on the water current of the surrounding environment. The imported sediment will be flushed away under strong current, and thus frequent replacement of sediment will be required. Moreover water diversion is not possible in the sea. Some disturbance of the contaminated sediment is expected during the placement of clean sediment. The transportation cost of the delivery of clean sediment to the site will be the major handling cost.

4.7.2 Advantages

- Simplicity of use
  In-situ capping is a simpler process to carry out than methods involving excavation and treatment. Simplicity of application can contribute to process effectiveness.
- Less pollution during application
  When remove-and-treat remediation methods are used, the threat of pollutants from disturbance and movement of contaminated sediments is greater because toxic chemicals are released more readily.

4.7.3 Disadvantages

- Application uncertainty
  Because in-situ capping is a relatively new remediation method, research is still being done to determine better capping alternatives with laboratory and field validation of capping procedures continuing as well.
- Cap placement concerns
  Mixing and consolidation of the underlying sediment squeezes contaminated water out, and poorly executed placement may not result in uniform, adequate coverage.
- Intact contaminants
  Although capping has been shown to seal contaminated sediments, it does leave toxic chemicals intact. Their continued presence may or may not be a problem, depending on the effectiveness of the capping layer and the rate of natural recovery processes.

4.7.4 Case Histories

At the Denny Way project, a layer of sandy capping sediment was spread over a three-arce contaminated near-shore area with water depths of 20 to 60 feet. A combination of a sewer outfall discharge and combined sewer overflow had contaminated the site with lead, mercury, zinc, PAHs and PCBs (Ralermo 1997).

At Eitrheirn Bay in Norway, a composite cap of geotextile and gabions was constructed as a remediation project in a fjord at an area contaminated with heavy metals. A total area of 100,000 square meters was capped, in water depths of up to 10 meters (Ralermo 1997).

4.7.5 Applicability in Hong Kong and Recommendations

In general, capping is most effective in environments where long-term stability of the cap is likely. Good candidates are underwater disposal sites that do not need maintenance dredging to keep shipping lanes open and are not prone to storms that cause erosion and movement of bottom sediments. Capping can also be used in areas prone to erosion and sediment movement, however, if the cap is stabilized with a layer of rocks.

Capping works well in sealing a variety of sediment bed types and a broad range of chemical pollutants. Some of the chemicals it effectively isolates include Aliphatic hydrocarbons, Chlorinated solvents, Inorganics (metals and radionuclides), Oxygen-demanding materials, Nitrates, Pesticides, Phosphates, Polychlorinated biphenyls, and Polynuclear aromatics.

In-situ capping is no panacea for dealing with the problem of contaminated sediments. Specifically, it may not be an appropriate remediation method at sites that:

- Must be dredged to facilitate shipping and other boating activities;

- Are subject to erosion and strong underwater currents;
- Have steeply sloped bottoms; and
- Contain large accumulations of hazardous chemicals in non-aqueous form.

Although In-situ capping is considered as a technically feasible option for management of contaminated sediments, it is likely that the method is only suitable for application on land with limited after use.

4.8 In-situ Treatment - Stabilisation with Flyash, Lime and/or Cement

4.8.1 General

Solidification / stabilisation (immobilisation) involves immobilisation of sediment and contaminants by treating them with reagents to solidify or fix them. Solidification implies the conversion of sediments into a solid block with a structural integrity that physically binds the contaminants. Stabilisation or chemical immobilization usually involves the addition of chemical agents that reduces the solubility or mobility of the contaminants, with or without changing the physical characteristics of the treated material.

The in-situ immobilisation of sediments is likely to be based on the concepts of solidification and stabilization and to involve the addition of Portland cement, fly ash, or other binding agents to keep contaminated sediments in place and to reduce contaminant mobility. Immobilization reduces contamination through a combination of chemical bonding, encapsulation in a solid, reduction of permeability to reduce fluid flow, and reduction of poor space for diffusion. For this type of treatment to be efficient, the contaminated sediments need to be temporarily isolated to allow the mixing of reagents.

4.8.2 Advantages

The processes are applicable to wide range of mixed contaminants in a range of soils. It can transfer difficult materials to be a more manageable form.

- Stabilised sediment could be allowed to remain in place and properly capped.
- Stabilisation methods, such as the cement deep soil mixing technology, have the ability to immobilise the organic and inorganic contaminants within the soil matrix but the stabilisation effectiveness is reduced at high organic content unless cement dosage is increased (Maher et al 2005).

4.8.3 Disadvantages

This option is not feasible in areas where solidified mass cannot be tolerated (e.g. for sites where future construction or dredging is required).

There are inaccuracies in reagent placement, erosion, long-term monitoring of the procedure to remove / detoxify contaminants. There are also difficulties in adjusting solidification mixtures / agents for subaqueous setting. There is limited information and knowledge on the costs of large-scale treatments, their effectiveness, or their possible toxic by-products.

4.8.4 Case Histories

Immobilization has been used on a small scale at Manitowoc Harbor in Wisconsin, where a cement and fly ash slurry was added to the sediment using a proprietary mixing tool and slurry injector (EPA, 1994b). The in situ mixing of cement with sediments for the primary purpose of enhancing compressive strength has not been proved or accepted for treatment of contaminated marine sediments in the United States (EPA, 1993a). Costs are estimated at $15/yd^3 to $160/yd^3 based on proposed applications (EPA, 1994b).

In situ chemical treatment involves the addition of chemical reagents to sediments to destroy organic contaminants. Theoretically, oxidants, such as ozone, hydrogen peroxide, and permanganate, could destroy PCBs and polyaromatic hydrocarbons. Chemical treatments would be difficult to implement because they require isolation during sediment mixing, and natural organic matter, oil and grease, and metal sulfide precipitates has very high oxygen demand. Furthermore, metals present in the sediments might be dissolved into the pore water after sulfide oxidation. Chemical dechlorination under ambient temperatures and typical water contents is not likely to occur or to be controllable.

Researchers at the Canadian National Water Research Institute have developed and demonstrated equipment capable of injecting chemical solutions into sediments at a controlled rate (EPA, 1994b). Chemical treatment of lake sediments to control eutrophication or to oxidize organic matter has also been demonstrated (EPA, 1994b). However, neither has been applied to the treatment of in situ contaminated marine sediments.

4.8.5 Applicability in Hong Kong and Recommendations

Large-scale use of the method has not been applied elsewhere. Further detailed investigation and research would be required to understand the effectiveness and possible toxic by-products of the method. It would not be likely to be adopted for general use in Hong Kong in the near future.

4.9 In-situ Treatment – Vacuum Dewatering System

4.9.1 General

Sometimes it is not feasible to place a fill embankment because the soft soil might be sometimes so weak that even a common 1.5m embankment might already cause instability problems. Then it can be suitable to use the method of vacuum preloading.

Vacuum preloading (Vacuum dewatering system) is the application of atmospheric pressure to form a temporary surcharge for soft clays while applying a vacuum to the surface of the soil beneath a membrane. The technique was developed in Sweden in early 1950s.

Vacuum Dewatering System is very similar to the Band Drain with Fill Surcharging technique in the sense that the soft marine soil is improved principally by preloading. Vertical drains are required to accelerate the rate of consolidation in both methods. In general, the time required for completing the consolidation settlement will be the same for both techniques but time can be saved, when the Vacuum Dewatering System is used, for omitting the need to apply and remove surcharge fill.

Using atmospheric pressure, total stresses remain constant, while effective stresses are increased by the application of the vacuum so draining water from the ground towards the surface zone of reduced air pressure. Water is sucked out of the clay which can only consolidate.

An impermeable membrane is placed over a sand or gravel filter layer 150-500mm thick, and sealed into the clay below the water table at its edges. A vacuum pump is connected and air is pumped out of the porous filter and groundwater out of the underlying clay. Pressure differences of 0.6-0.8 atmospheres (60-80kN/m^2) are the practical limit. This is equivalent to about 4-5m of loose sand fill. This method is usually used with band drains. Figure 4.7 illustrates the method.

4.9.2 Advantages

- There is no extra fill material needed.
- The construction times are generally shorter when comparing to band drains with surcharging and it requires no heavy machinery.
- No chemical admixtures would penetrate into the ground and thus it is an environmental friendly ground improvement method.

- Upon completion of the ground improvement works, the vacuum can be removed immediately and handed over for the next stage of construction rather than await the slow process of surcharge removal.
- Isotropic consolidation eliminates the risk of failure under additional loading of the permanent construction.
- There is no risk of slope instability beyond boundaries.
- It allows a controlled rate and magnitude of loading and settlement.

4.9.3 Disadvantages

- There would be difficulties with maintaining a vacuum due to the deterioration of the membrane from exposure to the elements particularly sunlight.
- Pressure applied is generally limited to 80 to 100kPa.
- The thickness of sediments that can be treated effectively by this method will depend on the limiting depth of the band drain installation which is typically limited to maximum 30m.

4.9.4 Case Histories

Inland Sea (Japan) – Reservoir Foundation (CIRIA Publication C573, 2002)
Well method (i.e. without membrane) pumping from well points and sand drains was adopted for consolidating 6m-thick clay and silt. The settlements were about 300mm to 600mm after 60-day application.

Brest (France) – Hydraulic Fill (CIRIA Publication C573, 2002)
Well method (i.e. without membrane) using negative pressure of 20-45kN/m^2 was adopted for consolidating 6m-thick clayey silt fill. For wall spacing of 10m, the settlements were about 30mm to 120mm after 30-day application. For wall spacing of 3.3m, the settlements were about 190mm to 420mm after 30-day application.

Airport Extension at Taipa, Macau
Vacuum preloading with band drains were used in the airport extension project at Taipa, Macau, as a method of ground improvement to treat the 10 to 15m thick of soft marine clays over an area of about 3 hectares. A vacuum pressure of about 50kPa has been applied and it took less than 6 months for the consolidation process without the imposition of surcharge mound.

Tianjin East Pier Project, China (Choa, V. 1990)
A pilot test was carried out for the Tianjin East Pier Project, China, to demonstrate the feasibility and performance of the vacuum preloading method. The method involved the placement of an air-tight membrane over a sand blanket. Suction tubes in the sand blanket were put through the membrane, sealed and connected to vacuum pumps. To enhance the effectiveness of the vacuum preloading method, prefabricated vertical drains were installed down to about 20m below ground level prior to the placement of the air-tight membrane. A vacuum of up to 90kPa was maintained and the effect of the vacuum preloading was felt within the depth of the vertical drains. However, it was also reported that vacuum preloading appeared to be less effective at depths greater than 14m. This could be caused b a loss of vacuum in the relatively permeable clayey silt lenses or due to a relatively impermeable clayey stratum below 14m. The effectiveness of the vacuum was also found to decreases at the perimeter of the vacuumed area. Nevertheless, the pilot test has demonstrated that vertical drains used in combination with vacuum preloading is suitable for soil improvement of the very soft to soft silt clay in the Tianjin East Pier Project.

Road project in Tianjin, China (Yan , S. and Chu J. 2003)

Vacuum preloading were used to improve the foundation soil for a road in Tianjin, China. A vacuum load of 80kPa was applied for 90 days to consolidate a 20m thick soft clay layer. The ground settled for about 1.5m, achieving an average degree of consolidation of 90%.

Vacuum Preloading Field Trial at Shenzhen Airport (Lui et al 2007)

A vacuum preloading test was carried out near the Shenzhen Airport as part of a research program of the University of Hong Kong. Similar to the geological conditions of Hong Kong, the site was underlain generally by a 7.5m thick soft marine deposit layer and covered by water. Insertion of 7m long wick drains at 1.5m spacing and installation of monitoring instruments were carried out in the end of 2006. To allow drilling and sampling equipments to move around, the site was prepared by dewatering the pond and covered with a layer of cushioned sand. Suction pipes and vacuum pumps were connected and the site was flooded with 2m deep of water. Two layers of geomembrane were then placed under water and their edges were secured with sand bags to maintain an airtight seal for developing vacuum pressure in the soft marine mud. It was reported that this fully instrumented field trail has demonstrated offshore vacuum preloading to be technically feasible.

4.9.5 Applicability in Hong Kong and Recommendations

Vacuum preloading has been demonstrated to be a technically feasible option to improve the settlement characteristics of reclamation worldwide. However, there has been no case record to date for its full-scale application in Hong Kong. The selection of the method is generally governed by the degree of improvement required, the depth of fill to be treated, the proximity to existing structures or facilities, and the relative cost benefits. This method could be considered for if site-specific conditions are favourable.

4.10 In-situ Treatment – Electrostabilisation and Electrohardening

4.10.1 General

Electroremediation (Electrostabilisation and electrohardening) involves the passage of low-level DC currents (a few A/m^2) through soil to remove contaminants through the combined action of electrokinetic and electrochemical processes. The contaminants contained in the soil are then removed from the electrodes for subsequent removal. This method is particularly suitable for inorganic contaminants and low concentrations of organic compounds.

The basic process has been used for many years for dewatering and consolidating soils in foundation engineering applications and the electrochemical mining of copper ores. The process was applied, at least experimentally, to treat alkaline soils many years ago. Use of the method for remedial purposes has been demonstrated on a pilot scale in the Netherlands and is the subject of research at a number of centres in the United States.

A number of processes are taking place during the application of a DC current to the ground:-

- Electro-osmosis: Movement of pore fluid through the soil under the influence of a constant low intensity DC field;
- Electrophoresis: Movement of charged particles, including colloids, clay particles, organic particles, droplets etc. Floating in the pore solution, under the influence of an electrical field;
- Electrolysis: Decomposition of ionic solutions caused by electric potential.

Figure 4.8 shows a schematic diagram of a field system. The system consists of a power source (generator or mains supply), and AC/DC transformer, and cathodes and anodes inserted into the ground. These may be vertical or horizontal. In one application, the cathodes consisted of horizontal steel cables laid between rows of vertical graphite anodes. They may also be constructed from activated titanium and 'ebonex'. Spacings between the electrodes are typically 1 to 2m.The environments around the anode and cathode are independently managed to control the pH and to remove contaminants and particles. A solution of hydrochloric acid, sodium chloride, or complexing agents may be infiltrated at the anode. The solutions circulated around the electrodes are passed through conventional treatment plant to remove contaminants and to adjust the composition (e.g. in terms of pH) to within the desired range. In principle, chemicals which will react with the contaminants, e.g. complexing agents, may be added and induced to flow through the soils.

The selection of electrode material is governed by the need for economy and robustness and for avoiding the entry into the ground of ions that may themselves be undesirable.

4.10.2 Advantages

- It is able to reduce large quantity of contaminated material to small amounts that are capable of treatment.

4.10.3 Disadvantages / Limitations

- The technique requires substantial borehole construction.
- There have been only limited field applications to date. Although laboratory experiments show that the method could remove organic contaminants, at present applicability should be regarded as being limited primarily to inorganics.
- The method can only be applied in solution or adsorbed onto clay particles etc.
- Application to insoluble and slightly soluble forms (e.g. hydroxides, sulphides) may be difficult but a trial to deal with soil contaminated with cadmium sulphide has been carried out recently using it as an ex-situ treatment for small volumes of acidified soil.

4.10.4 Case Histories

There have been only limited field trials to date and no full scale application. Lageman et al (1989) describe two field tests (in neither case was treatment carried through to completion):-

- Lead (340->5000mg/kg) and copper (35-1170mg/kg) concentrations in dredged sediment and underlying soil were reduced by an average of 74% (range 50-94%) in 43 days.
- Average concentrations of zinc were reduced from 2410 to 1620 mg/kg (33%) in 53 days (monitoring of the treatment system showed the removal of 1380g/m^3 soil treated – a consistent amount).

In 1989, a larger scale trial was carried out on a site contaminated with arsenic. An area of 150m^2 was treated to a depth of 1 to 2m (a total of 250m^3 were treated). Average concentrations were reduced from 110mg/kg (range 40-310mg/kg) to below the target concentration of 30mg/kg for three quarters of the treated area (average 10mg/kg) following treatment for about 80days. Excavation showed that the failure of the treatment on one area of the site was due to the presence of buried metal objects.

4.10.5 Applicability in Hong Kong and Recommendations

To date, it has not been demonstrated to be feasible on a large scale, hence, there are currently no costs available for the field scale use of the technique. Time frames are likely to involve medium term strategies and depend on the volume of material requiring treatment. It would not be likely to be adopted for general use in Hong Kong in the near future.

4.11 Submarine Utilities Construction – Pipe Jacking

4.11.1 General

Pipe jacking or microtunnelling involves the boring of a tunnel for the proposed sewer/drain, by a tunnelling shield (usually a fully automatic mechanized tunnelling machine) from a launch shaft towards a reception shaft. The shield is jacked forward incrementally by hydraulic jacks at the launch shaft. As the shield advances, jacking pipes are inserted behind the shield one by one and the whole string is jacked forward. When the tunnelling shield reaches the reception shaft, it is removed and the pipeline is complete. Usually, the tunnelling operation is carried out outside the view and the awareness of the public. Nevertheless, the launch shafts and the reception shafts still need to be excavated, and may need to be in operation throughout the tunnelling operation.

A number of excavation systems are available including manual, mechanical and remote control. Excavation methods are either manual or machine excavation. To install a pipeline thrust and reception pits are constructed, usually at manhole positions. The dimension and construction of a thrust pit may vary according to the specific requirements. Mechanised excavation may require larger pits than hand excavated drives, although pipe jacking can be carried out from small shafts to meet special site circumstances.

With suitable TBM selected, pipe jacking/micotunnelling methods are suitable for excavation in soft ground, mixed ground and rock. However, the method, unless compressed air shield is used, is not recommended for excavating ground with artificial materials such as left-in sheetpiles, old seawall and abandoned piles. For submarine utilities installation, a suitable type of TBM should be used. Open-shield with compressed air should be avoided wherever feasible due to safety and health concern.

Pipe jacking/microtunnelling can install pipes from 600mm to 3500mm in diameter. Pipe materials for pipe jacking works can be concrete or steel (less common). More flexible pipe materials such as HDPE or GRP are not suitable.

The maximum drive length for pipe jacking method (pipe size larger than 1000mm), with the assistance from intermediate jacks, is about 1200m. By the introduction of intermediate jacks at the starting shaft with predetermined locations, the required length of pipe to be jacked through the ground is limited only to the section between the two successive intermediate jacks. With the intermediate jacking system, the frictional resistance required to be overcome can be greatly reduced and no intermediate shaft is required. For microtunnelling (pipe size less than 1000mm), the practicable working length will be limited to 100m or less depending on ground condition. Intermediate jacks cannot be used for microtunnelling due to its non-man entry constraint.

4.11.2 Advantages

- The method provides a flexible, structural, watertight, finished pipeline as the tunnel is excavated.
- Minimal environmental disruption.
- Greater safety due to engineered launch shaft.
- Workable in difficult soils as no dewatering is required.
- Intermediate shaft is normally not required.

4.11.3 Disadvantages

- High capital investment.
- Skilful operators are required.
- For pipe sizes less than 1m, the practicable working length will be limited to 100m or less depending on ground condition.
- Change in vertical profile is normally restricted by 200m in radius.
- Disposal of a small quantity of sediments is still required.

4.11.4 Case Histories

Although pipe jacking or microtunnelling is commonly adopted in Hong Kong for utility installation under busy roads, railways and watercourses, there had been no case record of local submarine utility instillation project adopting this technique. Case histories of some of the land-based Drainage Services Department projects are summarised below:

Central, Western and Wan Chai West (CW3) Sewerage Project

This project involves the laying of 6 km of sewers of diameter 1050mm to 1800mm at a depth of 5 to 18 metres. The works started in 1996 and was completed in early 2000. (http://www.dsd.gov.hk/sewerage/technology_employed/pipe_jacking/index.htm)

Yuen Long, Tin Shui Wai and Tong Yan San Tsuen Trunk Sewer Project

This project involves the laying of 1300m of trunk sewers of diameter 1000mm and depth 3m to 12m. The works started in 1996 and was completed in 1998. (http://www.dsd.gov.hk/sewerage/technology_employed/pipe_jacking/index.htm)

There are also projects in other parts of the world, including USA and Europe, adopting pipe jacking or microtunnelling. Some of case histories in USA and Europe using this technique for submarine utility installation are tabulated in Table 4.11.

Table 4.11 – Case Histories of Using Pipe Jacking or Microtunnelling Method for Submarine Utility Installation (Overseas Experience)

Country	City	Year	Contractor	Pipe Size (mm)	Drive Length (m)	Geology
USA	Greenville, Table Rock	2004	Bradshaw, Krauter	1500	150	Rock, Black Schist
USA	Wrightsville, York, Lancaster River	2004	Bradshaw	1500	115	Rock, Schist
France	Sables D'Olonnes	2006	CSM Bessac	1500	630	Rock, Clay, Sand
France	Biarritz	2003	Smet Tunnelling	1400	400	Rock, Sand
England	Horden	1997	Johnston	1800	550	Sand/ Clay/ Limestone
Spain	San Sebastian, Mompas	2005	Mecanotubo	2000	1000	Limestone, Rock
Spain	San Pedro Del Pintar	2004	GEOSA	1400	350	Soft Rock Condition
Spain	La Coruna	2004	Eurohinca	2400	200	Rock, mixed soil condition
Portugal	Porto	1996	Cobetar	1600	520	Sand/ Granite

4.11.5 Applicability in Hong Kong and Recommendations

Every year, Drainage Services Department constructs and repairs tens of kilometres of underground sewers and drains. Many of these works are located in busy urban areas. Since ground excavations will result in large impact on the traffic and the public, they will be subject to stringent statutory, technical and administrative requirements. Trenchless pipe jacking techniques can reduce the impact and the time required for the work. DSD has been using these techniques on land for more than 10 years, and currently a significant proportion of pipe installation and repair works are carried out using trenchless techniques. There is, however, no case record of using pipe jacking or microtunnelling for marine-base installation in Hong Kong.

Based on overseas experience, it is considered that pipe jacking method is technically viable for marine-based works. Its applicability will depend on ground condition, pipe size and working length. The method is generally more suitable for large utilities (1200mm or above) which cannot be installed by horizontal direction drilling method as described in Section 4.13. The situation of lack of local experience can be improved by having input from overseas experts for the first few submarine pipe jacking projects.

4.12 Submarine Utilities Construction – Pipe Jetting

4.12.1 General

The jetting "spread" is typically based on a flat barge that will be towed into position over the pipeline at the start point and then anchored using a 4-anchor pattern. The forward anchors will be deployed some distance ahead of the barge and the stern anchors will be positioned close to the stern of the barge. These distances are variable depending on water depth, current conditions and the presence of any constraints. The contractor will determine these details in the course of its detailed design and will continually verify/update its practices and procedures in response to the results being obtained on site and any unforeseen or changed conditions.

The jetting machine will be chosen by the contractor based on its past experience with site conditions comparable to those existing along the pipeline route. There are many different designs of jet sled that have been developed by a number of general and specialist contractors operating in the pipeline industry. Whilst they all operate using the same principles, each one features several variables including:

- number and positioning of water jets;
- water pressure operating range;
- arrangement of eductor tubes;
- airlift or water venturi eductor tubes;
- depth of "cut" per pass and number of passes required for required depth;
- length of route "blocks"; and
- speed of forward travel.

These variables are adjusted to suit specific site conditions. While Contractors can predict reasonable starting values for the site based on site investigation results, it is probable that adjustments will be required on commencement of work and even in the course of work to obtain optimum trenching performance and/or to ensure that water quality standards are met.

During the process of pipe jetting, the soil is liquefied by the jetting machine to allow the pipeline to settle into the trench while the displaced materials will eventually settle back onto the sea floor. The trench will be backfilled naturally with indigenous soils. Jetting creates a plume of fine soil particles spreading from the seabed to the water surface which may travel with the current and affect the water quality. Silt curtains or silt screens therefore are needed to be erected to localise the siltation, especially in ecologically sensitive areas. Figure 4.9 shows equipments for the submarine pipeline jetting.

4.12.2 Advantages

The process is fast. A typical rate could be 65m per hour per pass. For each jetted excavation, three passes is usually required, and therefore, the speed of pipe installation is approximately 300m per day per jetting machine. There is practically no water depth limitation using this method.

4.12.3 Disadvantages

The width and depth of trench are dependent on the pipe size as well as power of the machines to be employed. The typical width and depth of the trench can be as large as 5m and 6m respectively using a medium-powered jetting machine.

Trenching and jetting to bury pipelines are costly operations and cause turbidity due to the silt contained in the sandy seabed. Silt clouds may travel over great distances by means of thermoclines and currents, enlarging the area affected by trenching or jetting. The seabed environment may suffer from the detrimental effects of silt precipitation.

4.12.4 Case Histories

Pipe jetting has been adopted for a section of Tolo harbour and Mirs Bay for Shenzhen to TaiPo submarine pipeline initiated by Towngas. It should be noted that its applications are dependent on ground conditions, trench depth, water depth and degree of pollutants spreading out.

Ocean Engineering System (OES), Leighton's subcontractor for jetting on the Towngas twin pipeline project, in which a submarine gas pipeline was installed successfully using pipe jetting under a comprehensive EM&A programme in Hong Kong in March 2006. It consisted of 2nos. 18" NS Twin pipelines of 50km-long on soft clay. The two Pipelines trenched together 300mm apart.

The potential silt precipitation and leakage problem into the adjoining water would generally be controllable with carefully devised operational control measures such as silt curtain and advanced jetting method.

(http://www.oes.net.au/recent_oes_post_trenching_projects.shtml)

4.12.5 Applicability in Hong Kong and Recommendations

The method has been used in a number of submarine utilities installation projects in Hong Kong

It can be considered as the potential installation method for the proposed submarine utilities if the specific site conditions are favourable for the use of the method.

4.13 Submarine Utilities Construction – Horizontal Directional Drilling

4.13.1 General

The Horizontal Directional Drilling (HDD) method contains impact support and is called the Grundodrill technique. The technique enables trenchless installations and has a spectrum of application including all pipe construction measures within the bounds of gas, district heating and drinking water supply, the installation of pressure lines for sewers as well as cable protection pipes for television or telephone cables, traffic routing systems, emergency call boxes or low, medium, high voltage and optical fibre cables.

Installation of a pipeline by Horizontal Directional Drilling (HDD) is generally accomplished in three stages.

Stage 1 - directionally drilling a small diameter pilot hole along a designed directional path.

Stage 2 - enlarging this pilot hole to a diameter which will accommodate the pipeline.

Stage 3 - pulling the pipeline back into the enlarged hole.

To overcome mechanical soil resistance high thrust and tension forces are required. The application of Bentonite might relieve the pilot bore and the pipe traction and provide the ability to steer in difficult soil qualities up to soil grade 5 or even 6.

The components of a horizontal drilling rig used for pipeline construction are similar to those of an oil well drilling rig with the major exception being that a horizontal drilling rig is equipped with an inclined ramp as opposed to a vertical mast. Horizontal Directional Drilling pilot hole operations are like those involved in directional drilling for an oil well. Drill pipe and downhole tools are generally interchangeable and drilling fluid is used throughout the operation to transport drilled spoil, reduce friction, stabilize the hole, etc.

HDD is suitable for pipeline installation in soft ground and rock. It could be problematic in ground with cobbles and gravels. Similar to pipe jacking works, HDD is not suitable for excavating artificial materials. HDD can be used to install pipes up to about 1200mm in diameter. The maximum drive length for HDD is about 2000m and no intermediate shaft is required. Pipe materials suitable for HDD include steel, HDPE and GRP. Concrete is too rigid for this technique.

4.13.2 Advantages

- There are several reasons for the application of the directional technique in central town areas. They mainly concern the construction costs, construction periods, permission procedures, soil displacement, surface restoration and the traffic, compared to open trenching methods.
- The HDD method is advantageous because surfaces worth conserving are neither broken up nor damaged, restoration and repair are not required, which leads to high economical advantages.
- The social costs are low because detours are avoided.
- The equipping, drilling and construction times are short.

4.13.3 Disadvantages / Limitations

- A costly solution.
- It can be used in a wide variety of ground and site conditions but is not the optimal method in all conditions.
- Unconsolidated soils (e.g. cobble) will needs to be specially treated or grouted before drilling.
- Workable pipe sizes diameter is restricted to 1.2m.
- Maximum drive length is about 2000m. Beyond this distance intermediate shafts are required which makes the operation difficult in particular for marine applications in busy navigation channel or across harbours.
- Change in vertical profile is normally restricted to 200m in radius.
- Concrete pipes might be too rigid for this technique.
- Disposal of a small quantity of sediments is still required.

4.13.4 Case Histories

Local experience of using pipe jacking or microtunnelling method for submarine utility installation are summarised the paragraphs below and in Table 4.13.1. Various overseas experiences with HDD submarine utility installation is further summarised in Table 4.13.2.

Hong Kong Electric Co. Ltd - Wong Chuk Hang to Deep Water Bay and South Bay to Chung Hom Kom Kok Cable, Hong Kong

In October 2002, Hong Kong Electric Co., Ltd. awarded a contract to Wo Hing Construction Co., Ltd. (Wo Hing) for the installation of 4 nos. 132 kV cable ducts from Wong Chuk Hang to Deep Water Bay and also from South Bay to Chung Hom Kok. Wo Hing, in turn, engaged

Utilities Construction Ltd. (Utilities) to be the specialist contractor to install four cable ducts using the horizontal directional drilling (HDD) method.

The HDD method was employed to install the cable ducts from Chung Hom Kok Road to Headland Road. Each cable duct was 270 m in length with 300 mm diameter.

The sequence of the works is as follows:

- Construction of launching and receiving pits
- Pilot hole drilling - 150 mm diameter
- Reaming the pilot hole from the bore size of 150 mm to 300 mm and then to 400 mm
- Pulling back the HDPE pipes inside the bore hole
- Grouting the gap between the HDPE pipe and the bore hole.

There was a reservoir in the middle of the site that restricted the cable ducts to run across the boundary of the reservoir. There were busy roads adjacent to the site, such as Stanley Gap Road and Repulse Bay Road, and the traditional cut-and-cover method will have severe impact on the traffic and disturbance to the public. Hence, the HDD method, together with an advanced survey system, Paratrack, was proposed to solve the above problems. This method not only reduces the construction time but also minimises the traffic impact and disturbance to the public. The PE 100, SDR 11 HDPE pipes were used as the cable ducts. As each pipe was 12 m long, they were joined together to form the 270m long cable duct by butt fusion equipment.

The setting-up works were commenced in June 2003 on site. After four months of preparation, the drilling commenced in October. Each pilot hole took about 2 to 3 weeks to complete, and finally all were completed on schedule in April 2004.

(http://chkstt.org/NEWS/cableduct/cableduct4.htm)

CLP Power Ltd - Ma Wan and Kap Shui Mun Cable Crossing, Hong Kong

CLP Power Ltd had installed over 1.3km cable networks across the Ma Wan Chanel and Kap Shui Mun Channel using the Horizontal Directional Drilling method. The project involved reaming of 800mm to 900mm diameter drillholes in rock to accommodate the 460mm diameter watermains and their 610mm diameter protective steel casings. The Horizontal Directional Drilling technique was selected for the project to overcome the problems of a seabed installation including irregular topography, strong current, heavy shipping traffic and damage the dragging of ship anchors. It was also selected to avoid interference to marine activities and minimise impact to the foreshore and seabed environment resulting from dredging and underwater blasting.

(http://www.golder.com/archive/TechSpeak43.pdf)
(http://www.gammonconstruction.com/hk/eng/projects/tunnel_index1.html)

Table 4.13.1 – Case Histories of Using HDD Method for Submarine Utility Installation (Local Experience)

Client	Location	Year	Contractor / Sub-contractor	Hole Size (mm)	Drive Length (m)	Geology
WSD	Sham Tseng to Ma Wan	2000	Leightons Asia / Lucas	900	1369	Medium grained granite, crystalline coarse ask ruff with granitic and rhyolitic intrusion
CLP	Lantau to Ma Wan and Ma Wan to Sham	2002	Skanska / Lucas	584	8 drives from 584 - 1320	96m below sea level, 40m rock cover except in fault zones

	Tseng					
CLP	Pui O Beach, Chi Ma Wan Cbale Crossing	2005	Dragages / Lucas	600	330	Marine sediments, marine deposits, highly fractured grades III-IV granite, grade II granite with closely spaced joints, maximum depth at -40mPD

Table 4.13.2 – Case Histories of Using HDD Method for Submarine Utility Installation (Overseas Experience)

Country	Location	Year	Contractor	Hole Size (mm)	Drive Length (m)	Geology
Australia	Sydney	1998	Lucas	200	380	N.A.
Australia	Collaroy NSW	1997	Lucas	200	870	N.A.
Australia	Bayview to Newport	1995	Lucas	300	710	Shale, Sandstone & Sand
China	San Jiang Kou, Jiang Su Province (across Yangze River)	2002	East China Pipeline Construction Co. Ltd.	660	1688	Alluvia formed fine sand, fine running sand, powdery clay and gravel
England	Plymouth	2000	LMR Drilling UK Ltd.	560	1400	Phyllite (slate), very soft silt, sand/gravel and Made ground

4.13.5 Applicability in Hong Kong and Recommendations

HDD has been widely used for the installation of marine utilities, including watermains, gas mains, oil pipelines and power cables. The completion of previous WSD and CLP marine utility projects prove this technology a feasible one in Hong Kong. The applicability of the method will depend on the actual ground conditions, pipe size and type and working length.

4.14 Advanced Foundation System – Suction Can Method

4.14.1 General

Suction cans have been initially used as anchors to moor floating offshore structures in deep waters since the 1980's. Because of their method of installation, and the ability to use large diameter steel cans, their use has been expanded to support fixed offshore structures in shallow and intermediate water depths and tension leg platform in deep waters.

Suction can foundations can also be used to support offshore wind turbines. The main advantage of using suction can foundations with a steel frame structure for a tall meteorological mast is that the large moment load on the structure is mainly resisted in the foundation by push pull action. Therefore, the axial capacity of the foundation is the major factor that controls its design. The foundation needs also to be checked for its adequacy to resist the applied lateral load. Suction cans, especially when designed to extend to a competent layer, develop their axial capacity mainly from end bearing, which is assumed to act on the gross cross-sectional area of the can. Bearing capacity formulas which are used for embedded shallow foundations are usually used to assess end bearing capacity of suction cans. Lateral capacity, on the other hand, is developed from the passive resistance along the suction can length.

Installation of tripod substructure with suction can foundation can usually be completed within a day during daytime. Suction cans are steel cylinders with a closed top and an open bottom. The top lid of the can is fitted with vent values and connections to suction pumps. When the can is first lowered onto the seafloor, the vent valves are kept open to allow water to escape freely and the cans to penetrate into the soil under its own self-weight. After that, the vent values are closed and suction is applied on inside of the can. For clayey soils, the net positive water pressure on the outside of the can will push it further into the soil. For sandy soils, suction creates an upward water flow at the tip of the can which reduces the effective stress on the tip, and therefore the soil resistance to can penetration thus allowing the can to advance more into the soil.

4.14.2 Advantages

- A key advantage of suction cans is that their method of installation allows large diameter steel cans to be embedded in the soil relatively quickly.

4.14.3 Disadvantages

- The foundation could be used for resisting light weight axial loadings.

4.14.4 Case Histories

Talisman Malaysia Ltd - East Bunga Raya Project
Installation of four (4) suction piles as part of the installation of the subsea jacket structure.
Location
South China Sea Offshore Malaysia/Vietnam
Client
PTSC / Clough Joint Venture
Year
2003

Centrica Bains Project
Installation of 4 suction piles for the foundation of a subsea manifold structure.
Location
Irish Sea, UKCS, 18m water depth
Client
Coflexip Stena Offshore Ltd
Year
2002

Texaco Galley G6 Project
Installation of 4 suction piles for the foundation of a subsea manifold structure.
Location
Galley G6 UKCS, 140 m water depth
Client
Coflexip Stena Offshore Ltd
Year
2002

North Nemba Flare jacket suction buckets
Design, fabrication and installation of suction pile foundation (3 total) for the NNF tripod.
Location
Offshore Angola, 120m wd
Client
McDermott-ETPM
Year
1999

Chevron Alba Drilling Centre Manifold Installation
Suction pile installation for subsea manifold structure.
Location

UK sector, 140m wd

Client

Stolt Comex Seaway

Year

1998

4.14.5 Applicability in Hong Kong and Recommendations

It can be considered as the potential foundation option for the proposed offshore structures if the specific site conditions are favourable for the use of the option. In fact, suction can is being proposed as the marine foundation for the offshore wind mast project initiated by CLP Co. Ltd. recently.

5 Review of Worldwide Ex-situ Treatment Options & Practices for Sediment Management

5.1 General

The London Convention (LC) identifies that marine disposal may often be an economically and environmentally preferred disposal solution to other options (IMO, 1991). However, it also recognizes that disposal of contaminated sediments may adversely affect water quality and aquatic organisms. The LC also recommends that the beneficial use of dredged material should be encouraged wherever possible (e.g. marsh creation, beach nourishment, land reclamation), and recommends that for contaminated dredged material, containment methods be considered, including confined marine disposal or land disposal.

If dredged and transported sediment is too contaminated for open-water disposal, it may require treatment or containment. Treatment processes attempt to physically, chemically, thermally, or biologically alter contaminants through concentration, isolation, destruction, degradation, or transformation. Containment systems are designed to remove the residuals from contact with the biologically accessible environment and to minimize contaminant losses from their boundaries.

Although considerable research has been done on the treatment of contaminants, particularly in soil, the ex-situ treatment of contaminated sediments is still very expensive and has been used only in a few projects around the world.

In the design of treatment systems for complex wastes, particularly when large sediment volumes are involved, the standard approach is to perform the simpler, easier, and less-expensive processes (e.g. particle size separation) first and the more difficult or more energy-intensive processes later. Because organic contaminants tend to associate with fine-grained sediments, particle separation by size could be carried out first to reduce the volume to be treated, provided the grain size distribution and contaminant distribution favor separation. Treatment processes requiring changes in temperature or additions of reagents work most efficiently on low volumes of highly concentrated materials.

After any sediment treatment process, placement sites must be found for large volumes of sediment and water. Small sediment volumes with highly concentrated contaminants can be isolated or destroyed using expensive processes, such as landfilling or incineration. Cleaner sediment can be put to beneficial use and may even have a market value, or can be placed in open water.

Residues remaining after treatment must be evaluated against regulatory standards to determine suitable placement alternatives, which may include hazardous waste landfills.

5.2 Mechanical Dewatering

5.2.1 General

The separation of solids from water is the simplest treatment process. The solids content of sediments varies with the technology used to recover them. Hydraulic dredges remove sediments in a liquid slurry that usually requires dewatering. Mechanical and pneumatic dredges remove sediment with solids contents at or near in situ levels. The dewatering of dredged material typically is accomplished in ponds or CDFs, which rely on seepage, drainage, consolidation, and evaporation (USACE, 1987). Dewatering is generally effective and economical, but slow, and the water generated, which usually contains contaminants, may also require treatment. Common industrial methods of dewatering slurries or sludges include centrifugation, filtration and filter presses, and gravity thickening. But these approaches are of limited value for sediments that contain silt- and clay-sized particles (EPA, 1993b).

5.2.2 Advantages

Mechanical dewatering is performed by using chamber filter presses or belt filter presses. The advantages of using mechanical dewatering includes:-

- The capacity is high and can be easily increased by using additional presses;
- The installation for treating 200tons materials needs an area less than $3m^2$, thus requiring small area;
- The dewatering is effective (>65% of solids) and efficient (a volume goes through the installation in about an hour); and
- The process is mobile for the installation being able to be transported and used nearby the location (even an installation on a pontoon is possible).

5.2.3 Disadvantages

- The disadvantages of using mechanical dewatering are relatively high investment and operation costs.
- It requires a processing plant.
- The treated sediments after dewatering are still considered contaminated which is not accepted by the existing landfills.

5.2.4 Case Histories

St. Lawrence River in Canada (EC, 1995)

Shallow areas in the St. Lawrence River at the Port of Sorel that posed a navigational hazard were dredged and found to contain elevated levels of metals (EC, 1995). This program was a small-scale demonstration program that treated approximately 5,000 cubic meters of sediment along the river. The project utilized a rotatry press and additives to remove water and decontaminate the sediment. The continuously operating press was fed a sediment slurry from a dredge operating in the waterway. The rotary press reduced the volume of sediments 5 to 10 times and the dryness level went from 15% to 72% of total particulate matter during dewatering.

The dewatering process yielded a dry cake, however production rates were low due to very high fine grain content. During the dewatering process approximately 30 percent of the metals were removed, making the sediment suitable for disposal. The cost of this process was estimated to add approximately 30% to the overall cost of dredging and disposal.

Lower Fox River (Montgomery Watson, September 2001)

The Lower Fox River, from Lake Winnebago to Green Bay, is the largest tributary to Lake Michigan located in Wisconsin. The Fox River Valley has been an area of substantial growth and development. Over time, this growth has resulted in impacts to the aquatic environment from industrial, municipal, and other discharges to the river. Since the 1970's, stricter laws and regulations have resulted in significant improvements to the Fox River's water quality. However, toxic substances, such as polychlorinated biphenyls (PCBs), are still present in the river sediment.

In 1998, DNR and the U.S. Environmental Protection Agency (EPA), in cooperation with several parties in the Fox River Group (a coalition of paper companies identified as responsible parties in the Fox River cleanup), agreed to conduct a demonstration project to evaluate full-scale sediment removal and disposal from the Fox River. The location chosen was at the Sediment Management Unit (SMU) 56/57 on the lower part of the river, below the De Pere dam.

The demonstration projects gathered information to assess the effectiveness and expense of large-scale sediment dredging and disposal of contaminated sediments from the Lower Fox River. In the process, a significant area of PCB containing sediment was removed from the river. The SMU 56/57 demonstration project included hydraulic dredging of contaminated sediment, mechanical dewatering (removing water from the sediment), water treatment, and the transportation and disposal of PCB-containing sediments. The details of the project are described in the Final Summary Report (Montgomery Watson, September 2001).

Mechanical dewatering would require much smaller basins because the dredged slurry would be processed each day to lower the water content (or increase the percent solids). Potential mechanical dewatering methods considered feasible included centrifuge, belt press, or filter press. Landfill disposal would occur within a few days of dredging for mechanical dewatering vs. years for passive dewatering. To shorten the time required to complete this Demonstration Project, the FRG and WDNR selected mechanical dewatering.

Water was removed from the dredged sediments using a process called mechanical dewatering. Two lined settling basins were constructed on the former Shell Oil Company property. The settling basins temporarily held the sediment and water slurry while the dewatering and water treatment facilities process the dredged materials. A simplified process flow diagram is shown on Figure 5.1.

A small 6-in. hydraulic dredge with a horizontal auger cutterhead was placed in each basin to remove the solids and convey them to the presses for dewatering. These dredges were basically smaller versions of the IMS 5012 river dredge. A cable and anchor system, like in the river, was used to position the dredge in each basin. Rubber-tired wheels were installed on each side of the horizontal auger on each dredge to maintain the cutterhead above the basin liner system during sediment removal.

Sediments from the basins were conveyed through approximately 1,200 lineal ft of 6-in. diameter HDPE pipe (SDR17) to a 20,000-gal mix tank located on the asphalt work pad. The dredge slurry from the basins passed through a 4 by 8 ft shaker screen with No. 4 sieve size before dropping into the mix tank. Gravel and/or debris from the screen fell onto the asphalt pad, where it was scooped up with a front-end loader and placed with the stockpiled dewatered sediment. Dry hydrated lime was fed into the tank and mixed with the dredge slurry. Lime was delivered to the site in bulk tank trucks and pneumatically fed to four lime storage silos. The dredge slurry with lime was pumped from the mix tank to a series of six 20,000-gal equalization/feed tanks, from which the slurry was pumped to the presses (Photo No. 12). When the second 200-cf press was added to the dewatering system, a seventh feed tank was also added.

Press cycle times varied greatly. The goal was to operate with press cycle times on the order of one hour. Water removed from the sediment was pumped to a 15,000-gal filtrate storage tank. When a press cycle was finished, plates were separated and the filter cake (about 1-in. thick) dropped onto a conveyer under the plates. The conveyer dropped the filter cake into steel bins, where the front-end loader scooped it up and placed it into the stockpile or directly into waiting trucks.

A typical work crew operating the dewatering system included six to seven personnel per 12-hour shift: the dredge operator in the basin, a labourer at the lime delivery system and mix tank, the loader operator, and three to four labourers operating the feed tanks and presses. The dewatering system generally operated at some capacity 24 hours per day, seven days per week, except for down time associated with system repairs and routine maintenance (e.g., maintenance and repairs of the pump on the mini-dredge, and maintenance and repairs of the press hydraulic pumps, air compressors, and conveyor belts).

The total work crew for dredging, water treatment, and dewatering was generally 11 to 12 labourers per 12-hour work shift. This number increased or decreased depending on site activities. An additional four operational personnel performed supervisory activities, health and safety oversight, and administrative activities.

METHA plant in Hamburg, Germany

The Geotechnical Engineering Office considered and visited one such operational system – the METHA plant in Hamburg, Germany in September 1991 (GEO, 1997). This plant uses sedimentation and pressure filtration to process contaminated spoil. The cost was estimated in the order of HK$100 per m^3 at 1991 prices over and above the subsequent landfill disposal costs.

5.2.5 Applicability in Hong Kong and Recommendations

Mechanical dewatering is the simplest treatment process of separating solids from water. This method is effective in dealing with sediments with the natural level of contamination typically found in Hong Kong waters. However, the investment and operation costs are anticipated to be high, and that the treated sediments after dewatering are still considered contaminated with a contamination level unacceptable by the existing landfills in Hong Kong. It is therefore considered that this management option is technically infeasible for use in Hong Kong.

5.3 Physical Separation

5.3.1 General

Soil washing and particle separation techniques are adaptations of mineral processing techniques used in the mining industry (see Galloway and Snitz, 1994). Soil washing is a general term for extraction processes that use a water-based fluid as a solvent; many soil washing processes rely on particle separation (EPA, 1994b and references therein).

Particle classification separates sediment particles based on one or more physical properties, such as size, density, or surface chemistry. In both freshwater and marine sediments, contaminants are associated mainly with the silt- and clay-sized fractions rather than with sandy material.

Soil washing techniques can be used to recover storage space, which can be a useful sediment management strategy. This approach was demonstrated at a CDF in Michigan, where sediments from the Saginaw River contaminated with PCBs and metals were separated into a large volume of fairly clean sand and a small volume of fine sediments containing the bulk of the contaminants (U.S. Army Engineer Detroit District, 1994). Soil washing has been used routinely at a CDF in Duluth, Minnesota, to reduce the volume of dredged sediments requiring confined disposal. Soil washing results in a large volume of "clean" material, which can be put to use, and a small, concentrated amount of highly contaminated material, which must be disposed of. Clean, sandy sediment can have a wide range of uses in urbanized coastal environments and may be more readily available than other sources of sand. Unfortunately, the sand fraction for most contaminated marine sediments is a small percentage of the total.

Physical separation can be facilitated by differences in surface chemistry. The minerals processing industry routinely separates desirable minerals from crushed rocks by adsorbing surfactants on the minerals of interest and selectively recovering the ore by flotation. Surfactants also have been used to solubilize more than 95 percent of the oil from contaminated sediments and to remove a comparable percentage of PCBs because the PCBs were strongly partitioned within the oil phase.

The cost of physical separation depends on the number of steps and the volume of sediment. For a sediment containing 75 percent clean sand and 25 percent contaminated silts and clays, the costs of physical separation using a system of screens, trommels, hydrocyclones, attribution scrubbers, and other equipment are estimated at \$23 to \$54/yd^3 for a volume of 10,000 to 100,000 yd^3 (U.S. Army Engineer Detroit District, 1994). In general, physical separation is worth the expense only if the contaminated sediment is at least 25% sand (D. Averett, USACE, personal communication to Marine Board staff, January 2, 1996).

5.3.2 Advantages

- Mature technology that can reduce volumes of contaminated material requiring subsequent treatment;
- Soil washing can be used to recover storage space for later reuse; and
- The reduced volume of concentrated waste may be suitable for high-energy chemical, thermal, or biological treatment, if the benefits outweigh the costs.

5.3.3 Disadvantages

- Physical separation is not an effective treatment for all sediments and does not destroy the contaminants but concentrates them into a smaller volume, leaving a large volume of only slightly contaminated sediment.
- Using physical separation, the original sediments should have a significant proportion of sand for the process to be cost effective and the process may become highly inefficient for sediments with particle size less than 20μm.
- Although the reduced volume of contaminated sediments might lower the handling and disposal costs, it is anticipated that high investment and operational costs and a large area will be needed for setting up the treatment plants and associated facilities required for physical separation.

5.3.4 Case Histories

In samples of sediment from the Saginaw River, 80 percent of the PCBs were associated with the finest-grained 20 percent of the sediment. Sand separation from silt and clay-sized material is achieved with hydrocyclones, in which particles exposed to a centrifugal field settle at size-dependent rates. In principle, particles larger than 0.0062 mm in size can be separated from dredged sediments by screening, but in practice separations are easier for particles larger than approximately 1 mm in diameter. (NRC 1997)

At Manistique Harbor, screens were used to separate dredged sediments from wood chips, which contained a high concentration of PCBs . (NRC 1997)

Sometimes schemes are combined. An example of multistage physical separation is the process used at the largest particle separation system for dredged material in the world at the Port of Hamburg in Germany, where all dredged sediments from the highly contaminated Elbe River are pretreated. The system uses screens, hydrocyclones, and belt filters to separate sand from silts and clays (Detzner, 1993).

5.3.5 Applicability in Hong Kong and Recommendations

Fine grained sediments have significant capacity to absorb certain organic chemicals and heavy metals, and serve as sinks for these contaminants. Therefore, physical separation of the fine and coarse (sandy) fractions can be a way of separating out of the contaminated fraction from the bulk volumes. However, this method is unlikely to be of general use in Hong Kong because most contaminated sediments are predominantly fine grained.

5.4 Bioremediation

5.4.1 General

Biotreatment is a process which makes use of the biodegrading ability of naturally occurring or specifically added bacteria to break down the contaminants in the soil or to convert them into harmless substances. This biodegradation process can take place anaerobically (without oxygen) or aerobically (with oxygen). Experimental data however show that these processes can be enhanced in the presence of oxygen and nutrients, hence shortening the treatment time required. There are a number of biotreatment methods available which can degrade a wide range of organics (e.g. petroleum and phenol).

Bioremediation is a process that exploits the catalytic abilities of living organisms to enhance the rate or extent of pollutant destruction. Most wastes are generally naturally biodegradable, unless they are subjected to extreme pH or toxicity. This natural degradation may, however, be too slow to be of value. To fasten the process, a proper environment (O_2, pH, temperature, moisture, mixing, nutrients etc.) shall be provided for the microorganisms. In bioremediation, usually naturally existed microorganisms in the polluted matrix are used for the controlled degradation and detoxification of the waste or contaminants. In situations where natural bacteria are not present, specific species of microorganisms or genetically manipulated organisms may be employed in a controlled manner to achieve waste degradation.

Dredged sediments may require pretreatment to condition the material to meet the feed requirements of the treatment process; and / or reduce the volume and or weight of the sediments that require transport, treatment or restricted disposal. Pretreatment for contaminated sediments includes the removal of debris or dewatering.

Bioremediation represents an attractive biological site remediation options for sediments contaminated with petroleum hydrocarbons, solvents, polychlorinated biphenyls, polycyclic aromatic hydrocarbons and heavy metals. This has been applied successfully at many different sites worldwide.

Bioreactor involves the use of mixing conditions to hasten the biodegradation of wastewater or soil bound contamination as suspended water slurry with biomass capable of degrading the target constituents of the waste.

The biomass can derive from the contaminated materials, an activated sludge treatment plant, pure cultures or genetically engineered organisms. These are in suspension or growing on fixed film or on solid support system. The addition of nutrients and / or oxygen sustains the growth of the organisms to optimize biodegradation. The reactors can be designed as batch, sequenced, continuous or semi-continuous tanks, ponds or large containers.

For previous successful applications, results have shown up to 99% removal rates of soluble contaminants such as phenols, acetones or alcohols. Reactors can provide cost effective alternatives for the treatment of volatile contaminants such as benzene and toluene although with lower carbon loadings, off gas treatment would be necessary.

Slurry-phase treatment is more costly (HK$650 to HK$1,200 per cubic yard) than solid-phase treatment (HK$400 to HK$650 per cubic yard).

5.4.2 Advantages

- Eliminates transportation of contaminated material;
- Eliminates contaminants permanently;
- Minimise site disruption;
- High treatment rates for PCB and PAHs;
- Greater degree of process flexibility and ease of control;
- Waste containment; and
- Reduced space.

5.4.3 Disadvantages

- Limited understanding of biological contribution to the effect of bioremediation and its impact on the ecosystem, hence, optimal conditions requiring extensive investigations;

- Technical limitations in monitoring target bacteria related to the degradation of contaminants. Therefore, it is difficult to identify the cause and developing measures if the remediation is not successful;
- Not suitable for soils containing metals, The presence of heavy metals can inhibit microbial metabolism and thus affects the removal efficiency;
- Higher cost of operation;
- Lack of application of database due to the lifespan of microbes;
- Normally operated in batch mode and very expensive;
- The process can generate residue streams that may require additional treatment (e.g. wastewater and air emissions);
- Products of biodegradation may be more soluble and toxic than the original materials.

5.4.4 Case Histories

Bioremediation at the Stauffer Management Company (SMC) Superfund Site, Tampa, Florida (FRTR 2001)

The SMC Superfund site is an inactive pesticide manufacturing / distribution facility in Tampa, Florida. From 1951 to 1986, the site was used to formulate organochlorine and organophosphate pesticides. From 1953 to 1973, waste materials from the facility were disposed on site, leading to pesticide contamination in soil, surface water, sediment, and groundwater.

Bioremediation was adopted for treatment of pesticide-contaminated surface soils and sediments at the site. From June 1997 to September 1998, a field demonstration of SMC's Xenorem^{TM} composting process was conducted in an enclosed warehouse at the site, using soil taken from "hot spots" at the site. Amendments consisted of cow manure and straw, and the pile was alternated between anaerobic and aerobic conditions.

Concentrations of DDD and toxaphene were reduced by more than 90% and chlordane by nearly 90%. Although no data are available about the cost for the field demonstration, SMC indicated that typical costs for use of this technology for treating chlorinated pesticides are HK$1,100/yd^3.

5.4.5 Applicability in Hong Kong and Recommendations

Bioremediation is effective in eliminating organic contaminants, but not effective in reducing concentrations of heavy metal contaminants. This is a major deficiency of this treatment option as heavy metals are one of the main contaminants of concern in Hong Kong. In addition, the products arising from biodegradation may be more toxic than the original materials which will require further treatment. These key disadvantages, together with the high investment and operation costs, lack of application in Hong Kong and land requirements to accommodate large reactors/ponds/containers make this option technically and practically infeasible.

5.5 Chemical Treatment

5.5.1 General

The full range of chemical reactions such as oxidation and reduction, hydrolysis, and neutralisation is available for the treatment of contaminants in dredged materials. Chemical treatment is, however, used to increase the effectiveness of other treatment methods and wastes from other remedial processes may be taken to a chemical hazardous waste treatment plant for final treatment.

These processes have limited use in the primary treatment of inorganic contaminants because, with the exception of a very few contaminants (e.g. cyanides), the toxic components cannot be destroyed. In the majority of cases, chemical treatment alone can result only in reduced availability (solubility) or reduced toxicity: the reactions involved will usually be reversible. The contaminants remain in the soil and would not therefore meet any applicable generic remediation guidelines based on total concentrations. In addition, a reaction reducing the solubility of one contaminant may increase the solubility of another.

Chemical treatment of organic chemicals is potentially more useful because many can be destroyed or degraded to less toxic compounds. However, the number of developed or researched processes is low. Many organic chemical reactions require very precisely controlled conditions (and frequently the use of catalysts) and it may be difficult to achieve these in a soil treatment system. There is also a danger, particularly when many chemicals are present, that unwanted reactions (e.g. formation of more toxic compounds) may occur.

5.5.2 Advantages

- Energy consumption is low.
- The process is relatively rapid.

5.5.3 Disadvantages

- Chemical treatment methods are specific to particular contaminants or classes of compounds. Thus, they may be of limited applicability when a mixture of contaminants is present. Natural soil constituents can also be a limiting factor.
- Chemical treatment may often have a marked affect on soil properties and its suitability for disposal or reuse.
- Chemical treatment requires extracted contaminants to be disposed of appropriately following the treatment.
- It is anticipated that high investment and operational costs will be involved and a large area will be needed to accommodate the different treatment plants required for chemical treatment. This is particularly the case if sediments with a mixture of contaminants are needed to be treated by this method.

5.5.4 Case Histories

A research on separating the TBT contaminated sea waster from the dredged marine sediment was undertaken by the Kyushu University in Japan. It is reported that TBT was successfully separated from the contaminated sea waster by applying coagulant called PSI-100 as well as filtering the water through fiber sheet, sand and activated carbon. Following the treatment, the concentration of TBT was reduced from 1,200-1,450ng/L to 3ng/L.

5.5.5 Applicability in Hong Kong and Recommendations

This treatment process is contaminant-specific. The Chemical Waste Treatment Centre (CWTC) at Tsing Yi has a physical-chemical treatment facility, which caters only for water-based chemical wastes. This plant is not suitable for treating contaminated marine sediments.

The processes of chemical treatment simply reduce availability and are unlikely to be widely applicable as a primary treatment. Though many soil contaminants can potentially be treated by chemical means but the plant currently available in worldwide is limited. This is in part due to the need to trailor processes to treat individual contaminants and the difficulties that arise when a combination of contaminants is present. Therefore, this method would be unlikely to be a cost-effective mean for management of contaminated sediments.

5.6 Brick Making

5.6.1 General

The contaminated sediments are treated and used as a raw material for manufacturing construction products such as building bricks. Technologies have been developed to produce these products, although full-scale commercial production is not yet available.

Industry estimates at HK$200 to HK$700 per cubic yard, which do not include contamination removal cost.

5.6.2 Advantages

- Both freshwater and marine sediments can be used.

5.6.3 Disadvantages

- Full-scale production is not yet available.

5.6.4 Case Histories

Hanseaten-Stein Ziegelei GmbH in Hamburg, Germany (Francingues and Thompson, 2000)

Bricks for building are manufactured from contaminated dredged sediment by Hanseaten-Stein Ziegelei GmbH in Hamburg, Germany. Using this technology, dewatered contaminated sediments from the Port of Hamburg are used in the production of regular bricks suitable for use in the building industry. During the drying and ceramization process, organic contaminants are oxidized and metal contaminants are converted to stable immobile compounds or are volatilized.

In operation, the fine-grained portion of dewatered dredge sediments is used as the raw material for the bricks. The sediments dredged from the Port of Hamburg are dewatered and segregated in a system operated by the port prior to being transported to the Hanseaten-Stein facility. Analytical data indicate that a large percentage of the contaminants are associated with the fine-grained fraction (less than 63 μm) of the sediment. At the manufacturing facility, the sediment is mixed with natural clay and ground brick in a pan mill. The mixture is dried from 30% moisture to below 2% moisture content using a steam dryer. The water removed (in the form of vapor) is condensed and treated using an activated carbon system. The mixture from the steam dryer is dry-pressed to form the bricks, which are then placed in a kiln. The bricks are dried at a temperature of 600 °C (1,112 °F). The temperature is then increased to 1,066 °C (1,950 °F) for the ceramization process. The bricks are cooled and prepared for shipment. Flue gas from the process is treated with calcium hydroxide and activated carbon, and passed through a fabric filter prior to discharge.

5.6.5 Applicability in Hong Kong and Recommendations

In November 1994, the Geotechnical Engineering Office made an initial enquiry with ETH/OAM of Germany, which holds a German patent to make bricks from harbour sludge and had planned to establish a plant in Shanghai (GEO, 1997). The plant uses high temperature baking of 50% harbour silt with 50% natural clay and additives to produce a top grade brick which satisfies all requirements for construction purposes and the environment. Based on the information provided, this method is unlikely to be economical because of the lack of natural clay locally and a limited market for bricks in Hong Kong. However, this technique may be feasible when the annual volume of contaminated mud is reduced to a much lower level.

5.7 Thermal Destruction / Incineration

5.7.1 General

Thermal treatment methods use heat to remove or destroy contaminants, including halogenated and non-halogenated volatiles, semivolatiles, petroleum contaminated soils PCB (polychlorinated biphenyl) contaminated sediments and gasworks soils containing hydrocarbon. Although generally applied for the treatment of organic contaminants, some thermal treatments like cyanide through thermal decomposition are effective for inorganic forms. Metals such as mercury, lead, arsenic, may be removed when they are present as species volatile at the applied temperatures. However, volatile metal species frequently pose difficulties in many processes due to potential air emissions and enrichment of metals in particulates.

Thermal destruction / incineration is a high-temperature (800°C - 1200°C) oxidation reaction between combustible substances and air under controlled conditions of retention time, temperature and turbulence within a single or multiple-stage combustion chamber. Although organic contaminants are destroyed in the process, air pollution control equipment must be provided to collect and treat combustion products, particulates and volatile metals present in exhaust gases. Incineration involves volatilization and desorption of water and organic contaminants, and probably some inorganics. A secondary combustion chamber is generally required to complete oxidation of the volatilized materials.

The high temperatures used during incineration have implications for the re-use of the treated soil due to changes to the physical, chemical and biological properties of the material. Changes in soil texture, together with the loss of natural organic constituents, reduce the ability of treated material to support vegetation and may affect engineering properties. The loss of soil structure and organic content may also increase the leachability of any heavy metals remaining in the treated product. Further treatment, e.g. immobilization / stabilization / solidification may therefore be required before the material is acceptable for re-use.

Incineration processes using direct-fired rotary kilns have been developed for the treatment of sediments.

Extensive experience of using direct-fired rotary kiln incinerators has been well developed. The capability of destructing toxic organics including PCBs and dioxins has been proved to be effective.

A schematic diagram of a direct-fired rotary kiln incinerator is shown in Figure 5.2. Directly-fired rotary kiln incinerators typically comprise a primary and a secondary combustion chamber. The primary chamber is a cylindrical, sloping, rotating, refractory-lined shell in which the soil is dried and heated by firing fuel or liquid wastes with a high calorific value. The secondary combustion chamber provides additional capacity for any contaminants not destroyed at the primary stage. Soil may move with or counter to the direction of gas flow. The kiln can be designed to operate in either an oxidation orpyrolysis (anoxic) mode, with the latter generating smaller flue gas volumes. Rotation and inclination provide the necessary mixing and heat transfer functions. Gases exiting the secondary combustion chamber pass through a multi-stage gas cleaning plant.

Treatment costs range from HK$3,700 to HK$10,500 per cubic yard.

5.7.2 Advantages

- Incinerators typically achieve greater than 99% destruction for organics.

5.7.3 Disadvantages

The limitations of incineration are:-

- Metals volatile at applied temperatures can cause problems in air pollution control systems; others remain in treated material;
- Alkali metals and other flxes such as chloride and fluorides cause refractory attack;
- Long residue times in air pollution plant required to deal with dioxin formation;
- Moisture contents affect energy use;

- Heat value of feedstock influences economics of process;
- Physical composition must be monitored to prevent blockages/damage and maintain performance;
- Particle size of feedstock influences carry over of particulates into later stages of process;
- Presence of organic halogens produces acidic gases and requires specific air pollution control provision; and
- Phosphorus compounds can attack refractory lining if burned alone without other captions.

5.7.4 Case Histories

Incineration at Drake Chemical Superfund (DCS) Site, Operable Unit 3, Lock Haven, Pennsylvania (FRTR 2001)

The DCS Site included a chemical manufacturing facility that operated from 1951 to 1982, producing chemical intermediates used in dye, cosmetic, textile, pharmaceutical, pesticide and herbicide manufacturing. Drums of chemical waste, chemical sludge, and demolition debris were disposed on the ground surface and in the shallow subsurface at the site. Site soil and chemical sludge were contaminated with VOCs, SVOCs including b-naphthylamine, the herbicide Fenac, and metals.

The incinerator was in full-scale operation between April 1998 and April 1999 as the remedial technology for addressing soil contamination at the site. It was designed to provide permanent destruction of soil contaminants. All site soil was excavated down to the water table and treated.

The incineration system consisted of a co-current, rotary kiln and a secondary combustion chamber. The kiln operated at an exit gas temperature above 1599°F and the secondary combustion chamber operated above 1801°F. Hot gases existing the secondary combustion chamber operated above 1801°F. Hot gases existing the secondary combustion chamber passed through an evaporative cooler, a baghouse, a venture quench unit, and a caustic scrubber. Excavated soil was dried and screened to remove oversized organic and inorganic debris. Excavated soil and shredded combustible material were fed to the incinerators. Treated soil and fly ash were stockpiled for compliance sampling. Treated soil and fly ash that met treatment standards were used as fill material at the site. There were no long-term waste management requirements following on-site backfill of incinerator ash.

5.7.5 Applicability in Hong Kong and Recommendations

There has been no application worldwide in treating the contaminated sediments though a land-based case is quoted in Section 5.7.4.

Thermal destruction/Incineration does not remove heavy metal contamination in sediments and is often associated with air pollution problems associated with the emissions from the thermal reaction. A high temperature incinerator is located at the Tsing Yi CWTC for the treatment of highly contaminated chemical waste in landfills. The costs of incineration at this facility generally begin at a basic charge of HK$1,600 per tonne. This incinerator may be employed for treating contaminated sediments generated from dredging. However, the current capacity of such facilities is limited to about 100,000 tonnes of chemical wastes per year, which is equivalent to about 63,000m^3 of marine mud. According to the forecast of contaminated sediments for disposal the average annual contamination for the next 5 years is about 1,500,000m^3. This is clearly insufficient to fulfil the requirements for the annual treatment demands of around 1.5Mm^3. Added to this, the residual material (e.g. ash) would still need to be disposed in a landfill.

5.8 Sediment Washing

5.8.1 General

Sediment washing is a volume reduction process based on using liquids and a mechanical process to remove contaminants from sediment to a small portion of the original volume. Thus, this process concentrates contaminants into a smaller volume for further treatment or disposal. Sediment washing can treat a wide variety of sediment contaminated with soluble metals, halogenated solvents, aromatics, gasoline, fuel soils, PCBs, chlorinated phenols and pesticides. The treatment costs range from HK$1,600 to HK$3,200 per cubic yard.

Sediment washing, as oppose to soil washing which was designed to treat coarse grained soils such as gravels and sands, is a remediation method specifically designed to treat very fine-grained factions. Many soil washing techniques are available but because of the difficulty of treating silts and clays, few sediment washing systems have successfully been demonstrated to treat contaminated marine sediments that are mostly associated with silts and clays which make up 80% to 95% of sediments and organic matter. Biogenesis was found at the time the only method that had treated marine sediment at the pilot-scale test phase. Other washing technologies were proven only for soil treatment and not marine sediment treatment (Arup-Scott Wilson Joint Venture, 2003).

5.8.2 Advantages

- Potential to treat wide variety of contaminants;
- High removal efficiency over 90% for volatiles (organics) and 40-90% for semivolatiles (inorganics).
- The process after blending could yield a product suitable for manufactured topsoils.

5.8.3 Disadvantages

- This process cannot efficiently treat fine particles, low-permeability packed materials, or sediment with high humid content;
- The method can only be useful for low to medium contamination levels.
- Residual solvents and surfactants can be difficult to remove after washing;
- High treatment cost;
- Capacity to treat large volumes at an acceptable rate is unknown
- Sediment washing typically entails the generation of by products, including over-sized debris, sludge and wastewater, which need to be treated and disposed of at existing waste and wastewater disposal facilities.

5.8.4 Case Histories

While soil washing is a relatively well-known, proven technology for treating contaminated soil, there is considerably less experience worldwide with sediment washing. Some of the experiences with sediment washings are summarised below.

<u>Research Programmes in United States</u>

Significant research carried out on contaminated sediment remediation seemed to prevail mainly in North America. During the 1990s, the governments of the United States and Canada established and carried out programmes to identify technologies that would be suitable for the treatment of contaminated sediments, notably:

- Assessment and Remediation of Contaminated Sediments Program, United State Environmental Protection Agency;
- Contaminated Sediment Treatment Technology Program under the Great Lakes Program, Environment Canada; and

- Water Resources Development Act, Fast Track Dredged Material Decontamination Demonstration for the Port of New York and New Jersey, United State Environmental Protection Agency, United States Army Corps of Engineers, and United States Department of Energy Brookhaven National Laboratory.

Some sediment remediation technologies have also been demonstrated under the Superfund Innovative Technology Evaluation Program of the United State Environmental Protection Agency. Over US$30 million have been spent on more than 10 years of research to establish the most appropriate technologies

Of the programmes mentioned above, it was reported that BioGenesis has demonstrated successful testing in the Contaminated Sediment Treatment Technology Program and Water Resources Development Act. Given the lengthy development programme and the extensive experience in the US and Canada, it is considered that there is a major benefit to be gained from using their knowledge as a starting point.

WESTON and BioGenesis, West Chester, PA. (Francingues and Thompson, 2000)
Advanced Sediment Washing Technology is marketed jointly by WESTON and BioGenesis, West Chester, PA. This technology is a multistaged sediment washing and organic oxidation process for decontaminating dredged sediments and producing a marketable fine-grained soil-like product for reuse after the addition of bulking materials. During the process, organic material is stripped from the solid particles and chemically oxidized. Removal efficiency is contaminant specific.

In operation, the dredged sediment is screened, and then high-pressure water and chemical cleaners are used to strip the outer layers of organic material from the sediment particles. Floatable organic material is removed using air sparging. Organic and inorganic materials are stripped from the sediment particles using high-pressure water and chemicals in a collision chamber. Organic material is oxidized by means of chemical oxidizer addition and processing in a cavitation unit. The treated sediment slurry is dewatered using a centrifuge and hydrocyclone. Bulking materials are added and mixed to produce a manufactured soil. Wastewater from the process is recycled into the process and/or treated and discharged.

Kai Tak Approach Channel Reclamation, Hong Kong
Sediment washing using Biogenesis has been considered in the review of remediation strategy for the Kai Tak Approach Channel Reclamation. The land requirement for full-scale set up of two Bio Genesis process lines was estimated to be 13,000m^2. The total estimated cost for the sediment washing option was approximately HK$485M to HK$710M, which was assessed to be the most expensive option amongst the five alternatives considered in the study (Arup-Scott Wilson Joint Venture, 2003).

5.8.5 Applicability in Hong Kong and Recommendations

Sine there has never been a precedent anywhere else in the work, in terms of both the combination of the large scale of the potential remediation work and the extensive level of contamination in Hong Kong, there is no technology specifically proven for application of this management option. This method is also unlikely to be of general use in Hong Kong because of high initial investment and operation costs.

5.9 Immobilization / Solidification / Stabilization

5.9.1 General

Immobilization mainly applies to the remediation of contaminated sediment with heavy metals. In this immobilization process, some stabilizing or immobilizing reagents are added to the soil so that the heavy metals present will be bound/chelated by chemical reaction or fixed/trapped by physical reaction. These immobilizing reagents range from molecular sieves, chelating exchange resins to hydrated lime. For heavy metal contamination, capping of a site so as to isolate the contamination from users of the developed area could be considered as an alternative to immobilization.

Stabilisation / Solidification method (sometimes called immobilisation methods) can change the physical state of a contaminated material, and / or reduce the availability of contaminants to potential targets through chemical stabilisation and usually by containment within a solid, low-permeability product.

Stabilisation involves adding chemicals to the contaminated material to produce more chemically stable constituents. It may not result in an improvement in the physical characteristics of the material.

Solidification involves adding reagents to contaminated material to reduce its fluidity / friability and prevent access by external mobilising agents to contaminants contained in the solid product. It does not necessarily require a chemical reaction between contaminants and the solidification agent, although such reactions may take place depending on the nature of the reagent.

In practice, many commercial systems and applications involve a combination of the two processes, i.e. stabilisation is followed by solidification to reduce exposure of the stabilised material to the environment. Although volatile constituents may be driven off and some hydrolysis of chlorinated organic compounds may occur during some processes, the destruction or removal of contaminants is not the objective of stabilisation / solidification. Contaminants may become available once again if the physical / chemical nature of the treated product alters in response to changes in the external environment.

The technique is most successful in wastes with inorganics and metals. Cement-based and silicate-based have been relatively more successful in treating hazardous wastes. The production costs vary by sediment type, raw material costs and the level and type of contamination. Costs of production were not inclusive of contamination removal which may be necessary prior to the immobilisation process. Estimated production costs for immobilization range from HK$250 to HK$1,300/yd^3 for total containment of metals.

5.9.2 Advantages

The advantages of using immobilization are:-

- Chemical isolation from biologically accessible environment;
- Process is simple and there is a history of use for sludge;
- The treated sediment in the form of concrete can be reused for public filling and the contaminants removed from site will not limit the future use of the area;
- Less expensive than chemical treatment, sediment washing and incineration.

5.9.3 Disadvantages

The limitations of using immobilization are:-

- Sediment should have moisture content of less than 50% and solidified volumes can be 30% greater than starting material;
- Highly contaminated sediments may need to be pre-cleaned with another process prior to immobilization process to produce a beneficial end product.
- Limited applicability to organic contaminants;
- High organic contaminant levels may interfere with treatment for metals immobilization;
- Need for placement of solidified sediments; and
- In some cases, the immobilization treatment may change the chemistry of the contaminants and render them more susceptible to leaching.

- It requires a potentially large area and high investment and operation costs for establishment of treatment plants and facilities.
- It is anticipated that high investment and operational costs and a large area will be needed for setting up the treatment plants and associated facilities required for Immobilization/ Solidification/ Stabilization.

5.9.4 Case Histories

Marathon Battery Superfund Site

Chemical immobilization by solidification converts sediments into solid blocks by the addition of cement, silicates, and proprietary reagents. Some stabilization processes adsorb or react with free water in the sediment to form a relatively dry material without hardening into a monolith. The stabilization process used at the Marathon Battery Superfund site produced a soil-like material that reportedly immobilized the metals in the sediment. Water contents below 50% are probably desirable to make the process cost effective. Solidified volumes can be up to 30% larger than the initial sediment volume (NRC, 1997).

New Bedford Sediments

Whether this approach is effective for treatment of organics is unclear (Averett et al., 1990). Laboratory experiments with New Bedford sediments showed that solidification successfully reduced the mobility of metals (Myers and Zappi, 1992). This approach has several benefits, including simplicity, a history of use with sludge, and the capability of improving handling of sediments. However, the solidified material must still be disposed of.

New York / New Jersey Harbour

Sediments at the New York / New Jersey Harbour were contaminated with Organochlorine pesticide, PAHs, PCBs, Dioxins and Furans and metals. Immobilisation was adopted in the treatment of the contaminated sediment. The treatment of the material was done in a barge. Stabilised materials have been used as structure fill at a parking lot and capping brownfield site in New Jersey.

(http://www.nan.usace.army.mil/business/prjlinks/dmmp/prevent/index.htm#decontam)

5.9.5 Applicability in Hong Kong and Recommendations

Immobilisation is one of the most commonly adopted methods for the treatment of industrial and/or chemical wastes but not for contaminated sediments in Hong Kong.

The technique is ineffective for treatment of sediments containing organics contaminants and moisture content of greater than 50%, which are however typical natural and physical properties of contaminants in the Hong Kong waters as shown in Section 2. Added to this, dredging operation will be required to remove the contaminated sediments, which will suspend the contaminants and pre-treatment is required to remove the water. The required off-site treatment methods also usually demand secondary treatment of the by-products such as wastewater, noxious emissions and solid waste. In these connections, it is considered technically infeasible to adopt this method as general management option for contaminated sediments in Hong Kong.

5.10 Use of Geo-Synthetic Products

5.10.1 General

Marine disposal of contaminated sediments within designated mud pits is a well-defined method that has been used successfully in Hong Kong for many years. Under the requirements of ETWB TC(W) 34/2002, category H sediments failing the biological dilution screening will need to be specially treated to render it suitable for confined marine disposal. Subjected to the approval of the Director of Environmental Protection in consideration of the site and project specific data, one of the possible methods of special pre-treatment may be to confine the sediment within geosynthetic containers (Cheek, P.M. and Yee, T.W. 2006).

Geosynthetic products have generally two potential applications for the marine disposal:

- In containers, for confinement of the mud during transportation to the disposal site, and during its placement and retention within the mud pit; and
- In tubes, for dewatering of the overflow from the hydrocyclones, and retention of the fines, for eventual disposal at the mud pit.

The geosynthetic containers/tubes are a suitable means of containing the contaminated sediments and prevent them from being dispersed in the water column during disposal at the mud pit. The containers are fabricated from a high strength woven geotextile with special high strength seaming techniques to resist pressures during filling and placing operations. The geotextile is designed to be permeable and the pore sizes can be designed to ensure retention of the sediments. They are suited to being stored underwater and have been used extensively around the world as stabilising units to form containment dykes, revetments, breakwaters etc.

Given the additional volume of water added during the dredging process the sediments will need to be dewatered, prior to placing in the containers. The land limitations of the site restrict using the containers as a means of dewatering at this stage. Instead an alternative process using hydrocyclones avoids storage/stockpiling of materials and is considered more appropriate.

After dewatering the sediments can be placed in the partially sewn geotextile container located in the bottom of a split bottom barge. Circular vents are incorporated in the ends and top of each container to allow the release of trapped air and water to reduce possible internal pressure. Once it is filled the geotextile liner is folded over and sewn using special seaming techniques to contain the material. After sealing the barge can be towed to the mud pit. Once in position the barge hull is then opened and the container dropped into the mud pit.

5.10.2 Advantages

- Spare capacity for open sea disposal if it can demonstrate that the treated sediments are suitable for open sea disposal.

5.10.3 Disadvantages

- High cost of geosynthetic-based products involved.
- Sediments would have to be dewatered before placing the material inside the containers.
- Confined marine disposal is needed for disposal of the contained sediments.
- There are uncertainties on the retention of the sediments within the containers and leakage of contaminants both during dumping of the containers and afterwards prior to sealing of the mud pit. The natural seepage of methane gas would also be an unknown.
- Subject to deterioration in long-term which may cause potential pollutants leakage to the adjoining water body.
- Geosynthetic-based product might not be applicable for different types of contaminants.
- Past application only for contaminated mud pit disposal.

5.10.4 Case Histories

It should be noted that all the Hong Kong cases listed below are for confined marine disposal only. There is no past experience in worldwide that the contained sediments can be dumped to an open sea disposal ground.

<u>Wan Chai Development Phase II Project, Hong Kong</u>

Highly contaminated mud was found at the Wan Chai Development Phase II project which requires special treatment and disposal under the ETWB TC(W) 34/2002. The total volume of dredged sediment was estimated to be approximately 990,000m^3 in which about 600,000m^3 would be classified as category H. It was estimated that some 2100 m^3 of sediment contaminated with PCBs may require pre-treatment or special disposal arrangement prior to marine disposal. The proposed method of disposal was to dredge and seal the sediments in geosynthetic containers and then disposed at the East Sha Chau mud pit via a split bottom barge. After dumping, the geosynthetic containers will be covered over with further disposed mud and ultimately clean capping material to achieve a fully confined mud disposal.

Kai Tak Approach Channel Reclamation, Hong Kong
Special treatment comprising containment of the dredged sediments in geosynthetic containers has been considered in the review of remediation strategy for the Kai Tak Approach Channel Reclamation to treat sediments for confined marine deposit. The total estimated cost for the marine disposal was estimated HK$420M (Arup-Scott Wilson Joint Venture, 2003).

Kwai Chung Container Port Terminal 4 and 6 - T4 & T4/6 Basin, Hong Kong
In this case, a permit was issued under the Dumping at Sea Ordinance for disposal of contaminated sediment requiring type 3 - special treatment and disposal contained in Geosynthetic Container and the contaminated sediment was disposed of at East of Sha Chau in 2006.

Projects in United States
Geosynthetic tubes have been used successfully in dewatering and storing of contaminated rive and like sediment in the United Stated. They have proved to be effective at confining high volumes of marine sediments, efficient in dewatering the sediments and volume reduction, a highly flexible containment method and cost effective. However, the dewatering and storage have only been implemented on land and the remaining sediments are disposed at locally classified landfills. Typical examples included the Conner Creek, Detroit City and Lake Maggiore Restoration Project. There are no examples of using geosynthetic tubes for marine disposal of contaminated mud.

5.10.5 Applicability in Hong Kong and Recommendations

It is considered that this management option is technical infeasible for use in Hong Kong due to its high cost and uncertainty in long-term performance and the specific contaminant nature for disposal into an open sea disposal site.

6 Review of Worldwide Disposal and Beneficial Reuse Options & Practices for Sediment Management

6.1 General

The optimum combination of disposal and reuse options need to be investigated for each dredging operation. The use of selective dredging where feasible may result in significant cost savings in any reuse or disposal option.

The following reuse options have been identified as a result of consultation and a review of available literature. The suitability of each is obviously dependent on local markets and any financial advantages or disadvantages.

- Use in landscape or reclamation projects including golf courses, landfill sites, etc. as covering material. Sandy / loamy material is specifically favoured for golf courses when it is incorporated in to the top layers as it improves the bearing capacity of this layer during wet periods. Much larger materials like gravels can be used as drainage fill.
- Road construction. Dredged material can be used only if the material is of an appropriate particle size.
- Use in industry, for example in the manufacture of bricks, ceramics, tiles or artificial gravel, or as low-quality construction material. In most cases the material needs to be clean and of an appropriate particle size, without any larger debris.

In order to determine the technical and economic viability of its future use of the dredged material, a thorough assessment of the material is vital, together with market research. It may be necessary to have separation of dredging, involving screening at the dredger and separate transportation. It may also require treatment of dredged material, for example sediment washing, prior to reuse. The quantities of dredged material may be too large to be handled for a particular use, thus requiring storage facilities.

When the material is used for road construction or landscape purposes, the quality of the material is paramount. If there is any doubt about the quality of the material (e.g. slightly contaminated with heavy metals), the possible effects on the surrounding environment need to be assessed. If the material is to be sold, the transfer records to the buyers need to be properly kept. When treatment techniques are used, either to wash or separate materials, consideration needs to be given to the effect of the possible waste products which might arise from such a process.

6.2 Confined Marine Disposal

6.2.1 General

The method consists of depositing sediments in the bottom of a natural depression or digging a hole in the bottom and placing the sediment in by hydraulic pipeline with or without a submerged diffuser, direct placement with a clamshell, or release from bottom-dump scow.

From December 1992 to November 1997, a series of purpose-dredged seabed pits at East Sha Chau (i.e. Contaminated Mud Pits (CMPs) I to III) were used to dispose of dredged contaminated mud in Hong Kong. East Sha Chau has a relatively shadow water depth (about 5-6m) and relatively low currents. These pits are formed to a depth of about 15m below seabed, backfilled with contaminated mud to about 3m below seabed, and then capped with a 3m thick layer of clean sand and mud to bring the cap back to the level of the surrounding seabed. They have a capacity of about 11Mm^3.

In 1996, as the capacity in these pits began to dwindle, the Government commissioned a study to examine the need for continued marine disposal of dredged material in Hong Kong in order to manage ongoing contaminated sediment arising. The study reviewed potential land-based options in Hong Kong, including strategic landfills, treatment of materials, and the incorporation of contaminated dredged material into land reclamation projects, but found each to have inherent drawbacks. In contrast, the study's review of environmental monitoring data collected at CMPs I-III from 1992-1995 concluded that there was no evidence of contaminant impacts on biota due to disposal, and that contaminants in dredged materials had been successfully contained. The study therefore recommended continued disposal in capped seabed pits in the East of Sha Chau area as the preferred option.

This finding led the Government to commission an EIA evaluating the use of disused borrow pits in the East of Sha Chau area as the next contaminated mud disposal facility. This facility is known as CMP IV, consisted of three pits (CMP IV a, b and c) which had been dredged for sand during construction of the new airport at Chek Lap Kok and represented a capacity of approximately 30 Mm^3, making the total capacity of pits I, II, III and IV as approximately 41Mm^3. The CMP IV EIA study formulated an environmental design for disposal operations, which included specifications for disposal rates, cap thickness, and backfilling level. The Study concluded that impacts to water quality, marine ecology, air and noise were expected to be maintained within acceptable limits under the specifications of the agreed Operations Plan. The CMP IV EIA Report was endorsed by the Advisory Council on the Environment (ACE) in March 1997.

Since the first operation of the mud pit in 1992, CEDD has been carrying out EM&A throughout the years. The EM&A programme comprises periodic collection of sediment, water and biological samples in the vicinity of the CMPs, laboratory analysis of the samples for a number of chemical / biological parameters, and statistical analysis of the data and desktop review / reporting. QA / QC procedures are also built into all field laboratory and analytical procedures to ensure the quality of data.

In 2007, CEDD conducted a comprehensive review of all the past monitoring results for the CMPs (Ref: Environmental Monitoring and Audit for Contaminated Mud Pit IV at East Sha Chau (2005 – 2008) – Investigation, Review of Past Monitoring Results for Contaminated Mud Pits, November 2007) . A total of 5 tasks had been designed for assessing the potential environmental impacts. These tasks include 1) Sediment Quality Monitoring, 2) Sediment Toxicity Testing, 3) Trawling & Tissue / Whole Body Contamination Testing, 4) Water Sampling and Water Column Profiling and 5) Benthic Macroinfauna Sampling and Identification.

According to its findings, there is no evidence of any adverse impacts caused by the disposal activities at the East Sha Chau CMP, and the CMP operation and facility have proceeded in an environmental acceptable manner.

6.2.2 Advantages

- Relatively lower cost and lower risk than in-situ and ex-situ treatments;
- Placement of the dredged material to be stored can be fast. A hopper barge can be used if access via water is available; in other situations pumping might be possible.
- This can avoid multiple sediment handling steps. The sediment could be transported in the same device from which it will be discharged.
- This has been well established in Hong Kong and the monitoring results of the past 15 years show no adverse impacts

6.2.3 Disadvantages

- Suitable disposal and capping site is required;
- Dredging equipment for each case needs to be evaluated based on sediment and capping material characteristics and disposal site considerations;

- The accuracy of placement relies on site-specific placement technique;
- Water quality monitoring programme is required to minimise the risk of water pollution.

6.2.4 Case Histories

Port of Oakland (Hartman, 1997)

The Port of Oakland has proposed the use of a large CAD site in Oakland Middle Harbour to contain several million cubic yards of material and increase shallow water habitat, including threatened eelgrass beds and fish nursery areas.

Boston Harbour Navigation Improvement Project, MA

The project was constructed in two phases in the Federal navigation channels of the Boston Inner Harbour. The phase 1 works carried out in 1997 involved a single contained aquatic disposal cell with a capacity of 23,000 yd^3 while the phase 2 works carried out in 1998 involved construction of eight contained aquatic disposal cells with a total capacity of 1 million yd^3. The various contaminants contained included heavy metals, PCBs and PAH.

Lower Duwamish Waterway, Seattle, WA

This is a contained aquatic disposal pilot study carried out in 1984 to evaluate removal of shoaled contaminated sediment with disposal in a subaqueous depression (borrow pits) and capped with sand. The pits contained a total 1100 yd^3 of contaminated fine sandy, clayey silt plus 4000 yd^3 cap material. The various contaminants contained included heavy metals, PCBs, Aldrin and others.

Rotterdam Harbour, Netherlands

The project involved a two phased construction of subaqueous disposal pits to dispose of contaminated dredge material. The phase 1 disposal pits was constructed in 1981 to 1982 and contained 1.1 million yd^3 of contaminated dredge materials while the phase 2 works was constructed in 1983 and had a 600,000 yd^3 of highly contaminated dredged materials. The various contaminants contained included chlorinated hydrocarbons and pesticides.

6.2.5 Applicability in Hong Kong and Recommendations

Marine disposal of contaminated sediments within designated mud pits is a well-defined method that has been used in Hong Kong for many years. Previous experience at East Sha Chau with no adverse impact to the environment noted through continuous monitoring has proven success of this option for Hong Kong application. Furthermore, the EIA study for the new mud pit at the north-east of East Sha Chau was completed and approved by EPD under the EIAO in 2005.

6.3 Confined Nearshore Disposal / Poldering

6.3.1 General

Diked containment areas are used to retain dredged material solids while allowing the carrier water to be released from the containment area. The two objectives of a containment area are: (a) to provide adequate storage capacity to meet dredging requirements and (b) to attain the highest possible efficiency in retaining solids during the dredging operation in order to meet effluent suspended solids requirements. These considerations are interrelated and depend upon effective design, operation, and management of the containment area.

Consideration must be made in the location of the site as to the ultimate use of the material and the efficiency of delivery of material to the facility. The most efficient offloading methods are slurry pumping and clamshell delivery directly to the pond. Delivery methods and rates to a confined disposal facility (CDF) are regulated by several factors. The accessibility or distance of a CDF from the offloading site is the primary determinant of offloading rate. Facilities that are directly accessible to barge traffic can efficiently accept material using a clamshell or other mechanical delivery system. When direct access is not possible, material is mixed with water and pumped as slurry to the CDF. Pumping requires access to a large pump with a constant power source, right-of-way for pipelines, and a large water source.

Dewatering of dredge material from a containment facility is critical to the operation of a CDF. As dredged material settles, associated pore water and slurry water are extruded and must be discharged. The dewatering flow may contain contaminants and this may affect the ability to discharge water back to the ocean or harbour.

In order to avoid excessive dewatering, or when most of the water has been extracted, the dredge material within the CDF may be augmented with drying agents or mechanically manipulated to facilitate drying. Once material is dried to a manageable consistency it can be moved off-site for reuse.

The cost ranges about HK$52 to HK$208 per cubic metre.

This technology is suitable for contaminated sediment to be removed from their original location, e.g. near navigation channel, harbour, ports, etc.

6.3.2 Advantages

- Does not require land for onshore disposal;
- Less expensive than reuse cost;
- An attractive and cost effective method of dredged material disposal;
- If properly located and constructed, they can isolate contaminated sediment from environment fairly well;
- Some treatments can be applied in the confined disposal facility, such as biodegradation;
- Much cheaper than biological treatment and chemical treatment; and
- They can maintain efficient contaminant pathway control, facilitate efficient long-term monitoring of the dredge material and dewatering effluent, and allow easy access to material for removal and reuse.

6.3.3 Disadvantages

- Turbidity caused from dredging may impact denitrification capacity and marine species as a result of light reduction;
- Potential for spreading exotic pest species.
- Difficulties in finding a suitable space from nearshore disposal / poldering.
- Restriction from local residents and government bodies;
- Transportation expenses;
- The potential for contaminant migration into groundwater and surface drainage of contaminated water, and plant and animal uptake of contaminants.

6.3.4 Case Histories

Rotterdam Harbour (Palermo and Averett, 2000)

The sludge on the barge from Rotterdam Harbour, The Netherlands, is contaminated with TBT. The TBT levels in the harbour are high, up to 0.4mg/kg sediment and well above the Dutch acceptable levels in sediments (0.0007mg/kg). Annually, approximately 20 million tons of sludge is dredged from the harbour, of which 16 million tones is dumped in the North Sea, just outside of the Port of Rotterdam, and 4 million tones, classified as heavily contaminated, is disposed of in a special depot. Papegaaiebek (Parrot's Beak) site in Rotterdam is a 40-ha upland confined disposal facility specially designed for highly contaminated dredged material from Rotterdam Harbour. The site was designed with a 2mm-thick HDPE liner and leachate collection system.

The Slufter, Netherlands

The Slufter (Netherlands) is a nearshore confined disposal facility which takes contaminated material dredged from the Port of Rotterdam (note that the most heavily contaminated material is disposed of at the Parrot's Beak described above). The Slufter has been in operation since 1987 and has a capacity of 90 million m³.

Outer Harbour

The main shipping channel at the Outer Harbour was deepened by 2 m to a depth of 14.2 m in order to accommodate larger shipping vessels to berth at Port Adelaide, Australia. The $45 million project involved dredging 2.7 – 3.0M m^3 of spoil comprised of sand, clayey sand, gravels and shells, and various clays by using a trailer hopper suction dredge (THSD). The reminder of the material contains limestone, sandstone and calcrete. This material was too hard to dredge using THSD, therefore a cutter suction dredge (CSD) was deployed.

All the dredged material was taken by the THSD to a spoil dump site in the middle of Gulf St Vincent located approximately 38 km westwards from the Outer Harbour. The dump site sea floor was estimated to be approximately 30 – 35 m deep and covered in fine sediments. The environmental assessment indicated that the sea bed at the dump site was characterised by a low level of biological activity due to the low concentrations of total organic carbon and calcium carbonate in the sediments.

The option of using the dredged material onshore as engineering fill was considered, which would require large settling ponds to treat slurred clays before using as fill. If clays were to be used onshore, an excavator dredge would need to be deployed. This option would take more than two years to dredge the channel and would be expensive, hence the option was discounted.

Using a THSD was selected for this project as it is the quickest way to dredge the channel, which will minimise the period of turbidity and sedimentation and subsequently reduce the short and long term environmental consequences. A CSD was also used as it would deposit ground up materials close to the sea bed and therefore reducing the concentration of sediments in the water column (Flinders Port 2007).

Port Philip Bay

Another project in Australia used the confined nearshore disposal option is the deepening of the shipping channels in Port Philip Bay. The overall cost of the project is estimated at AUD 400 million, which include the cost of work for the project and relocation of services, but not include berth works. This cost will be finalised after the completion of the approval process (Port of Melbourne Corporation, 2004).

The project involves the followings:

- Removal of rock at the entrance of the bay in order to allow the channel to accommodate ships of 14 m draught at all tidal conditions;
- Dredging of sediments including sands, clays and silts; and
- Placement of dredged material at underwater dredged material grounds in the bay.

It is estimated that a total of 43.2 million m^3 of dredged material will be created by the project and 2 million m^3 of the material is identified as moderately contaminated. Mobilisation of contaminants during dredging and increased contamination caused by the placement of material at the designated material grounds will be controlled by implementing control methods including:

- Ensuring no overflow of contaminated dredged material from dredging; and
- Sequence dredging to allow contaminated material to be used to construct bunds within the designated material ground.

Sandefjord, Norway

Contaminated material dredged from shallow areas within the harbour of Sandefjord was placed into a confined disposal facility in a deeper part of the harbour. The disposal facility was constructed using rock fill on soft clay covered by geotextiles. The dredged material was covered by geotextiles and a 0.5m layer of sand. The confined disposal facility has a capacity of 55,000m^3.

6.3.5 Applicability in Hong Kong and Recommendations

Confined nearshore disposal is a technically feasible alternative, primarily due to its cost-effectiveness. However, actual feasibility depends on several logistical considerations including: availability of a suitable coastal site; future use of the compressible and contaminated land; disposal of decanted water; and long-term effects, relating to the potential for the release of contaminated pore water.

The possibility of using poldering was considered in 1990 under the "Fill Management Study Phase I". It outlined a scheme to use poldering in Deep Bay to accommodate uncontaminated mud. The plan was not pursued any further due to concerns of environmental and social impacts to a number of villagers along the coastline, the oyster beds in the shallow waters of the Bay, and the Mai Po Marshes.

The expected arisings of contaminated mud in the next 5 years are over 7.43Mm^3, which would require an area some 9 times the size of the lagoon at Lamma Power Station for storage of Pulverized Fly Ash. This means that a large area of the nearshore environment would be impacted, and the resulting land would have little scope for subsequent development.

6.4 Reuse as Construction Fill / Reusing Sediments Dredged from Seawall Construction as Filling Materials for Reclamation

6.4.1 General

Dredged material, especially that from ports and harbours, is generally fine grained; however, many areas contain large amounts of sand. Some areas may even contain large gravel and rocks. Each of these different grain size characteristics may be thought of as a separate resource. Fine-grained material, when combined with stabilizers, can be used to form products ranging from cements, to construction materials.

Sand can be used to augment structural fill, or used directly as beach replenishment material. Finally, gravels and rocks can be used as sub-base aggregate. Since most contamination is typically found in the fine-grained fractions, separation of sands can provide a clean resource.

Efficient separation of these resources can be done in a variety of ways, depending on the goal or expected final use. Before the dredged material can be separated into its grain size fractions, the water must be removed. Following dewatering, the dry or nearly dry dredged material can be removed from a containment area and separated into its major fractions.

6.4.2 Advantages

- Efficient use of dredged sand;
- Enhancement in water purification functions and restoration of ecosystem in bay areas through biological process of benthic species; and
- Saving cost to purchase construction fill and therefore reducing construction cost;

6.4.3 Disadvantages

- High cost of determent/dewatering;
- Need to ensure dredged material is suitable for fill and pre-treatment may be required;
- Storage facilities for treated dredged material may be required;

- Metal sulphide soils generate sulphuric acid when exposed to oxygen during excavation;
- Disposed of at licensed premises with certified environmental management plans;
- Sediment type / quality needs to be suitable for benthic species; and
- Dredging and reclamation could potentially change physical and chemical characteristics of water and sediments. The change in pH and dissolved oxygen, mobilisation of nutrients and toxicants could cause algal blooms, mortality to aquatic biota and bioaccumulation.
- Site must be within suitable distance for transporting material.

6.4.4 Case Histories

Reclamation Project of the Proposed Port Botany Expansion in Sydney

The sediment was re-used as filling material for reclamation project of the Proposed Port Botany Expansion in Sydney. A total of about 220,000m^3 of sediment was dredged for port development, allowing ships to manoeuvre and berth at the new terminal. Hydraulic dredging methods using water as the transport medium were adopted to pump seabed material which comprised generally fine to medium grained sands. A multi-terraced embankment was proposed for fill containment, which does not require much dredged material for filling.

New Parallel Runway for Brisbane Airport

Another project in Australia reusing sediment as filling reclamation for reclamation is the New Parallel Runway for Brisbane Airport. The construction comprised extraction of 15Mm^3 sand from Middle Banks (Moreton Bay) with a trailer suction hopper dredge to provide fill and surcharge material for the runway reclamation site. Whilst the dredged sediment was beneficially reused, the creation of a turbid plume by the dredger could have impacts on water quality and subsequently result to changes in ecological functioning. A dredge mooring facility and pipeline was established to transfer the dredged material to the reclamation site, thus requiring additional costs for logistic issues and further excavation.

Moss Landing Harbour Project

On the West Coast, the Moss Landing Harbour project is an example of a small to medium sized beneficial reuse project. The Moss Landing Harbour District (MLHD) was unable to dredge their commercial and recreational harbour as a result of elevated pesticides and a lack of a suitable upland site for disposal. The MLHD, working closely with Federal (e.g., EPA, USACE, U.S. Fish and Wildlife Service, National Marine Sanctuary) and State (RWQCB, California Department of Fish and Game, California Coastal Commission) agencies obtained permits to develop an upland drying and processing site. In conjunction with this site, the MLHD utilized cement additives (a waste product from a refractories plant) to provide base material for structural fill in road construction, parking lot, and the development of a new recreational use facility (HLA, 1999). Approximately 110,000 cubic yards has been utilized in this manner to date.

Claremont Channel in New Jersey

Dredged material from the Claremont Channel in New Jersey was used in several innovative projects (O'Donnel and Henningson, 1999). Sediment was used in major site improvements in the Hugo Neu Schnitzer East (HNSE) ship loading facility that included noise control berms, site re-grading for storm water control, dock rebuilding and rail extensions, and an inter-tidal wetland was created using dredged material from the channel. Sediment from the channel was treated with a PROPAT, a recycled product from automobile shredders, and used as volumetric fill and grading for a new golf course and nearby residential development. Finally, dredged material was mixed with fly ash and a proprietary activator to prepare a low-strength, compacted cementitous grout. This grout was used to seal abandoned Pennsylvania coal mines to reduce acid mine drainage. The estimated cost of the PROPAT demonstration project was $5 million. The estimated cost of using 150,000 cubic yards of material to produce grout to seal mines in Pennsylvania is $6.75 million ($45/cubic yard). Habitat improvement costs associated with the Claremont Channel projects are estimated at $4.5 million.

6.4.5 Applicability in Hong Kong and Recommendations

There has been very little enthusiasm in the industrial and commercial communities to utilise dredged material as a resource.

There will be a need to educate the end use community as to the risks involved with reuse of dredge material before it is widely accepted from a public standpoint.

It would be difficult to have suitable sized filling materials after treatment to suit the purpose of a particular reclamation, with the typical volume of dredged material in the range of 12 to $16m^3$ by the use of conventional grab dredger commonly adopted in dredging activity in Hong Kong.

6.5 Sanitary Landfill Cover

6.5.1 General

The characteristics of contaminated sediments can be investigated to determine their potential for use as sanitary landfill cover. The rates and depths of drying were determined for various dredged material layer thicknesses. The various sediments were ranked according the rate of dewatering and the quantity of dried material produced. With appropriate disposal site management, the dredged material can be dewatered so that it is suitable for use as sanitary landfill cover.

6.5.2 Advantages

- Efficient use of dredged material;

6.5.3 Disadvantages

- Pre-treatment/dewatering of dredged material may be required;
- For dredged materials to be used as sanitary landfill cover, both the water content and quality of the sediment after dewatering/pre-treatment must fulfill all the landfill cover requirements stipulated by the government authorities. This usually includes moisture content and contamination level of dewatered and pre-treated sediment.
- Assessment of permeability and chemistry of the dredged material is required;

6.5.4 Case Histories

<u>Elizabeth, MJ</u>

The immobilisation technology was developed and used by the OENJ Cherokee Corporation, Bayonne, NJ, for cover at an old city landfill in Elizabeth, NJ, using dredged sediment. This technology is a nonthermal, mixing process using chemical additives to transform dredged sediments into a structural-cover product. During the process, contaminants are not destroyed, but their mobility is reduced due to chemical stabilization and incorporation in the physical matrix of the product. Reduction in mobility is dependent on the contaminant and the type and amount of chemical additives used.

In operation, the dredged sediment is screened to remove large debris and then transferred to a pug mill. Solidification additives (portland cement was used for this particular project) are added and mixed into the sediment. The resulting mixture is transported to the work site where it is allowed to dry and gain strength as a result of hydration of the additives. The material is then spread and compacted to provide a smooth, hard surface.

6.5.5 Applicability in Hong Kong and Recommendations

In Hong Kong, sanitary landfills have been developed for domestic and industrial waste but with only limited capacity. Sanitary landfill cover could be an option for management of contaminated sediment if the site specific conditions are favourable. Nevertheless, pre-treatment to dewater the contaminated sediments have to be undertaken so essentially mechanical dewatering technique and its associated impacts on land use, technology and economics need to be carefully considered before implementation. In addition, the dredged materials have to be assessed for its suitability for use as sanitary landfill cover; this includes ensuring that both the water content and quality of sediment after dewatering/pre-treatment meet the landfill cover requirements, e.g. moisture content and contamination level of dewatered and pre-treated sediment. The minimal landfill cover requirement each year compared with the large quantity of sediments produced also means that only a very small portion of the dredged sediments can be deposited to the landfill sites as covering materials every year.

6.6 Creation of Artificial Mudflats

6.6.1 General

Artificial mudflat means generally unvegetated mud bottoms exposed by human action. Dredged material can be used beneficially to enhance or create various wildlife habitats. This may be either incidental to the project purpose or planned. For example, nesting meadows and habitat for large and small mammals and songbirds have been developed on upland or floodplain (seasonally flooded) dredged material placement sites. Numerous examples are available where dredged material has been used to create nesting islands for waterbirds and waterfowl.

Many technical considerations are necessary for the creation of nesting islands. An island can be built where none existed, and vegetation states (bare ground versus sparse herb cover versus tree/shrub habitat) can be managed using periodic dredged material applications. The types of dredged material can be manipulated to provide proper substrates for nests; that is, softer silts and clays can be capped with sand, shell, and cobbles. The placement of the dredged material can be manipulated to provide the most acceptable habitat characteristics.

Upland wildlife habitats are typically dredged material containment areas that are no longer used or have long periods between maintenance dredged material placement. This allows native vegetation to grow and provide food and cover for wildlife. Site management is minimal, but can be intensified to provide special food crops, overwintering waterfowl feeding areas, and numerous other natural resource opportunities.

6.6.2 Advantages

- Implementation of the beneficial use of dredged material, carefully considered, can provide opportunities for habitat and water quality restoration in areas where restoration may not be possible without the use of dredged material.

6.6.3 Disadvantages

- Artificial mudflats usually have limited or no value for fish and wildlife due to the unpredictability and usually prolonged duration of exposure.
- In some cases, this will involve a "habitat tradeoff", that is, the elimination of an existing habitat to replace it with a restored habitat that has suffered greater losses and/or is more valuable to the local ecosystem. This loss of degraded or relatively low value habitat would be justified only if the replacement habitat provides a greater ecological function (e.g., provide more fish and wildlife habitat, provide greater sediment/toxic retention, provide enhanced water quality or water circulation, etc.).

6.6.4 Case Histories

In the USA, the use of contaminated dredged material for habitat creation has been studied for the past 10 years and is considered to be a major innovation in beneficial use (Brandon et al, 1992). Some of the case histories are listed below:-

Aransas National Wildlife Refuge, Texas, north of Corpus Christi, along the Gulf Intracoastal Waterway in 1993-1994
Maintenance dredged material was used for stabilization of eroded marsh shoreline. Engineering and bioengineering techniques were coupled with marsh plantings for stabilization. Combinations of geotextiles, concrete/ stones, and bioengineering structures were used. Smooth cordgrass was planted in and around the protective material. Several miles of refuge shoreline protected.

Upper Mississippi River National Fish and Wildlife Refuge Complex, Winona, Minnesota in 1988
Dewatered maintenance dredged material was used for freshwater marsh and riparian restoration for an approximate area of 5,000 acres. Dredged material was used to plug eroded channels that were causing washout of fresh marsh within Weaver Bottoms, and to build waterfowl nesting islands that would also help break up wind fetch. The dredged material itself was used for structural support and erosion control.

Mouth of the Atchafalaya River, Louisiana at various times in the 1970's and 1980's
Maintenance dredged material used for marsh and bird island nourishment. Vegetation was allowed to colonize naturally (in case of bird islands, vegetation is not encouraged).

Similar projects in the UK are still rare in comparison. Several small scale intertidal recharge and creation schemes have been undertaken along the Suffolk and Essex coasts providing a beneficial use of material dredged from Harwich Harbour and the Blackwater Estuary for coastal defence and nature conservation purposes. Dredged material has been used in the creation of mudflats in Poole Harbour. A case study undertaken to investigate the potential for the use of clean dredged material for the creation of mudflat in a south coast bay in the UK concluded that there is significant scope for such projects in such locations (Paipai 1995).

In Japan, dredged material is used for creation of tidal flats or artificial lagoon in Osaka Bay. The benefits of the creation of artificial tidal lagoon include efficient use of dredged sand as well as facilitating water purification functions and restoration of ecosystem in the bay areas through biological process of benthic species.

It is also noted that reuse of sediment for creation of tidal flats or artificial lagoon has disadvantages including:-

- Metal sulphide soils generate sulphuric acid when exposed to oxygen during excavation;
- Disposed of at licensed premises with certified environmental management plans;
- Sediment type / quality and environmental conditions such as topography, habitat, salinity, organic matter, nutrients and dissolved oxygen need to be suitable for benthic species; and
- Site must be within suitable distance for transporting material.

6.6.5 Applicability in Hong Kong and Recommendations

Creation of artificial mudflats using uncontaminated or lightly contaminated sediments has been adopted as a sediment remediation option in the USA and the UK over the past 10 years. However there has been no case study in utilizing contaminated sediments for the formation of mudflats as there exists a high risk of an impact to the water quality and effect to the marine or wildlife habitat. Insufficient land suiting the mudflats poses a major difficulty in implementing this option. Because of high initial investment, high environmental impact to the marine habitats and lack of appropriate sites for mudflat creation, it is considered technically unfeasible for this method to be of general use in Hong Kong.

6.7 Re-use as Filling / Capping Materials for Restoration Projects

6.7.1 General

Dredged sediments are mixed with other proprietary materials to produce a topsoil. Manufactured top soil has been produced from dredged material, organic waste material, and biosolids (such as Bionsoil™ or N-ViroSoil™) according to a patented formulation.

High quality manufactured soil can be used, unrestrictedly, as topsoil for landscaping, lawns, parks, ballfields, golf courses, highways, street improvement, and bagged soil products.

Production costs estimated at approximately HK$200 per cubic yard, but do not include contamination reduction costs.

6.7.2 Advantages

- Beneficial and efficient use of dredged materials;
- Saving cost to purchase fill materials;
- Provide opportunities to restore habitat and water quality in areas;
- It could provide beneficial use for other waste products. Topsoil product can be sold to both municipalities and the public; and
- Dredged material kept in the confined disposal facilities (CDFs) can be emptied to provide storage capacity required for future waterway dredging.

6.7.3 Disadvantages

- High cost of determent/dewatering;
- Need to ensure dredged material is suitable for fill and pre-treatment may be required;
- Storage facilities for treated dredged material may be required; and
- Sediment type / quality and environmental conditions need to be suitable for flora and fauna species; and
- The process could handle relatively small (<5,000 cubic yard) per batch).

6.7.4 Case Histories

<u>Sonoma Baylands Tidal Marsh Restoration Project</u>

In the Sonoma Baylands Tidal Marsh Restoration Project (developed by the California State Coastal Conservancy and the Sonoma Land Trust), restored a bayland to its "historic" conditions using approximately 2 million cubic yards of clean dredged material from the San Francisco Bay area (ENTRIX et al., 1991; Urso and Mohan, 1996). Most of the dredged material (approximately 1.7 million cubic yards) came from the Port of Oakland's –42 foot project, and the remainder (approximately 0.25 million cubic yards) came from the Petaluma River. This uncontaminated material was placed in a 322 acre tidal wetland designed to aid two endangered species: the salt marsh harvest mouse, and the California clapper rail.

<u>Toledo Harbour</u>

Dredged material from Toledo Harbour has been tested and field demonstrated as manufactured soil with organic waste and N-ViroSoil™ biosolids.

Commercialisation of the process has been proposed to manufacture soil products from up to 800,000 cubic yard per year of dredged material from Toledo Harbour CDF Cell1.

The proposal will provide CDF storage space for at least 10 years of harbour dredging instead of constructing a new CDF; this will result in a substantial cost savings.

6.7.5 Applicability in Hong Kong and Recommendations

This method is unlikely to be of general use in Hong Kong because of high initial investment involved in treatment processes and lack of appropriate storage areas and restoration projects. Unless there is substantial opportunities for promoting restoration projects in Hong Kong there is little opportunity to further consider this management option.

6.8 Treated for Open Sea Disposal

6.8.1 General

Open sea disposal to the gazetted dumping grounds has been adopted in Hong Kong with the specified contamination level of the sediments satisfying the requirements stipulated in ETWB TCW No. 34/2002.

For the purpose of this management option, the contaminated sediments are firstly treated, usually with dewatering and/or other chemical treatments, to lower the contamination level such that they are suitable for open sea disposal through on field or laboratory tests stated in ETWB TCW No. 34/2002.

6.8.2 Advantages

- There are spare capacities for the gazetted open sea disposal sites in Hong Kong.

6.8.3 Disadvantages

- High cost of treatments would be involved though there has been no past application.
- Barges with treatment plant and/or nearshore treatment facility would be required for operation during the removal of contaminated sediments for prompt treatment before disposal.
- Substantial time required in treatment process and testing before ascertaining the treated material is suitable for open sea disposal.
- Treatments are usually contaminant specific and soil specific.
- No application in the jurisdiction worldwide.

6.8.4 Case Histories

There has been no past case in the jurisdiction worldwide by disposal to an open sea ground following treatments.

6.8.5 Applicability in Hong Kong and Recommendations

It is considered that this management option is technically infeasible for use in Hong Kong due to the sophisticated treatments involved which are contaminant and soil specific in nature.

7 Methodology in Assessment of Management Options

7.1 General

As discussed in Section 3.4 the generation and subsequent disposal of sediments resulting from various marine related works commonly applied in Hong Kong can be classified into the following three types:-

a) To increase water depth, e.g. for new shipping lanes, navigation channels and turning basin, anchorages, typhoon shelters, submerged structures, improved drainage in river channels and removal of siltation in harbours and fairways (maintenance dredging);

b) To provide a suitable foundation, e.g. for seawalls, drainage outfalls and other structures and general reclamation; and

c) To provide protection system for submarine utilities.

For case a) dredging is unavoidable and therefore only ex-situ treatment methods or disposal and beneficial reuse can be considered. The cases b) and c) fall into the avoidable category and therefore appropriate in-situ treatment methods can be introduced for different types of application to reduce the demand for disposal of contaminated sediments.

The management options described in Sections 4 to 6 that are considered to be applicable under each of the three types of marine activities listed above are assessed in detail in Section 8 below.

7.2 Pre-screening Assessment

It is considered reasonable to eliminate management options from a detailed scoring assessment which are considered to be principally impracticable in Hong Kong. In this manner a qualitative pre-screening exercise is firstly undertaken to review the practicability of each management option with respect to the local conditions by considering some or all of the following critical factors:

- Ability to cope with the estimated quantities of sediments that are expected to be generated over the next few years arising from the ongoing and known future projects;
- Ability to deal with the different nature and level of contaminants with consideration to the spatial variation within the Hong Kong waters;
- Lack of available land which is a restricting factor in the development of strategies for contaminated sediment management in Hong Kong; and
- Past experience of applications of such management option in Hong Kong governing its performance and effectiveness with respect to technology, workforce, management and statutory constraints.

Following this pre-screening process the remaining viable options will then be assessed by undertaking a scoring and ranking analysis, which is addressed in Section 7.3 below.

7.3 Scoring and Ranking Analysis

7.3.1 General

A scoring and ranking system has been established in order to objectively determine the five preferred options for managing contaminated sediments in Hong Kong from the recommended long-list of management options. Depending on the assessment results these preferred options will be put forward as proposed management options for field trials.

7.3.2 Parameters for Assessment

A set of key parameters reflecting the main tasks to be undertaken has been developed in Table 7.3.2 below. Each parameter carries a weighting to represent the relative significance and impact on the overall assessment criterion. In this manner each relative weighting also directly represents the percentage importance to the whole process.

An importance-weighting approach is proposed that classifies the parameters into three levels. These three levels are interpreted as "High", "Medium" and "Low" importance and assigned with relative weights of "6", "3" and "1" respectively. This weighing method has been adopted in a variety of government and private projects such as the Alignment review for the Shenzhen Western Corridor and the Option Review for Boundary Crossing Facilities for the Macau Landing Point of Hong Kong-Zhuhai-Macau Bridge.

The "High" importance parameters (weighting of 6) are those which are considered to be essential. The "Medium" importance parameters (weighting of 3) are those which are considered very important but not essential while the "Low" importance parameters (weighting of 1) are those that can normally be dealt with where the impacts are not significant.

Table 7.3.2 – Key parameters for assessment

No.	Parameter	Descriptions	Weighting
P1	Volume of Sediment	Volume of sediments that can be treated/handled by the management option	6
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	Flexibility of the management option to cater for the anticipated quantities of sediment disposal for the next few years	6
P3	Engineering Constraints	Degree of difficulties in construction stage including (1) Permanent works; (2) Temporary works requirement and access roads; and (3) Special plant and specially trained skilled labour	6
P4	Operational Restrictions	Degree of difficulties in operation stage	6
P5	Capital Cost	Relative costs and associated cost effectiveness for (1) Construction of the associated facilities; and (2) Resumption required to resume or reduce the land lots, allocations, reserves etc. that clash with the proposed facilities with respect to the management option	6
P6	Recurrent Cost	Relative costs for Operation/maintenance including management and environmental monitoring	6
P7	Programme	Time required for (1) Statutory procedures in implementing the option, (2) Detailed design; and (3) Construction	6
P8	Impact on Water Quality	The water quality impact resulting from the construction/operation of the management option	3

No.	Parameter	Descriptions	Weighting
P9	Impact on Marine Ecological Habitats/Species	The impact on marine ecology during the construction and operation stages including (1) Aquatic ecology such as Chinese white dolphin, Finless porpoise and Benthos in the vicinity; (2) Intertidal ecology; and (3) Terrestrial ecology	3
P10	Impact on Fisheries	Impact on fisheries during the construction and operation stages	3
P11	Risks on Human Health and Safety	Risks on human health and safety during the construction and operation stages	3
P12	Physical Properties of Sediment	Applicability of the management option in dealing with the sediment with typical physical properties for Hong Kong waters	3
P13	Nature and Level of Contamination	Applicability of the management option in dealing with the sediments with typical level of contamination for Hong Kong waters	3
P14	Sources and Locations of Contaminated Sediments	Effects of sources and locations of contaminated sediment on the implementation of the management option	3
P15	Impact to the Hong Kong Construction Industry	Experience and technology of local construction industry in constructing/operating the facilities related to the management option	3
P16	Legal, Environmental and Societal Constraints	Impact on the statutory legislations, environmental and public perception of the interested/affected parties such as local residents and environmental groups	3
P17	Impact to Energy Footprint	Impact on energy transfer and efficiency due to the implementation of management option	1
P18	Impact on Land Use	Amount of land requirement for the construction and operation stages. Effect of the management option on the existing land use, planned land use and future development potential of the assessment area	1

7.3.3 Rating for Each Parameter

An overall score is established for each parameter depending upon their relative impact on the management option with higher scores awarded for the perceived beneficial options. For this purpose a pre-weighting score between 1 and 5 has been assigned to each parameter depending on the impact. Table 7.3.3 summarizes the interpretation of the impact level assigned for each parameter with a rating between 1 and 5.

Table 7.3.3 – Rating Table for Each Parameter

Score	Quantities / Flexibility/ Applicability	Impact/ Risk/ Restrictions	Cost	Programme
	P1, P2, P12, P13	P3, P4, P8, P9, P10, P11, P14, P15, P16, P17, P18	P5, P6	P7
5	Very High	Very Low	Very Low	Very Fast
4	High	Low	Low	Fast
3	Medium	Medium	Medium	Medium
2	Low	High	High	Slow
1	Very Low	Very High	Very High	Very Slow

7.3.4 Scoring and Ranking System

The relative merits and demerits of each of the feasible options has been assessed and compared against each other based upon the key parameters described above. For this purpose an options evaluation matrix has been created to compare each option.

Having assigned a score (1 to 5) to each of the parameters according to Table 7.3.3, the result is multiplied by the relative weighting (1, 3 or 6) as shown in Table 7.3.2 from which a total score for each management option is derived by the addition of scores arising from each of the 18 parameters. The options have been ranked in accordance with the overall ratings.

8 Assessment of Management Options

8.1 Pre-screening Assessment

8.1.1 Marine Works involving the Increase of Water Depth

There is no alternative other than dredging if the water depth is required to be increased. Common maritime works involving this type of unavoidable dredging include the provision of new shipping lanes, navigation channels and turning basin, anchorages, typhoon shelters, submerged structures, drainage improvement in river channels and maintenance dredging with removal of siltation in harbours and fairways.

The management options that can be theoretically applied in these cases are those under the categories of ex-situ treatment as well as disposal and beneficial reuse, as described in Sections 5 and 6 respectively.

Ex-situ Treatment Options

(a) Mechanical dewatering is the simplest treatment process of separating solids from water. This method is effective in dealing with sediments with the natural level of contamination typically found in Hong Kong waters. However the investment and operation costs are anticipated to be high, and that the treated sediments after dewatering are still considered contaminated with a contamination level unacceptable by the existing landfills in Hong Kong. Therefore this method is considered infeasible and will not be assessed further.

(b) Physical separation is considered to be impractical in treating the contaminated sediments in Hong Kong as most of the sediments are predominately fine grained in silty or clayey form. This management option is fundamentally not feasible to treat the contaminated sediments within the Hong Kong waters and therefore should not be assessed further.

(c) Bioremediation is effective in eliminating organic contaminants, but not effective in reducing concentrations of heavy metal contaminants. This is a major deficiency of this treatment option as heavy metals are one of the main contaminants of concern in Hong Kong. In addition, the products arising from biodegradation may be more toxic than the original materials which will require further treatment. These key disadvantages, together with the high investment and operation costs, lack of application in Hong Kong and land requirements to accommodate large reactors/ponds/containers make this option technically and practically infeasible.

(d) Chemical treatment is contaminant-specific and therefore has limited use in treatment of inorganic contaminants since the toxic compounds cannot be destroyed. For organic chemical treatment, the operation requires precise control of the chemical reaction process and may trigger unwanted reactions to occur. The existing Chemical Waste Treatment Centre (CWTC) at Tsing Yi handles only chemical wastes and thereby is not suitable for treating contaminated marine sediments. It does not appear to be cost effective to build a new facility to treat the contaminated sediments in this manner and therefore Chemical treatment is not recommended as a viable management option.

(e) Brick making involves the mixing of the contaminated sediments to be treated with natural clay materials. In view of the limited market for bricks in Hong Kong this option is not considered cost effective. The option is also unable to cope with the expected volumetric demands for treatment of contaminated sediments arising from the dredging work for navigation use and maintenance dredging for the coming few years. Hence, unless the annual volume of contaminated sediments is reduced substantially this management option is not recommended.

(f) Thermal destruction/Incineration does not remove heavy metal contamination in sediments and is often associated with air pollution problems associated with the emissions from the thermal reaction. A high temperature incinerator is located at the Tsing Yi CWTC for the treatment of highly contaminated chemical waste in landfills which may be employed for treating contaminated sediments generated from dredging. However, the current capacity of such facilities is limited to about 100,000 tonnes of chemical wastes per year, which is equivalent to about 63,000m^3 of marine mud. According to the forecast of contaminated sediments for disposal the average annual contamination for the next 5 years is about 1,500,000m^3. This is clearly insufficient to fulfil the requirements for the annual treatment demands of around 1.5Mm^3.

(g) Sediment washing is most effective in handling coarse sand and gravel, and least effective in treating fine particles such as clay and silt. However it is noted that most of the sediments in Hong Kong are of fine grained and low permeability nature. In addition, the method becomes ineffective to treat sediments with high contamination levels and is very costly. The method is therefore determined to be not fundamentally viable to be applied in Hong Kong.

(h) Immobilization / Solidification / Stabilization utilize the technologies developed in solidification and stabilization and apply them in treating the contaminated sediments. The combined treatment process of solidification and stabilization, usually named Immobilization, is ineffective in treating sediments containing organics contaminants and moisture content of greater than 50%. However these are typical natural and physical properties of contaminants in the Hong Kong waters as shown in Section 2 above. In this connection this method is not further considered.

(i) Use of geosynthetic-based product has been used in Hong Kong for handling of contaminated sediments and dumping to the contained aquatic disposal. However this method has never been utilized for open sea disposal due to high cost involved and the uncertainty in long-term performance using geosynthetic-based products that may cause leakage and hence pollutants leakage to the adjoining water. It is therefore recommended not to proceed for assessment with this option.

<u>Disposal and Beneficial Reuse</u>

(a) Confined marine disposal, the most commonly adopted management option for dealing with contaminated sediments generated from the dredging work in Hong Kong is a viable option and will be assessed by going through the scoring and ranking exercise.

(b) Reusing sediments dredged from seawall construction as filling materials for reclamation is not applicable for this category of marine works.

(c) Confined nearshore disposal and poldering are technically feasible because of their cost-effectiveness compared to other treatment options. However the major drawback of this option is lack of suitable available coastal sites and land in Hong Kong which makes this option infeasible. The "Fill Management Study Phase I" carried out in 1990 proposing poldering in Deep Bay has not been pursued due to environmental and societal impacts to the nearby residents and ecology.

(d) Reuse of the marine sediment as construction fill is a management option utilizing the separation and dewatering techniques to treat the contaminated sediments. The option is feasible though costly in handling the dredged sediments especially when selective dredging might be necessary as an initial screening process for different reuse purposes. From past experience there has been very little enthusiasm in the industrial and commercial communities to accept the reuse of dredged sediments as construction fill. The feasibility of implementation is hence very politically driven and would need clear incentives for its adoption.

(e) Sanitary landfill cover could be an option if only a small amount of dewatered sediments is deposited to the landfill sites as covering materials. Nevertheless pre-treatment to dewater the contaminated sediments have to be undertaken so essentially mechanical dewatering technique and its associated impacts on land use, technology and economics are to be carefully considered before implementation.

(f) Creation of artificial mudflats using uncontaminated or lightly contaminated sediments has been adopted as a sediment remediation option in the USA and the UK over the past 10 years. However there has been no case study in utilizing contaminated sediments for the formation of mudflats as there exists a high risk of an impact to the water quality and effect to the marine or wildlife habitat. Insufficient land suiting the mudflats poses a major difficulty in implementing this option and as such it would have no scope for further development.

(g) Reuse as filling / capping materials for restoration projects has been developed in the North of America but not in Hong Kong. This method, like the option for reusing sediments as construction fill, requires a confined disposal facility to pre-treat the sediments in order to produce a material suitable for reuse. Unless there is substantial opportunities for promoting restoration projects in Hong Kong there is little opportunity to further consider this management option.

(h) Treated for open sea disposal can hardly be applied primarily due to the high costs involved in different treatments (treatments are also soil and contaminant specific) in order to reduce the contamination level suitable for open sea disposal which is considered a highly demanding process. Substantial time is also required in treatments and further testing before ascertaining the suitability of sediments for open sea disposal. In this regards this option is considered not viable and will not be assessed further.

Summary of Pre-screening Assessment

Non-removal options	Applicability	Further Assessment
All Non-removal options	• Dredging is unavoidable hence Non-removal options are not applicable	No
Ex-situ treatment options	**Applicability**	**Further Assessment**
Mechanical dewatering	• High investment and operational costs • Treated sediments are still with contamination level not accepted by landfills	No
Physical separation	• Limited application to specific types of soil only	No
Bioremediation	• Not effective in reducing heavy metal contaminants • Further treatment required following bioremediation • High investment and operational costs • Land requirement for processing plant	No
Chemical treatment	• Contaminant specific and weak in treating organic contaminants • High costs and land requirement for a new processing plant	No
Brick making	• Requires natural clay material for treatment • Unable to cope with the quantities generated from dredging • Limited market for bricks	No
Thermal destruction/Incineration	• Ineffective in treating heavy metal contaminants • Generates air pollution • Unable to handle the annual treatment demand	No

Sediment washing	• Limited application to specific types of soil only • Costly in treating sediments with high contamination level	No
Immobilization /solidification /stabilization	• Contaminant specific and weak in treating organic contaminants and soil with high moisture content	No
Use of geosynthetic-based product	• High cost • Uncertainty in long-term performance of geosynthetic-based product	No
Disposal and beneficial reuse options	**Applicability**	**Further Assessment**
Confined marine disposal	• Technical viable • Proven success at East Sha Chau	Yes
Reusing sediments dredged from seawall construction as filling materials for reclamation	• Only for general reclamation work	No
Confined nearshore disposal and poldering	• Lack of suitable coastal sites • High environmental and societal impact	No
Reuse of the marine sediment as construction fill	• Feasible though costly involving selective dredging • Effectiveness is dependent on demand	Yes
Sanitary landfill cover	• Feasible only if small amount of dewatered sediments is involved • Pre-treatment still required	Yes
Creation of artificial mudflats	• No past application in Hong Kong • High water quality impact and detrimental effect to marine habitat • Insufficient land suitable for mudflats formation	No
Reuse as filling / capping materials for restoration projects	• Pre-treatment required • Limited demand for restoration projects	No
Treated for open sea disposal	• High costs involved in various treatment processes • Substantial time required in treatment and testing before ascertaining the suitability for open sea disposal	No

8.1.2 Marine Works involving the Provision of Foundations and Reclamation

Dredging works associated with the provision of suitable foundation systems for seawalls, drainage outfalls and other structures and general reclamation are considered to be avoidable. With the exception of the viable management options outlined in the section on ex-situ treatment and disposal and beneficial reuse, the adoption of non-removal techniques by reducing the amount of contaminated sediments to be disposed of has been commonly exercised in many jurisdictions worldwide particularly for reclamations normally involving a substantial amount of sediments to be handled.

Non-removal Options

All the management options, detailed in Section 4, are applicable to cases involving general reclamation and foundations construction and hence should be given an opportunity for further review with the exception of the following options:

- Monitored Natural Recovery;
- Stabilisation with Flyash, Lime and/or Cement; and
- Electrostabilization and Electrohardening

The options relating to submarine utilities installation are assessed in Section 8.1.3.

(a) Monitored Natural Recovery is an option with the sediments being left in place and a continuous monitoring of the natural recovery progress. Without introducing some kind of ground improvement works to the untreated ground it is considered technically infeasible to be applied in reclamations where the land is required for future development with long term settlement a major concern.

(b) Stabilisation with flyash, lime and/or cement is basically an in-situ application of Immobilization method. The method has no application in the treatment of in-situ contaminated marine sediment and is considered to have no advantageous effect over the more frequently applied options of Deep cement mixing and lime piles and therefore will not be further assessed.

(c) Electrostabilization and Electrohardening, often called Electroremediation, is primarily used to eliminate inorganic contaminants and low concentrations of organic compounds which is a concern with the consideration that the sediments in Hong Kong waters usually contain both organic and inorganic contaminants, as well as heavy metals. With only limited field applications to date, it has not been demonstrated to be feasible. Hence there are currently little successful case histories and no cost references available for the use of this technique.

Ex-situ Treatment Options

The pre-screening process for ex-situ treatment options for the marine works involving the provision of foundations and general reclamation is the same as that given in Section 8.1.1 and is not repeated here.

Disposal and Beneficial Reuse

The pre-screening process for disposal and beneficial reuse options for the marine works involving the provision of foundations and general reclamation is almost the same as that given in Section 8.1.1 except the option described below.

(a) Reusing sediments dredged from seawall construction as filling materials for reclamation is considered to be infeasible in view of the soft nature of the dredged sediments that would cause intolerable settlement to the reclamation during the construction and operation stages. Pre-treatment will also be required to remove the contaminants to prevent humans from toxic exposure.

Summary of Pre-screening Assessment

Non-removal options	Applicability	Further Assessment
Leave the sediments in place (Monitored natural recovery)	• No value for future development without ground improvement	No
Band drains with surcharging	• Technical feasible • Fruitful experience in Hong Kong	Yes
Deep cement mixing	• Technical feasible • Costly application • Dependent on site specific ground conditions	Yes
Vibro-replacement/ Vibro-displacement lime piles	• Technical feasible • Costly application • Dependent on site specific ground conditions	Yes

Granular pile - stone columns and sand compaction pile	• Technical feasible • Some past full-scale applications for stone column, but currently no experience on sand compaction pile in Hong Kong	Yes
In-situ capping	• Technical feasible • Application only likely for land with limited after-use	Yes
Stabilisation with flyash, lime and/or cement	• No application in the treatment of in-situ contaminated sediments • Not preferable compared to DCM in terms of ease of implementation, cost and environmental impact	No
Vacuum dewatering system	• Technical feasible • Dependent on site specific conditions	Yes
Electrostabilisation and Electrohardening	• Contaminant specific process • Very limited field applications worldwide	No
Pipe jacking	• Only for submarine utilities installation	No
Pipe jetting	• Only for submarine utilities installation	No
Horizontal directional drilling	• Only for submarine utilities installation	No
Suction can method	• Technical feasible • Dependent on site specific ground conditions	Yes
Ex-situ treatment options	Applicability	Further Assessment
All Ex-situ treatment options	• Same as the Summary in Section 8.1.1	No
Disposal and beneficial reuse options	Applicability	Further Assessment
Reusing sediments dredged from seawall construction as filling materials for reclamation	• Pre-treatment required • Materials too soft for reuse which will cause soft ground and settlement concerns	No
Confined marine disposal	• Same as the Summary in Section 8.1.1	Yes
Reuse of the marine sediment as construction fill	• Same as the Summary in Section 8.1.1	Yes
Sanitary landfill cover	• Same as the Summary in Section 8.1.1	Yes
All other Disposal and beneficial reuse options	• Same as the Summary in Section 8.1.1	No

8.1.3 Submarine Utilities Installation

Where utilities such as water mains, stormwater pipes, sewerage, gas, cables etc. are to be installed across the harbours or fairways a proper protection system is required against strong water currents, collision from vessels, anchor related damages and attack by large fish or marine mammals.

Conventional submarine utilities installation is undertaken by forming pre-pipelay trench typically using a dredging method, followed by mechanical backfilling with gravels or armour rocks depending on the locations where the submarine utility passes through. More stringent protection and burial requirements are to be adopted when the utility section encounters marine navigation channel or gazetted sand borrow areas.

Non-removal Options

Pipe jacking, pipe jetting and horizontal directional drilling are considered as relevant alternatives to dredging for submarine utilities installation. They are readily applicable all around the world including Hong Kong and therefore it is worthwhile to undergo the scoring and ranking exercise for these options.

Ex-situ Treatment Options

The pre-screening process for ex-situ treatment options for submarine utilities installation is the same as that given in Section 8.1.1 and is not repeated here.

Disposal and Beneficial Reuse

(a) Confined marine disposal is still viable and cannot be completely replaced by the advanced non-dredged methods where the submarine utility is approaching the shore or landfall. However the quantities of dredging and hence disposal are greatly reduced with the maximal use of non-dredged methods.

(b) Reusing sediments dredged from seawall construction as filling materials for reclamation is irrelevant to submarine utilities installation.

(c) For a review of the feasibility and effectiveness of other management options under the Disposal and Beneficial Reuse category reference should be made to Section 8.1.1.

Summary of Pre-screening Assessment

Non-removal options	Applicability	Further Assessment
Pipe jacking	• Technical feasible • Applications are dependent on ground conditions, pipe size, working length etc. • No application in Hong Kong for marine-based works	Yes
Pipe jetting	• Technical feasible • Applications are dependent on ground conditions, trench depth, water depth and degree of pollutants spreading out. • Some applications in Hong Kong for marine-based works	Yes
Horizontal direction drilling	• Technical feasible • Applications are dependent on ground conditions, pipe size and type, working length etc. • Some applications in Hong Kong for marine-based works	Yes
All other Non-removal options	• Not relevant to submarine utilities installation	No
Ex-situ treatment options	**Applicability**	**Further Assessment**
All Ex-situ treatment options	• Same as the Summary in Section 8.1.1	No
Disposal and beneficial reuse options	**Applicability**	**Further Assessment**
Confined marine disposal	• Technical viable • Proven success at East Sha Chau • Use in shore approaching sections or landfall even if non-dredged option is used	Yes

Reusing sediments dredged from seawall construction as filling materials for reclamation	• Not relevant to submarine utilities installation	No
Reuse of the marine sediment as construction fill	• Same as the Summary in Section 8.1.1	Yes
Sanitary landfill cover	• Same as the Summary in Section 8.1.1	Yes
All other Disposal and beneficial reuse options	• Same as the Summary in Section 8.1.1	No

8.1.4 Recommendations for Scoring and Ranking Assessment

The table below summarizes the management options that are to be assessed in the scoring and ranking system following pre-screening.

Table 8.1.4 – Management Options for Scoring and Ranking Assessment

	Marine Works Involving the Increase of Water Depth **"Unavoidable"**	**Marine Works Involving the Provision of Foundations and Reclamations** **"Avoidable"**	**Submarine Utilities Installation** **"Mixed"**
Non-removal	N/A	Band Drains with Surcharging Deep Cement Mixing (DCM) Vibro-replacement / Vibro-displacement Lime Piles Granular Pile - Stone Column and Sand Compaction Pile In-situ Capping Vacuum dewatering system Suction Can	Pipe Jacking Pipe Jetting Horizontal Directional Drilling
Ex-situ Treatment	N/A	N/A	N/A
Disposal and Beneficial Reuse	Confined marine disposal Reuse as construction fill Sanitary landfill cover	Confined marine disposal Reuse as construction fill Sanitary landfill cover	Confined marine disposal Reuse as construction fill Sanitary landfill cover

8.2 Scoring and Ranking Assessment

Following the pre-screening assessment, a scoring and ranking assessment has been conducted on each of the remaining management options to determine its overall ranking with the consideration of the 18 key parameters identified in Section 7.

8.2.1 Marine Works Involving the Increase of Water Depth

A comparison of the 3 viable management options for this kind of works considering the 18 key parameters is shown in Appendix A and the table below:

Option	**Confined Marine Disposal**	**Reuse as Construction Fill**	**Sanitary Landfill Cover**

Total Score	263	191	172
Rank	1	2	3

Based on the score table, it is found that Confined Marine Disposal has the highest score of 263 which is significantly higher than the scores for the others (scores of 172 to 191).

Confined marine disposal for contaminated sediment has been applied successfully in Hong Kong in the past 15 years. Since the operation of the first contaminated mud pit in December 1992, a total of 40Mm^3 of contaminated mud has been deposited safely in the facility with close environmental monitoring and control of the disposal and capping operations. It is the cheapest and most technically feasible option amongst the others with mature technology and workforce developed. In terms of environmental impact, it has been demonstrated with independent studies and intensive monitoring records that there are no adverse trends in contaminant levels in water, marine sediment or marine life near the disposal facility. The facility is considered to be successful in isolating contaminated sediment from the marine environment.

It is therefore recommended that Confined marine disposal should be continuously adopted in Hong Kong in handling the contaminated dredged sediment involving an increase of water depth.

8.2.2 Marine Works Involving the Provision of Foundations and Reclamation

The scores given to the 10 viable management options for this kind of works are presented in the score tables below and shown in Appendix B.

Option	Band Drains with Surcharging	Vacuum Dewatering System	Granular Pile (Stone Column and Sand Compaction Pile)	Suction Can	Confined Marine Disposal	Deep Cement Mixing
Total Score	325	295	279	258	254	252
Rank	1	2	3	4	5	6

Option	In-situ Capping	Vibro-replacement/ Vibro-displacement Lime Piles	Reuse as Construction Fill	Sanitary Landfill Cover
Total Score	243	240	163	144
Rank	7	8	9	10

For reclamation works on soft ground, non-dredged methods coupled with various ground improvement options generally have higher scores than the ex-situ treatment and disposal and beneficial reuse options involving dredging. Amongst the viable options, the most commonly used system using Band drains with surcharging is rated top of the list (Score 325). Vacuum dewatering system (or sometimes called Band drains with vacuum preloading) and Granular Pile (Stone Column and Sand Compaction Pile) are Rank Second (Score 295) and Third (Score 279) respectively. The ground improvement options are particularly outstanding with regard to their negligible impact to the water quality, marine ecology, fisheries, human health, safety, energy use and land use and are usually independent of the volume of sediment to be handled. The investment and operational costs associated with ground improvement works are generally low compared to the other treatment options. In recommending options for field trials it is noted that although Band drains with surcharging has been given the highest score it is considered that no further assessment to its feasibility and performance is necessary in view of its past success in Hong Kong and all over the world.

Deep cement mixing (Score of 252) is ranked closely to the top three ground improvement methods with slightly lower scores received than the conventional Confined marine disposal option (Score of 254). DCM has been well developed in the Mainland China and Japan. With the numerous amount of research that has been undertaken on this system in the past it is considered worthwhile to study its feasibility and overall effectiveness by field trial in Hong Kong.

Confined marine disposal continues to have the highest ranking (Rank 5^{th}) other than the top four non-removal options because of the successful past experience and ease of implementation. It is recommended that for the dredging work involving reclamations which is avoidable Confined marine disposal shall be minimized as much as possible in order to promote the government's policy of minimizing dredging and alleviate the pressure on the demand of mud pits.

For marine foundations works, the Suction can is given a moderately high Score of 258 for its low impact induced to the water quality and marine ecology and flexibility during operation stage. Although there is no past experience of using suction cans in Hong Kong it is presently being proposed as a foundation system for a new offshore wind mast in Hong Kong by CLP Co. Ltd. Subject to the ongoing liaison with the local statutory bodies and trial tests this is believed to be a viable foundation type for the development of marine structures in Hong Kong.

8.2.3 Submarine Utilities Installation

The scores and ranking determined for the 6 viable management options for submarine utilities installation is tabulated here and shown in Appendix C.

Option	Horizontal Directional Drilling	Pipe Jacking	Pipe Jetting	Confined Marine Disposal	Reuse as Construction Fill	Sanitary Landfill Cover
Total Score	322	316	280	257	173	154
Rank	1	2	3	4	5	6

It is noted that the non-dredged method using pipe jacking, pipe jetting and horizontal directional drilling have higher scores than the Confined marine disposal option (Scores of 280 to 322).

Confined marine disposal, having a Score of 257, is ranked immediately after the non-dredged options. Owing to the potential impacts on water quality, marine ecology and fisheries, and the need of creation of new mud pits it is recommended to, wherever possible, adopt the non-dredged submarine utilities installation methods.

Among the 3 non-dredged methods, horizontal directional drilling has been applied in Hong Kong for a few numbers of submarine utilities installation projects whereas 2 local projects have been identified for past application of Pipe jetting. Whilst Pipe jacking has been used frequently in land application it has never been adopted in submarine pipeline installation in Hong Kong. In view of little local experience of applying these techniques in the field of submarine utilities installation and their specific limitations in working length, pipe sizes and ground condition, sufficient implementation and verification with field trials and on-site applications to ascertain their effectiveness with respect to the local environment and conditions is needed before they can be considered as readily applicable in Hong Kong.

Since pipe jacking and pipe jetting have been rarely applied in Hong Kong in the submarine utilities installation field and considering that an assessment on the degree of pollutants spreading using the pipe jetting method is of utmost importance to assess its effectiveness and overall impact on the water quality, ecology and fisheries it is recommended to carry out a field trial on the Pipe Jetting option.

9 Recommendation and Conclusion

- The study is to explore and review the management options in Hong Kong and the jurisdiction worldwide in dealing with the contaminated sediments generated from different marine works in Hong Kong.
- A review of the concentration level, nature, spatial variation and level of contamination for the contaminated sediments in the Hong Kong Waters has been carried out. The current government regulations, statutory procedures and mode of operation in managing the contaminated sediments in Hong Kong have been reviewed.
- A detailed desk study of management options available worldwide for contaminated sediments has been carried out with respect to the categories of Non-removal, Ex-situ treatment and Disposal and Beneficial reuse. Table 9.1 below summarises the merits/demerits of each of the management options together with remarks on their approximate unit costs, if available, and a conclusion as to its applicability in Hong Kong.
- To assess and compare the viable options with respect to different types of marine works in Hong Kong the management options have been allocated to three categories (1) Marine works involving the increase of water depth; (2) Marine works involving foundations and general reclamations; and (3) Submarine utilities installation. An assessment entailing a pre-screening exercise and scoring and ranking system has been carried out.

Marine Works involving the increase of water depth

- As described in Section 8, there are various options other than the conventional Confined marine disposal which are considered feasible in dealing with the contaminated sediments under this category, namely Reuse as construction fill and Sanitary landfill cover. These options possess various limitations and disadvantages over the Confined marine disposal option such as high investment and operation costs, small amount of sediments that can be treated and little enthusiasm in the society in receiving the treated materials both in terms of size of treated materials and suitability of these materials for particular reuse.
- Confined marine disposal, on the contrary, has been applied successfully in Hong Kong in the past 15 years. It is the cheapest and most technically feasible option amongst the others with mature technology and workforce developed. It has also been demonstrated with independent studies and intensive monitoring records that there are no adverse trends in contaminant levels in water, marine sediment or marine life near the disposal facility. It is therefore concluded that for marine works involving the increase of water depth the conventional Confined marine disposal is considered to be the most viable option and should be continuously adopted.

Marine Works involving foundations and general reclamations

- With reference to Section 8, for reclamations and marine foundations the non-dredged options outweigh the others with particular higher scores on Band drains with surcharging, Vacuum dewatering system, Granular Pile (Stone Column and Sand Compaction Pile) and Deep cement mixing. Except the Band drains with surcharging option, these viable non-dredged options shall be subject to sufficient implementation and verification with field trials and on-site applications to ascertain their effectiveness with respect to the local environment and conditions before they can be readily applied. The time frame in getting these management options readily applicable in Hong Kong is reasonably anticipated to be 3 to 5 years.

- Amongst all the feasible non-dredged options only the Band drains with surcharging option is considered to be readily applicable in Hong Kong since it has been successfully applied in reclamations over the past 20 years. However, even if this common option is adopted there would still be some disposal demands for seawall foundation and other associated constructions, and therefore Confined marine disposal might still need to be exercised in this regard.
- It is expected that, whilst Band drains with surcharging is proved to be not favourable for a particular reclamation project during the transition period with all other feasible management options not readily available, Confined marine disposal may still be required in certain circumstances. The above is also applicable to the introduction of suction can method for marine foundations.

Submarine Utilities Installation

- Following the assessment in Section 8, it is found that the advanced non-dredged methods using Pipe jacking, Pipe jetting and Horizontal directional drilling have higher scores than the Confined marine disposal option. Therefore, it is recommended that they should be adopted in the field of submarine utilities installation as much as possible in lieu of the conventional dredging and backfilling method involving marine disposal demand.
- Among the 3 non-dredged methods, horizontal directional drilling has been applied in Hong Kong for a few numbers of submarine utilities installation projects whereas 2 local projects have been identified for past application of Pipe jetting. Whilst Pipe jacking has been used frequently in land application it has never been adopted in submarine pipeline installation in Hong Kong.
- In view of little local experience of applying these techniques in the field of submarine utilities installation and their specific limitations in working length, pipe sizes and ground condition, sufficient implementation and verification with field trials and on-site applications to ascertain their effectiveness with respect to the local environment and conditions is needed before they can be considered as readily applicable in Hong Kong. Again, the time frame in getting these management options readily applicable in Hong Kong is anticipated to be 3 to 5 years. Therefore, it is expected that, whilst none of these non-dredged methods is considered to be feasible for a particular submarine utilities installation project during the transition period, Confined marine disposal may still be required in certain circumstances.

Recommendation for Field Trials

- With consideration of applications in different types of marine works it is recommended to exercise field trials for the following five management options – (1) Vacuum dewatering system; (2) Granular Pile - Sand Compaction Pile; (3) Deep cement mixing; (4) Suction Can; and (5) Pipe jetting. They will be put forward as implementation plan to identify the purpose and scale of the trials that would be required, and the suitable testing/monitoring proposals to be established.

Table 9.1 – Summary of Management Options for Contaminated Sediments

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
1. Non-Removal Options				
1.1) Leave-in-Place with Monitored Natural Recovery	- Minimizes risk from handling and disposal of contaminated sediments. - Avoids environmental impacts generated by the by-products from treatments. - Most economical option.	- Relies on natural process such as input of uncontaminated sediments, thus requiring longer time to complete the process. - Requires long term water quality monitoring. - No development value for future land use.	Not available	- Technical feasible. - No development value in future.
1.2) In-situ Treatment – Band drains with Surcharging	- High permeability to permit rapid dissipation of pore water pressure. - Sufficient flexibility to accept large vertical and lateral ground movement. - It does not cause so many disturbances as to make the surrounding soil too impermeable for the drain to be effective. - It has the ability to function for a few months up to two years. - It has adequate drain characteristics and has filters that do not become clogged by the surrounding fine-grained soils.	- Surcharge fill may need to be placed in stages thus requires more time. - Risk of soil squeezing may make the drain discontinuous. - Unknowns in their mechanical, hydraulic and durability properties. - No international standard available. - Prefabricated drains can deteriorate under bacteriological or chemical attack. - Discharge capacity of filters may be reduced by over 60% in less than a year in organic ground (BSI, 2007). - The ground is disturbed with the installation of the drain. - Distortion, folding and kinking of drains may reduce the discharge capacity. - The thickness of sediments that can be treated effectively by this method will depend on the limiting depth of the band drain installation which is typically limited to maximum 30m.	Band drain as HK$160/no. for a 20m long 100mmx10mm section. Surcharge as HK$15/m^3	- Technical feasible. - Fruitful applications in Hong Kong such as Chek Lap Kok airport, Pak Shek Kok reclamation, Penny's Bay reclamation stage 2.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
1.3) In-situ Treatment – Deep Cement Mixing (DCM)	- Dredging and filling not required. - The weight of treated soil is basically unchanged, and hence, no additional surcharge will be induced on the underlying soil strata. - It is flexible in application and can suit different soil properties and engineering requirements. - Soft sediment can be improved to a required strength. - It would not cause lateral displacement of the soil being treated. - Minimal disturbance to the surrounding structures.	- The cost may be several times higher than that of a conventional dredging scheme. - Stringent quality control and monitoring is required. - Field trials may be necessary. - May not work properly in ground with obstructions. - Investigation is required to assess the environmental impacts. - It does not work well in certain soils, (e.g. high organic content or acidic soils). - Quantity of spoils generated may be large and require special treatment.	*Unit cost:* JY7,000 - 9,000/m^3 [i.e. approx. HK$500 -$ 650/m^3] excluding mobilisation/ demobilisation costs; and *Operational cost:* HK$0.65M per 24-hour-working day for large deep cement mixing barge (including staff and fuel cost but excluding material cost) and HK$0.10M per 12-hour-working day for medium-class barge (excluding both staff cost and material cost). Both based on projects in Japan (W. T. Yeung and K. S. Tam, 2006)	- Technical feasible. - Only used in Hong Kong at trial scale except the construction of a section of the Lantau and Airport Railway cut and cover tunnels at Central. - Applications are dependent on site-specific ground conditions.
1.4) In-situ Treatment – Vibro-replacement / Vibro-displacement Lime Piles	- Offers seismic stability by reducing soil liquefaction risk. - Enhances soil bearing capacity and slope stability. - Requires short mobilization and execution periods. - Allows foundation construction to start almost immediately. - Allows flexibility in case of design changes. - Can be used to treat almost all soil types.	- Lime columns suffer similar disadvantages as deep cement mixing motioned in 1.3. - Lime columns can act as drains, and their bearing capacity can decrease with time because of leaching by slightly acidic groundwater. - The cross-sections of the columns can be non-uniform with depth, as a result of variations in chemical reaction. It can be cracked in layers at every 20-50mm and be weakest in the centre.	Not available	- Technical feasible. - Applications are dependent on site-specific ground conditions.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
1.5) In-situ Treatment – Granular Pile (Stone Column and Sand Compaction Pile)	- Granular piles share the external loads with the native soil in the form of a composite foundation, and hence the method effectively utilizes the original ground without dredging in principle. - It immediately increases the rate of settlement of the soil in the presence of sand and gravel that acts as drainage material. - It is flexible in application because the diameter and spacing of the granular piles can be easily adjusted to suit different site conditions.	- The method is more costly than the conventional dredging method, although it may be cheaper than the deep cement mixing method. - Granular piles in the form of stone column may not be feasible if the strength of the soil to be treated is too low; whilst sand compaction piles may not be applicable for soils with SPT-N values exceeding 15 to 25. - Stringent quality control is required. - Installations may cause lateral or upward soil displacement and result in heaving of the seabed. - The soil in the vicinity of the granular piles may be disturbed leading to reduced strength.	Approx. HK$250/m for a 500mm size onshore stone column, including mobilisation costs Cost data for sand compaction pile is not available.	- Technical feasible. - Granular pile in the form of stone column was used in Hong Kong in Penny's Bay reclamation and Deep Bay Link. There is however no current experience with the use of sand compaction pile in Hong Kong.
1.6) In-situ Treatment – In-situ Capping	- A relatively simple process to carry out. - Generates minimal pollution during application. - Works well in sealing a variety of sediment bed types and a broad range of chemical pollutants.	- It is a relatively new remediation method and research is still on-going. - Mixing and consolidation of the underlying sediment squeezes contaminated water out. - Poorly executed placement may not result in uniform/adequate coverage. - Toxic chemicals are left intact. - Stabilization by a layer of rocks may be needed for areas prone to erosion and sediment movement. - In-situ capping is no panacea for dealing with the problem of contaminated sediments. - The existing seabed level will be altered by overlying with imported materials.	Not available	- Technical feasible. - Application only likely for land with limited after-use.
1.7) In-situ Treatment – Stabilisation with Flyash, Lime and/or Cement	- It is applicable to mixed contaminants in a range of soils. - It can transfer difficult materials to a more manageable form. - Stabilised sediment could be allowed to remain in place and properly capped.	- It is not feasible in areas where solidified mass cannot be tolerated (e.g. future construction or dredging). - Large-scale use of the method has not been applied. Detailed investigation and research is needed.	US$15 – 160/$yd^3$ [i.e. approx. HK$152 - $1,620/$m^3$] based on proposal for a small scale immobilisation in Wisconsin, U.S. (EPA, 1994)	- Technical feasible. - Little applications around the world. - Not preferable compared to DCM in terms of ease of application, cost and environmental impact.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
1.8) In-situ Treatment – Vacuum Dewatering System	- No extra fill material needed. - Construction times are generally shorter. - It requires no heavy machinery. - No chemical admixtures would penetrate into the ground and hence it is an environmental friendly ground improvement method. - The vacuum can be removed immediately upon completion of the ground improvement. - Isotropic consolidation eliminates the risk of failure under additional loading of permanent construction. - No risk of slope instability. - The rate and magnitude of loading and settlement can be controlled.	- Deterioration of the membrane may cause difficulties in maintaining a vacuum. - Pressure applied is generally limited to 80 to 100kPa. - The thickness of sediments that can be treated effectively by this method will depend on the limiting depth of the band drain installation which is typically limited to maximum 30m.	Approx. HK$75 - $100/m^2	- Technical feasible. - Applications are dependent on site-specific conditions.
1.9) In-situ Treatment – Electrostabilisation and Electrohardening	- It is able to reduce large quantity of contaminated material to small amounts that are capable of treatment.	- The technique requires substantial borehole construction. - Only limited field applications to date. - Current applicability limited primarily to inorganics. - Application to insoluble and slightly soluble forms (e.g. hydroxides, sulphides) may be difficult.	Not available	- Technical infeasible due to limited application to specific types of contaminants only.
1.10) Submarine Utilities Construction – Pipe Jacking	- The method provides a flexible, structural, watertight, finished pipeline as the tunnel is excavated. - Minimal environmental disruption. - Greater safety due to engineered launch shaft. - Workable in difficult soils as no dewatering is required. - Intermediate shaft is normally not required.	- High capital investment. - Skilful operators are required. - For pipe sizes less than 1m, the practicable working length will be limited to 100m or less depending on ground condition. - Change in vertical profile is normally restricted by 200m in radius. - Disposal of a small quantity of sediments is still required.	Approx. HK$36,000/m for a 700mm dia. pipe	- Technical feasible. - Applications are dependent on ground conditions, pipe size, working length etc. - No application in Hong Kong for marine-based works.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
1.11) Submarine Utilities Construction – Pipe Jetting	- The process is fast. The speed of pipe installation is approximately 300m per day per jetting machine. - No limitation in water depth.	- Costly operations. - Trench width and depth are limited by 5m and 6m respectively using a medium-powered jetting machine. - Silt contained in sandy seabed may cause turbidity. - Seabed environment may suffer from the detrimental effects of silt precipitation. - Contaminants may leak into adjoining water and affect habitats nearby but would be controllable with carefully devised operational control measures.	Approx. HK$400/m excluding utilities cost	- Technical feasible. - Applications are dependent on ground conditions, trench depth, water depth and degree of pollutants spreading out. - Some applications in Hong Kong such as the Tolo harbour and Mirs Bay sections for Shenzhen to TaiPo submarine pipeline by Towngas.
1.12) Submarine Utilities Construction – Horizontal Directional Drilling	- Surfaces worth conserving are neither broken up nor damaged; restoration and repair are not required, which leads to high economical advantages. - Low social costs because detours are avoided. - Short equipping, drilling and construction time.	- A costly solution. - It can be used in a wide variety of ground and site conditions but is not the optimal method in all conditions. - Unconsolidated soils (e.g. cobble) will needs to be specially treated or grouted before drilling. - Workable pipe sizes diameter is restricted to 1.2m. - Maximum drive length is about 2000m. Beyond this distance intermediate shafts are required which makes the operation difficult in particular for marine applications in busy navigation channel or across harbours. - Change in vertical profile is normally restricted by 200m in radius. - Concrete pipes might be too rigid for this technique. - Disposal of a small quantity of sediments is still required.	Approx. HK$13,000/m for a 700mm dia. pipe	- Technical feasible. - Applications are dependent on ground conditions, pipe size and type, working length etc. - Some applications in Hong Kong such as WSD Sham Tseng to Ma Wan section, CLP Lantau to Ma Wan and Ma Wan to Sham Tseng sections and CLP Pui O Beach/Chi Ma Wan cable crossing.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
1.13) Advanced Foundation System – Suction Can Method	- Allows large diameter steel cans to be embedded in the soil relatively quickly. - Retrieval of suction can is possible after use.	- The foundation could be used for resisting light weight axial loadings only.	Not available	- Technical feasible. - Applications are dependent on site specific conditions. - The method will be adopted as the marine foundation for the offshore wind mast project initiated by CLP.
2. Ex-situ Treatment Options				
2.1) Mechanical De-watering	- The capacity is high and can be increased by using additional presses. - Installation requires small area. - The process is effective, efficient and mobile.	- Relatively high investment and operation costs. - Needs a processing plant. - The treated sediments after dewatering are still considered contaminated.	In the order of equivalent HK$100/$m^3$ excluding land disposal costs based on experience in METHA, Hamburg, Germany (GEO, 1997)	- Technical infeasible because the existing landfills do not receive contaminated sediments, even after certain treatment process to lower the degree of contamination.
2.2) Physical Separation	- It can reduce volumes of contaminated material requiring subsequent treatment, leading to lower handling and disposal costs. - Soil washing can be used to recover storage space for later reuse. -	- The original sediments should have a significant proportion of sand for the process to be cost effective. - It may not be an effective treatment for all sediments and does not destroy the contaminants themselves. - Potentially high investment and operational costs and a large area are required for setting up treatment plants and associated facilities.	US$23 - $54/$yd^3$ [i.e. approx. HK$233 - $548/$m^3$] for 10,000 to 100,000$yd^3$ of sediments with 75% clean sand & 25% contaminated silts/clays (U.S. Army Engineer Detroit District, 1994).	- Technical infeasible due to limited application to specific types of soil only.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
2.3) Bioremediation	- Eliminates contaminants permanently. - Minimise site disruption. - Allows a high treatment rates for PCB and PAHs.	- Currently limited understanding on the effect of bioremediation and its impact on the ecosystem; extensive investigation is needed. - Difficult to identify the cause and developing measures if the remediation is not successful. - Not suitable for soils containing metals. - High operational cost. It normally operated in batch mode and hence is very expensive. - Residue stream generated requires additional treatment. - By-Products may be more soluble and toxic than the original materials. - Potentially high investment and operational costs and a large area are required for setting up treatment plants and associated facilities.	-Slurry phase treatment at HK$650 - $1200/yd^3 [i.e. approx. HK$845 - $1560/m^3]. -Solid phase treatment at HK$400 - $650/yd^3 [i.e. approx. HK$520 - $845/m^3].	- Technical infeasible due to contaminant-specific nature.
2.4) Chemical Treatment	- Low Energy consumption. - Relatively rapid process.	- It is contaminant-specific and may be of limited applicability for mixed contaminants. - Natural soil constituents can be a limiting factor. - It may have marked effect on soil properties and its suitability for disposal or reuse. - Disposal of extracted contaminants is needed. than the original materials. - Potentially high investment and operational costs and a large area are required for setting up treatment plants and associated facilities.	Not available	- Technical infeasible due to contaminant-specific nature. - The existing Chemical Waste Treatment Centre (CWTC) at Tsing Yi, is not suitable for treating contaminated marine sediments.
2.5) Brick Making	- Both freshwater and marine sediments can be used.	- Full-scale production not yet available. - Needs processing plant and equal volume of natural clay.	Industry Estimates at HK$200 - $700/yd^3 [i.e. approx. HK$260 - $910/m^3] excluding contamination removal cost.	- Technical infeasible with applications depending on market demand for bricks and small quantities of treatment of contaminated sediments.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
2.6) Thermal Destruction / Incineration	- Incinerators typically achieve greater than 99% destruction for organics.	- Metals volatile at applied temperature can cause problems in air pollution control systems. - Alkali metals and phosphorus compounds can cause refractory attack. - Long residue time is required to deal with dioxin formation thus lengthening the overall thermal process. - Physical composition must be monitored. - Presence of organic halogens produces acidic gases and requires specific air pollution control provision. - Residual material (e.g. ash) would still need to be disposed in a landfill.	Treatment costs range from HK$3700 - $10,500/yd^3 [i.e. approx. HK$4810 - $13650/m^3].	- Technical infeasible due to contaminant-specific nature.
2.7) Sediment Washing	- Potential to treat wide variety of contaminants. - High removal efficiency over 90% for volatiles (organics) and 40-90% for semivolatiles (inorganics). - The process after blending could yield a product suitable for manufactured top soils.	- This process cannot efficiently treat fine particles, low-permeability packed materials, or sediment with high humid content. - The method is only useful for low to medium contamination levels. - Residual solvents and surfactants can be difficult to remove after washing. - High treatment cost. - Capacity to treat large volumes at an acceptable rate is unknown - Sediment washing typically entails the generation of by products, including over-sized debris, sludge and wastewater, which need to be treated and disposed of at existing waste and wastewater disposal facilities.	Treatment costs range from HK$1,600 - $3,200/yd^3 [i.e. approx. HK$2,080 - $4,160/m^3].	- Technical infeasible due to limited application to specific types of soil only.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
2.8) Immobilization / Solidification / Stabilisation	- Chemical isolation from biologically accessible environment. - Process is simple and there is a history of use for sludge. - Treated sediment in the form of concrete can be reused for public filling. - Contaminants removed from site will not limit the future use of the area. - Less expensive than chemical treatment, sediment washing and incineration.	- Sediments should have moisture content of less than 50% and the solidified volumes can be 30% greater than that of the starting material. - Highly contaminated sediments or sediments with high water content may need to be pre-treated. - Limitation in applicability to organic contaminants. - High organic contaminant levels may interfere with treatment for metal immobilization. - Need for placement of solidified sediments. - Chemistry of the contaminants may be changed to substances more susceptible to leaching. - Need for secondary treatment of the by-products such as wastewater, noxious emissions and solid waste. - Potentially high investment and operational costs and a large area are required for setting up treatment plants and associated facilities.	Estimated production costs range from HK$250 - $1,300/yd^3 for totalcontaminant of metals [i.e. approx. HK$325 - $1690/m^3].	- Technical infeasible due to contaminant and soil specific nature.
2.9) Use of Geosynthetic-based Product	- Spare capacity for open sea disposal.	- High cost of geosynthetic-based products involved. - Subject to deterioration in long-term which may cause potential pollutants leakage to the adjoining water body. - Geosynthetic-based product might not be applicable for different types of contaminants. - Past application only for contaminated mud pit disposal. - Sediments would have to be dewatered before placing the material inside the containers. - Confined marine disposal is needed for disposal of the contained sediments. - There are uncertainties on the retention of the sediments within the containers and leakage of contaminants both during dumping of the containers and afterwards prior to sealing of the mud pit. The natural seepage of methane gas would also be an unknown.	Not available	- Technical infeasible due to high cost, uncertainty in long-term performance and contaminant specific nature.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
3. Disposal and Beneficial Reuse Options				
3.1) Confined Marine Disposal	- Relatively lower cost and lower risk than in-situ and ex-situ treatments. - Placement of the dredged material to be stored can be fast. - This can avoid multiple sediment handling steps. - The sediment could be transported in the same device from which it will be discharged.	- Suitable disposal and capping site is required. - Dredging equipment for each case needs to be evaluated based on sediment and capping material characteristics and disposal site considerations. - The accuracy of placement relies on site-specific placement technique. - Water quality monitoring programme is required to minimise the risk of water pollution.	Approx. HK\$50/m^3	- Technical feasible. - Proven success at East Sha Chau with no adverse impacts to the environment through continuous monitoring.
3.2) Confined Nearshore Disposal/Poldering	- It does not require land for onshore disposal. - Less expensive than reuse cost and much cheaper than biological treatment and chemical treatment. - An attractive and cost effective method of dredged material disposal. - If properly located and constructed, they can isolate contaminated sediment from environment fairly well. - Some treatments can be applied in the confined disposal facility, such as biodegradation. - It can maintain efficient contaminant pathway control, facilitate efficient long-term monitoring of the dredge material and dewatering effluent, and allow easy access to material for removal and reuse.	- Turbidity caused from dredging may impact identification capacity and marine species. - Difficulties in finding a suitable space from nearshore disposal / poldering. - Restriction from local residents and government bodies - Transportation expenses. - Potential for contaminant migration into groundwater and plant and animal uptake of contaminants. - Potential for spreading exotic pest species. - Land with very limited after-use.	Costs range from HK\$40 - \$160/yd^3 [i.e. approx. HK\$52 - \$208/m^3].	- Technical infeasible due to lack of coastal area to accommodate the expected demand and limited future land use.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
3.3) Reuse as Construction Fill / Reusing Sediments Dredged from Seawall Construction as Reclamation Fill	- Efficient use of dredged mud. - Enhancement in water purification functions and restoration of ecosystem in bay areas through biological process of benthic species. - Saving cost to purchase construction fill and therefore reducing construction cost.	- High cost of determent/dewatering. - Need to ensure dredged material is suitable for fill. - Pre-treatment may be required. - Storage facilities for treated dredged material may be required. - Sediment type/quality needs to be suitable for benthic species. - It could change the physical and chemical characteristics of water and sediments, causing algal blooms, mortality to aquatic biota and bioaccumulation. - Site must be within suitable distance for transporting materials.	Estimated costs of using 150,000yd^3 of materials to produce grout to seal mines was $6.75M [i.e. approx. HK$460/m^3] based on a project in New Jersey (O'Donnel&Hennings,1999)	- Technical infeasible due to very high cost in treatment and selective dredging and limited future land use.
3.4) Sanitary Landfill Cover	- Efficient use of dredged material.	- Pre-treatment/dewatering of dredged material may be required. - Water content and quality of the sediment after dewatering/pre-treatment must fulfil all the landfill cover requirements stipulated by the government. - Assessment of permeability and chemistry of the dredged material is required. - Treatment of leachate required.	HK$200 - $300/tonne excluding costs for dewatering (CEDD, 1997)	- Technical feasible. - Applications are dependent on landfill capacity.
3.5) Creation of Artificial Mudflats	- It can provide opportunities for habitat and water quality restoration.	- It have limited or no value for fish and wildlife due to the unpredictability and prolonged duration of exposure. - It may involve a "habitat tradeoff".	Not available	- Technical infeasible due to high environmental impact and insufficient land available.
3.6) Re-use as Filling / Capping Materials for Restoration Projects	- A means for beneficial and efficient use of dredged materials. - Saving cost to purchase fill materials. - Opportunities to restore habitat and water quality in areas. - Opportunities to free space in CDFs for future waterway dredging.	- High cost of determent/dewatering. - Need to ensure dredged material is suitable for fill and pre-treatment. - Storage facilities for treated dredged material may be required. - Sediment type/quality and environmental conditions need to be suitable for flora and fauna species.	Production costs estimated at approx. HK$200/$yd^3$ [i.e. approx. HK$260/$m^3$].	- Technical infeasible due to high initial investment involved in pre-treatment and lack of appropriate storage areas.

Management Options	Merits	Demerits	Approx. Unit Cost	Applicability in Hong Kong
3.7) Treated for Open Sea Disposal	- Spare capacity for open sea disposal.	- High cost of treatments involved. - Barges with treatment plant and/or nearshore treatment facility would be required. - Substantial time required in treatment process and testing before ascertaining the treated material is suitable for open sea disposal. - Treatments are usually contaminant specific and soil specific. - No application in the jurisdiction worldwide.	Not available	- Technical infeasible due to sophisticated treatments involved which is contaminant and soil specific in nature.

10 References

1. Aoki Corporation (1995), Lantau and Airport Railway - Soil Mix Wall Method Statement, doc. ref. 501/MS/05/003A dated November 1995, GEO file ref. 3/6/40/ part 2.

2. Arup and Scott. (2002) Agreement No. CE43/2000(CE) South East Kowloon Development Kai Tak Approach Channel Reclamation Design and Construction. Arup – Scott Wilson Joint Venture, November 2002.

3. Aspinwall. (1998) *A Study of Tributyltin Contamination of the Marine Environment of Hong Kong.* Final Report for Environmental Protection Department, The Government of the Hong Kong Special Administrative Region.

4. Averett, D.E., B.D. Perry, E.J. Torrey, and J.A. Miller. (1990) *Review of removal, containment and treatment technologies for remediation of contaminated sediment in the Great Lakes.* Miscellaneous Paper EL-90-25. Vicksburg, Mississippi: U.S. Army Engineer Waterways Experiment Station.

5. Binnie and CES. (1993) Agreement No. CE35/93 Environmental Monitoring and Audit Programme for Contaminated Mud Pit II at East of Sha Chau.

6. Blackmore G. (1998) *An Overview of Trace Metal Pollution in the Coastal Waters of Hong Kong.* The Science of the Total Environment. 214, 21-48.

7. Brandon D. L., Lee C. R., and Simmers J.W. (1992) *Long-term Evaluation of Plants and Animals Colonising Contaminated Estuarine Dredged Material Placed in Upland and Wetland Environments.* Environmental Effects of Dredging, Vol D-92-4, US Army Corps of Engineers, Waterways Experiment Station.

8. BSI (2007), BS EN 15237:2007, Execution of special geotechnical works – Vertical Drainage, March 2007.

9. Cheek, P.M. and Yee, T.W. (2006), The use of geosynthetic containers for disposal of dredged sediments – a case history, 8ICG 8th International Geosynthetics Conference Proceedings, Millpress Science Publishers.

10. Chen Y. M., Zhan L., and Chen P. (2004) *Ground Improvement for Soft Clays and Post-Construction Settlement in China.* Seminar on Ground Treatment, HKGS, HKIE and HKC, 147-167.

11. Choa V. (1985) *Preloading and Vertical Drains.* Third International Geotechnical Seminar – Soil Improvement Methods, Nanyang Technological Institute, Singapore, 87- 99.

12. Ciria Publication C573. (2002) *A Guide to Ground Treatment.* Mitchell J. M. and Jardine F. M. Construction Industry Research and Information Association, London, ISBN 0 86017 573 1.

13. Davis, J. A. G and Jackson, J. A. (1987), *Lime Columns*, Report of a presentation at a joint meeting of HKIE Geotechnical Group and Civil Division on 18 February 1987 by Shelton, J. C., Hong Kong Engineer, April 1987, P.51.

14. Detzner, H.D. (1993) *Mechanical treatment of the dredged material from Hamburg Harbor.* Proceedings of the CATS II Congress 1993. Antwerp, Belgium: Technological Institute of the Royal Flemish Society of Engineers, 3.25-3.28.

15. Dredging Research Limited. (May 1996) *Study and Measurement of Dredged Materials (CE2/93), Fill Management Study.* Report to the Geotechnical Engineering Office, Civil Engineering Department, Hong Kong.

16. DRL. (1993) Agreement No. CE2/93 The Study and Measurement of Dredged Material. Dredging Research Limited.

17. EMR-Hong Kong, Ltd. (1999b) *Environmental Monitoring and Audit for Contaminated Mud Pit IV at East Sha Chau.* 7th Quarterly Report for Environmental Protection Department, The Government of the Hong Kong Special Administrative Region.

18. Environment Canada (EC). (1995) *Demonstration Project of a Physico-Chemical Treatment Process of Contaminated Sediment at the Port of Sorel. St. Lawrence Technologies – Contaminated Sediment.* Ministry of the Environment. EM 1-17/23-1995.

19. Environment Canada (EC). (1995) *Demonstration Project of a Physico-Chemical Treatment Process or Contaminated Sediment at the Port of Sorel.* St. Lawrence Technologies – Contaminated Sediment. Ministry of the Environment. Em 1-17/23-1995.

20. Environmental Protection Department (EPD). (2000a). *Marine Water Quality in Hong Kong in 1999.* Hong Kong.

21. EPA. 1994b. *Assessment and Remediation of Contaminated Sediments (ARCS) Program.* Remediation Guidance Document. Great Lakes National Program Office. EPA 905-R94-003. Chicago: EPA.

22. ERM. (1999) Agreement No. CE105/98 Strategic Assessment and Site Selection Study for Contaminated Mud Dispoal. ERM-Hong Kong Ltd., July 1999.

23. ERM. (2003) Agreement No. GEO07/2002 Review of the Contaminated Mud Disposal Strategy and the Need for an Intermediate Contaminated Mud Disposal Facility. ERM – Hong Kong Ltd., February 2003.

24. ERM. (2005) Agreement No. CE12/2002(EP) Detailed Site Selection Study for a Proposed Contaminated Mud Disposal Facility within the Airport East / East of Sha Chau Area. ERM – Hong Kong Ltd., May 2005.

25. ERM-Hong Kong, Ltd. (1999a) *Sustainable Development for the 21st Century – Environmental Baseline Study Reports: Toxic in Marine Sediments and Biota.* Environmental Protection Department, The Government of the Hong Kong Special Administrative Region.

26. EVS. (1996) Agreement No. CE68/94 Review of Contaminated Mud Disposal. EVS Environment Consultants, May 1996.

27. Federal Remediation Technologies Roundtable (FRTR). (2001) *Abstract of Remediation Case Studies.* Member Agencies of the Federal Remediation Technologies Roundtable, Volume 5, EPA 542-R-01-008, May 2001.

28. Fill Management Committee (FMC). (1989) *Alternative Method of Disposing of Marine Mud. A Review of Options.* Paper FMC/89. Geotechnical Engineering Office, Civil Engineering Department, Government of Hong Kong.

29. Francingues, N. R., and Thompson, D. W. (2000) *Innovative Dredged Sediment Decontamination and Treatment Technologies.* ERDC TN-DOER-T2, DOER Technical Report, Engineer Research and Development Center, U.S. Army Corps of Engineers. (http://el.erdc.usace.army.mil/elpubs/pdf/doert2.pdf)

30. Gabay J., Lam S. K., Premchitt J., and Wong C. K. (April 1994) *Duty Visit to Japan Construction of Seawall on Improved Seabed 14-17 March 1994*, Duty Visit Report CR 5/94, Civil Engineering Office.

31. Galloway, J.E., and F.L. Snitz. (1994) *Pilot-scale demonstration of sediment washings.* Dredging '94: Proceedings of the 2nd International Conference on Dredging and Dredged Material Placement. E.C. McNair, Jr., ed. New York: American Society of Civil Engineers, 981-990.

32. Gasbarro, P., J. Henningson, G. Pottecher, and J.J. Cardoni. (1998) *Solvent Extraction Process Development to Decontaminate Sediments*. Proceedings of the U.S. EPA National Conference on Management and Treatment of Contaminated Sediments, Cincinnati, Ohio. EPA/625/R-98/001.

33. Geotechnical Engineering Office (1997), Paper FMC/234 - Management Options for Contaminated Sediments in Hong Kong (1992 – 2002), Fill Management Committee Secretariat, Geotechnical Engineering Office, Civil Engineering Office, June 1997.

34. Harding Lawson Associates (HLA). (1999) *Operations Plan – Dredge Drying and Rehandling Site*, Moss Landing Harbor District, Moss Landing, California. Technical report to the US Army Corps of Engineers, San Francisco District.

35. Hartman Consulting Corp. (1997) *Draft Middle Harbour Habitat Enhancement Area Dredging and Disposal Plan*. Prepared for the Port of Oakland, Oakland, California.

36. Hyder Consulting Ltd. (October 2006) *Literature Review on the Handling and Treatment Methods for Contaminated Sediment*. Environmental Impact Assessment Report, Relocation of Yiu Lian Floating Dock No. 3, Appendix 3A.

37. IMO (1991) The London Dumping Convention, IMO, London, ISBN 92-801-1276-7.

38. Lageman, R., Wieberen, P., and Seffinga, G. A. (1993) *Electro-reclamation: State-of-the-art*. Proceedings of the 4th Annual Conference on Contaminated Land: Policy, Economics and Technology, London 1993, IBC Technical Services Ltd (London).

39. Landin, M.C., J. Brooke, C. Adnitt, and N. Meakins. (1999) *Saltmarsh Restoration in the United Kingdom Using Manipulations And Dredged Material*. Proceedings of the 19th Western Dredging Association (WEDA XIX) Annual Meeting and Conference and 31st Texas A&M University Dredging Seminar (TAMU 31), Louisville, Kentucky.

40. Lau K. W. and Lam K. C. (2003) Application of Vibroflotation Technique in the San Tin Eastern Drainage Channel Project, The HKIE Geotechnical Division Annual Seminar 2003 – Case Histories in Geotechnical Engineering in Hong Kong, 9 May 2003.

41. Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder (1995), Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments," Environmental Management 19(1), 81–97.

42. Lui V., Ng J. and Kwong, A. (2007), Reclamation Ground Settlement Monitoring by using GPS and other Positioning Techniques at Shenzhen Airport, Strategic Integration of Surveying Services, FIG Working Week 2007, 13-17 May 2007, Hong Kong.

43. Marine Fill Committee. (2006) *Fill Management Database, Statistics Summary (June 2006 Update)*. Civil Engineering Office, Civil Engineering and Development Department, The Government of the Hong Kong Special Administrative Region.

44. Maher, A., Najm, H. and Boile, M. (2005), *Solidification/Stabilization of Soft River Sediments Using Deep Soil Mixing*, Final Report, FHWA-NJ-2005-028, The State University of New Jersey Piscataway, October 2005.

45. Maunsell (2005) Agreement No. CE87/2001 (CE) Further Development of Tseung Kwan O Feasibility Study, Final Topical Study Report: Western Coast Road.

46. Montgomery Watson. (September 2001) *Final Summary Report for Sediment Management Unit 56/57 Demonstration Project, Fox River, Green Bay, Wisconsin*. Prepared for Fox Fiver Group of Companies and Wisconsin Department of Natural Resources. Project No. 1242291/2082057.01470101.

47. Morton B. (1989) Pollution *of the Coastal Waters of Hong Kong*. Marine Pollution Bulletin 20, 310-318.

48. Mott Macdonald. (1991) Agreement No. CE30/90 Contaminated Spoil Management Study. Mott Macdonald Hong Kong Ltd. in association with Dredging Research Ltd., October 1991.

49. Mouchel (1998 and 1999) Agreement Nos. CE41/95, 66/95 and 95/96 Environmental Monitoring and Audit for Contaminated Mud Pit II and III at East of Sha Chau.

50. Murphy T.P., Lawson A., Kumagai H. & Babin J. (1999) Review *of Emerging Issues in Sediment Treatment.* Aquatic Ecosystem Health and Management 2, 419-434.

51. Myers, T.E., and M.E. Zappi. (1992) *Laboratory evaluation of stabilization/solidification technology for reducing the mobility of heavy metals in New Bedford Harbor Superfund site sediment.* Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes, vol. 2. T.M. Gilliam and C.C. Wiles, eds. ASTM STP 1123. Philadelphia: American Society of Testing and Materials, 304-319.

52. National Research Council (NRC). (1997). *Contaminated Sediments in Ports and Waterways : Cleanup Strategies and Technologies.* Committee on Contaminated Marine Sediments, Marine Board, Commission on Engineering and Technical Systems. National Academy Press, Washington, D.C. 1997.

53. O'Donnell, S. and J. Henningson. (1999) *The Beneficial use of Dredged Material to Mitigate Acid Mine Drainage.* Proceedings of the 19th Western Dredging Association (WEDA XIX) Annual Meeting and Conference and 31st Texas A&M University Dredging Seminar (TAMU 31), Louisville, Kentucky.

54. O'Rourke, T. D. (2006), *Lessons Learned for Ground Movements and Soil Stabilization from the Boston Central Artery,* Journal of Geotechnical and Geo-environmental Engineering, American Society of Civil Engineers, August 2006, Volume 132, Number 8, 966-988.

55. Paipai E. (1995) *Environmental Enhancement using Dredged Material.* Terra et Aqua (International Journal on Public Works, Ports and Waterways Developments), 59:5-21.

56. Palermo M. R. (1997) *In-situ Capping of Contaminated Sediment Overview and Case Studies.* Proceedings Cincinnati, OH May 13-14, 1997. National Conference on Management and Treatment of Contaminated Sediments, United States Environmental Protection Agency, Office of Research and Development Washington, DC.

57. Palermo, M.R., and Averett, D.E. (2000) *Confined disposal facility (CDF) containment measures: A summary of field experience.* DOER Technical Notes Collection (ERDC TNDOER- C18), U.S. Army Engineer Research and Development Centre, Vicksburg, MS. (http://www.wes.army.mil/el/dots/doer)Ravensrodd Consultants Ltd. (1991). *Report on Sediment Transport in Hong Kong and Adjacent Waters and the Implications for Mud Dumping.* Report to the Geotechnical Engineering Office, Civil Engineering Department, Hong Kong.

58. Suzuki Y. (1982) *Deep Chemical Mixing Method using Cement as Hardening Agent.* Proceedings of the International Symposium on Recent Developments in Ground Improvement Techniques, Bangkok, pp299-340.

59. U.S. Army Corps of Engineers (USACE). (1987) *Beneficial uses of Dredged Material – Engineering Manual.* USACE. Washington D.C. EM 1110-2-5026.

60. U.S. Army Corps of Engineers and the Port of Oakland (USACE/POAK). (1994) *Final Supplemental Environmental Impact Report/Environmental Impact Statement.* Oakland Harbor Deep-Draft Navigational Improvements. SCH 91073031.

61. U.S. Army Engineer Detroit District. 1994. *Assessment and Remediation of Contaminated Sediments (ARCS) Program: Pilot-Scale Demonstration of Sediment*

Washing for the Treatment of Saginaw River Sediments. Great Lakes National Program Office. EPA 905-R94-019. Chicago: EPA.

62. USEPA. (1993) Selecting Remediation Techniques for Contaminated Sediment, Office of Water, USEPA, June 1993.

63. VSL International Ltd. (2003) *Hong Kong, Stone Columns in Disneyland*. The VSL-Intrafor Magazine, Issue One, 2003.

64. Whiteside, P.G.D., S.T. Gilbert, B.B. Jayasekera and C.A.M. Franks. (1990) *Fill Management Study Phase I Report*. NRR 1/90. Geotechnical Control Office, Civil Engineering Services Department, Government of Hong Kong.

65. Wong P. K. (2004) *Ground Improvement Case Studies – Chemical Lime Piles and Dynamic Replacement*. Australian Geomechanics Society Journal, Vol 39, No.2, June 2004.

66. Yeung, W. T. and Tam, K. S. (2006), *Report on Duty Visit to Japan Treatment of Soil Mud for Seawall Foundation 15-20 October 2006*, Civil Engineering Department, 13 November 2006.

67. Yin J. H. (1998) *Stress-strain-strength Characteristics of Soft Hong Kong Marine Deposits Improved Using Cement*. Urban Ground Engineering, 11-12 Nov 1998, Hong Kong, edited by B. Clarke, Thomas Telford, pp296-307.

68. Yin J. H. (2001a) *Properties and Behaviour of Raw Sludge Mixed with PFA and Lime*. Geotechnical Testing Journal (ASTM), Vol. 24, No. 3, pp299 - 307.

69. Yin J. H. (2001b) *Stress-strain-strength Characteristics of Soft Hong Kong Marine Deposits Without and With Cement Treatment*. Journal of Lowland Technology International, Vol. 3, No. 1 pp1-13.

70. Yin J. H. and Lai C. K. (1998) *Strength and Stiffness of Hong Kong Marine Deposits Mixed with Cement*. Journal of Geotechnical Engineering, SEAGS, Vol. 29, No. 1, pp29-44.

71. Yin, J H. (2004) *Properties and Behaviour of a Cemented Mixed Hong Kong Marine Clay and Design Applications*. Seminar on Ground Treatment, HKGS, HKIE and HKCU, 97-105.

72. Ying W. L. (February 1999) *The Uncertainties of Vertical Drain Design*. Thesis for the Degree of Master of Philosophy, the University of Hong Kong.

FIGURES

Parameter	Tolo Harbour and Channel				Hong Kong Island		West Lamma Channel	
	Harbour Subzone		Buffer Subzone	Channel Subzone	(South)			
	TS2	TS3	TS4	TS5	SS1	SS2	SS3	SS4
Number of samples	10	10	10	10	10	10	10	10
Particle Size Fractionation <63μm (%w/w)	71 (14 - 86)	69 (43 - 88)	65 (34 - 80)	90 (80 - 95)	68 (57 - 84)	87 (74 - 97)	74 (52 - 93)	78 (49 - 96)
Electrochemical Potential (mV)	-342 ((-376) - (-294))	-328 ((-364) - (-279))	-339 ((-390) - (-260))	-337 ((-360) - (-308))	-149 ((-205) - (-95))	-164 ((-338) - (-87))	-156 ((-215) - (-91))	-159 ((-192) - (-100))
Total Solids (%w/w)	34 (30 - 40)	33 (25 - 45)	39 (28 - 54)	31 (28 - 35)	56 (48 - 60)	47 (43 - 51)	51 (41 - 59)	46 (42 - 52)
Total Volatile Soilds (%w/w)	10.1 (8.6 - 11.0)	10 (7.4 - 12.0)	9.6 (5.0 - 12.0)	11.2 (9.7 - 13.0)	6.6 (5.6 - 9.6)	8.1 (6.7 - 14.0)	7 (6.0 - 8.7)	8.2 (6.4 - 16.0)
Chemical Oxygen Demand (mg/kg)	24000 (21000 - 28000)	23000 (21000 - 25000)	21000 (17000 - 23000)	20000 (16000 - 23000)	11000 (10000 - 13000)	15000 (13000 - 16000)	19000 (14000 - 25000)	16000 (14000 - 23000)
Total Carbon (%w/w)	0.8 (0.7 - 0.9)	0.7 (0.6 - 0.7)	0.9 (0.8 - 1.0)	0.8 (0.8 - 0.9)	0.9 (0.7- 1.0)	0.7 (0.6 - 0.7)	0.9 (0.6 - 1.4)	0.7 (0.6 - 1.3)
Ammonical Nitrogen (mg/kg)	10.3 (0.1 - 32.0)	5.4 (<0.05 - 14.0)	11.2 (2.1 - 24.0)	16.7 (6.0 - 25.0)	5.7 (0.2 - 11.0)	10.5 (0.4 - 37.0)	5.6 (1.6 - 13.0)	3.6 (0.4 - 7.6)
Total Kjeldahl Nitrogen (mg/kg)	572 (470 - 720)	520 (350 - 630)	605 (460 - 750)	735 (620 - 860)	378 (260 - 490)	400 (230 - 520)	380 (240 - 470)	374 (240 - 500)
Total Phosphorus (mg/kg)	178 (160 - 220)	160 (140 - 200)	184 (140 - 210)	211 (180 - 240)	217 (160 - 250)	198 (150 - 240)	233 (200 - 270)	197 (160 - 250)
Total Sulphide (mg/kg)	223 (84 - 400)	175 (30 - 320)	201 (100 - 330)	218 (150 - 430)	37 (15 - 70)	52 (31 - 100)	36 (12 - 72)	49 (8 - 140)
Total Cyanide (mg/kg)	0.2 (<0.1 - 0.3)	0.1 (<0.1 - 0.2)	0.2 (<0.1 - 0.3)	0.2 (<0.1 - 0.2)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.1)
Arsenic (mg/kg)	8.7 (6.6 - 11.0)	9.1 (5.9 -13.0)	8.2 (6.6 - 9.5)	6.5 (5.5 - 8.2)	6.6 (4.6 - 7.5)	9 (7.9 - 12.0)	7.3 (6.0 - 8.8)	8.2 (6.2 - 11.0)
Cadmium (mg/kg)	0.5 (0.3 - 0.6)	0.5 (0.4 -0.7)	0.4 (0.2 - 0.6)	0.3 (0.2 - 0.3)	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)
Chromium (mg/kg)	27 (21 - 31)	23 (14 - 35)	24 (19 - 30)	35 (30 - 38)	25 (17 - 36)	34 (28 - 38)	32 (25 - 38)	36 (26 - 44)
Copper (mg/kg)	44 (26 - 54)	40 (22 - 60)	26 (18 - 39)	23 (19 - 26)	12 (8 - 18)	23 (19 - 25)	20 (15 - 23)	31 (18 - 43)
Lead (mg/kg)	86 (71 - 100)	97 (75 - 130)	68 (55 - 82)	52 (44 - 60)	27 (21 - 35)	36 (28 - 39)	34 (23 - 41)	40 (25 - 50)
Mercury (mg/kg)	0.08 (0.05 - 0.13)	0.06 (<0.05 - 0.08)	0.06 (<0.05 - 0.07)	0.06 (<0.05 - 0.07)	0.06 (<0.05 - 0.08)	0.09 (<0.05 - 0.11)	0.09 (0.07 - 0.11)	0.11 (0.08 - 0.14)
Nickel (mg/kg)	17 (12 - 22)	14 (8 - 22)	16 (13 - 20)	25 (22 - 28)	17 (12 - 23)	23 (20 - 26)	22 (17 - 26)	22 (16 - 26)
Silver (mg/kg)	0.7 (0.3 - 1.0)	0.7 (0.4 - 1.0)	0.6 (<0.2 - 1.0)	0.5 (0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.6 (0.3 - 1.0)	0.5 (<0.2 - 1.0)	0.6 (0.2 - 1.0)
Zinc (mg/kg)	198 (140 - 270)	227 (170 - 380)	147 (75 - 220)	130 (110 - 150)	74 (56 - 110)	103 (93 - 120)	91 (75 - 110)	107 (75 - 130)
Total Polychlorinated Biphenyls (PCBs) (μg/kg) (3) (4)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)
Low Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (μg/kg) (5) (6)	91 (90 - 98)	90 (90 - 94)	90 (90 - 90)	90 (90 - 93)	92 (90 - 106)	91 (90 - 94)	91 (90 - 95)	93 (90 - 100)
High Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (μg/kg) (7) (8)	57 (31 - 120)	43 (21 - 100)	53 (23 - 87)	52 (16 - 72)	56 (26 - 188)	72 (30 - 133)	63 (23 - 123)	98 (41 - 169)

Note: 1. Data presented are arithmetic means ; data in brackets indicate ranges.

2. All data are based on the analyses of bulk (unsieved) sediment and are reported on a dry weight basis unless stated otherwise.

3. The Technical Circular 'ETWB (W) No. 34/2002 Management of Dredged / Excavated Sediment' issued in 2002 has revised the definition of 'Total PCBs' as the summation of 18 specific PCB congeners. Following the new definition, the monitoring of these 18 PCB congeners started in 2002 and the Total PCBs results only refer to 2002 – 2005.

4. Total PCBs results are derived from the summation of 18 congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

5. Low molecular weight polyaromatic hydrocarbons (PAHs) include 6 congeners of molecular weight below 200, namely : Acenaphthene, Acenaphthylene, Anthracene, Flourene, Naphthalene and Phenanthrene.

6. As the monitoring of Naphthalene only started in 2002, the Low Molecular Weight PAHs results are based on sediments samples collected in 2002 – 2005.

7. High molecular weight polyaromatic hydrocarbons (PAHs) include 10 congeners of molecular weight above 200, namely : Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene.

8. Low and high molecular weight PAHs results are derived from the summation of the corresponding congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

(Table extracted from EPD's Publication "20 Years of Marine Water Quality Monitoring in Hong Kong.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Summary Statistics for Bottom Sediment Quality in the Tolo Harbour and Channel and Southern WCZs, 2001 - 2005**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 2.1

Parameter	Lantau Island (East) SS5	Lantau Island (South) SS6	Junk Bay JS2	Inner Deep Bay DS1	Inner Deep Bay DS2	Outer Deep Bay DS3	Outer Deep Bay DS4
Number of samples	10	10	10	10	10	10	10
Particle Size Fractionation <63µm (%w/w)	94 (79 - 99)	70 (44 - 100)	85 (56 - 96)	68 (8 - 92)	79 (63 - 90)	85 (44 - 96)	65 (37 - 88)
Electrochemical Potential (mV)	-194 ((-299) - (-92))	-156 ((-207) - (-72))	-234 ((-323) - (-98))	-273 ((-366) - (-145))	-175 ((-272) - (-34))	-180 ((-237) - (-96))	-147 ((-210) - (-29))
Total Solids (%w/w)	38 (35 - 41)	62 (57 - 65)	44 (40 - 52)	47 (34 - 53)	47 (43 - 50)	47 (43 - 54)	55 (46 - 66)
Total Volatile Soilds (%w/w)	8.5 (7.5 - 9.0)	4.5 (3.8 - 5.2)	7.5 (6.5 - 8.4)	6.6 (4.7 - 7.8)	6.9 (6.0 - 7.5)	7 (5.9 - 7.6)	5.9 (4.6 - 7.1)
Chemical Oxygen Demand (mg/kg)	15000 (13000 - 17000)	11000 (9200 - 12000)	17000 (13000 - 19000)	20000 (15000 - 25000)	17000 (12000 - 19000)	16000 (12000 - 18000)	16000 (13000 - 19000)
Total Carbon (%w/w)	0.6 (0.5 - 0.6)	0.5 (0.5 - 0.6)	0.7 (0.6 - 0.8)	0.6 (0.4 - 0.7)	0.6 (0.5 - 0.7)	0.5 (0.5 - 0.6)	0.6 (0.5 - 0.8)
Ammonical Nitrogen (mg/kg)	9.3 (0.2 - 21. 0)	7.5 (0.3 - 21.0)	7.1 (4.8 - 12.0)	42.9 (2.5 - 230.0)	10.5 (<0.05 - 53.0)	3.4 (0.2 -7.9)	3.5 (<0.05 - 11.0)
Total Kjeldahl Nitrogen (mg/kg)	494 (350 - 870)	291 (200 - 350)	442 (340 - 500)	383 (210 - 750)	391 (160 - 510)	335 (160 - 470)	245 (110 - 410)
Total Phosphorus (mg/kg)	208 (150 - 340)	180 (130 - 210)	198 (170 - 230)	259 (110 - 580)	291 (140 - 380)	228 (120 - 320)	165 (77 - 240)
Total Sulphide (mg/kg)	67 (9 - 110)	26 (2 - 59)	129 (19 - 230)	365 (22 - 1200)	124 (29 - 320)	60 (2 - 160)	19 (3 - 76)
Total Cyanide (mg/kg)	0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.2)	0.1 (<0.1 - 0.2)	0.2 (<0.1 - 0.3)	0.2 (<0.1 - 0.6)	0.2 (<0.1 - 0.3)	<0.1 (<0.1 - 0.2)
Arsenic (mg/kg)	8.6 (7.7 - 9.6)	6 (5.4 - 7.5)	7.9 (6.8 - 9.6)	11.2 (8.5 - 14.0)	13.2 (9.9 - 18.0)	13.9 (7.7 - 17.0)	12.6 (7.6 - 18.0)
Cadmium (mg/kg)	(<0.1) (<0.1 - 0.1)	(<0.1) (<0.1 - <0.1)	0.2 (0.2 - 0.3)	0.3 (<0.1 - 0.6)	0.3 (0.1 - 0.4)	0.2 (<0.1 - 0.4)	<0.1 (<0.1 - 0.2)
Chromium (mg/kg)	43 (34 - 47)	25 (20 - 32)	53 (45 - 65)	40 (28 - 56)	41 (22 - 49)	45 (24 - 53)	34 (26 -47)
Copper (mg/kg)	38 (30 - 43)	13 (10 - 17)	128 (110 - 150)	56 (16 - 100)	57 (26 - 70)	55 (12 - 77)	26 (15 - 64)
Lead (mg/kg)	51 (41 - 57)	26 (22 - 32)	55 (42 - 110)	59 (39 - 86)	57 (30 - 87)	53 (32 - 69)	39 (29 - 51)
Mercury (mg/kg)	0.16 (0.12 - 0.19)	0.06 (0.05 - 0.08)	0.25 (0.21 - 0.35)	0.12 (<0.05 - 0.29)	0.14 (0.06 - 0.23)	0.13 (<0.05 - 0.16)	0.07 (<0.05 - 0.14)
Nickel (mg/kg)	27 (22 - 29)	16 (13 - 22)	25 (18 - 38)	25 (18 - 33)	26 (14 - 29)	30 (16 - 37)	20 (15 - 31)
Silver (mg/kg)	0.8 (0.5 - 1.0)	0.5 (<0.2 - 1.0)	2.5 (2.0 - 3.0)	0.8 (<0.2 - 2.0)	0.8 (0.2 - 1.0)	0.7 (<0.2 - 1.0)	0.6 (<0.2 - 1.0)
Zinc (mg/kg)	139 (110 - 160)	70 (62 - 86)	150 (120 - 200)	195 (100 - 380)	180 (91 - 240)	155 (81 - 230)	92 (60 - 140)
Total Polychlorinated Biphenyls (PCBs) (µg/kg) (3) (4)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)
Low Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (µg/kg) (5) (6)	90 (90 - 90)	90 (90 - 90)	94 (90 - 110)	92 (90 - 104)	92 (90 - 96)	92 (90 - 96)	91 (90 - 94)
High Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (µg/kg) (7) (8)	71 (44 - 131)	24 (19 - 33)	196 (121 - 379)	104 (18 - 355)	99 (54 - 190)	92 (29 - 151)	51 (16 - 132)

Note: 1. Data presented are arithmetic means ; data in brackets indicate ranges.

2. All data are based on the analyses of bulk (unsieved) sediment and are reported on a dry weight basis unless stated otherwise.

3. The Technical Circular 'ETWB (W) No. 34/2002 Management of Dredged / Excavated Sediment' issued in 2002 has revised the definition of 'Total PCBs' as the summation of 18 specific PCB congeners. Following the new definition, the monitoring of these 18 PCB congeners started in 2002 and the Total PCBs results only refer to 2002 – 2005.

4. Total PCBs results are derived from the summation of 18 congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

5. Low molecular weight polyaromatic hydrocarbons (PAHs) include 6 congeners of molecular weight below 200, namely : Acenaphthene, Acenaphthylene, Anthracene, Flourene, Naphthalene and Phenanthrene.

6. As the monitoring of Naphthalene only started in 2002, the Low Molecular Weight PAHs results are based on sediments samples collected in 2002 – 2005.

7. High molecular weight polyaromatic hydrocarbons (PAHs) include 10 congeners of molecular weight above 200, namely : Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene.

8. Low and high molecular weight PAHs results are derived from the summation of the corresponding congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

(Table extracted from EPD's Publication "20 Years of Marine Water Quality Monitoring in Hong Kong.)

Job Title

CEDD

Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong

Figure Title

Summary Statistics for Bottom Sediment Quality in the Southern, Junk Bay and Deep Bay WCZs, 2001 - 2005

ARUP

Ove Arup & Partners Hong Kong Limited

Scale N.T.S.

Drn. DN Date 10/07 Chd. PW Passed PAT

Job No. 24599 Figure No. 2.2

Parameter	Inner Port Shelter	Outer Port Shelter		Starling Inlet	Crooked Island		Port Island	Mirs Bay (North)
	PS3	PS5	PS6	MS1	MS2	MS7	MS17	MS3
Number of samples	10	10	10	10	10	10	10	10
Particle Size Fractionation <63μm (%w/w)	86 (55 - 95)	42 (8 - 68)	81 (73 - 90)	86 (78 - 95)	92 (83 - 98)	93 (85 - 99)	91 (84 - 98)	89 (73 - 98)
Electrochemical Potential (mV)	-254 ((-324) - (-110))	-155 ((-249) - (-56))	-212 ((-281) - (-160))	-331 ((-379) - (-230))	-360 ((-385) - (-341))	-362 ((-388) - (-319))	-242 ((-342) - (-152))	-239 ((-346) - (-135))
Total Solids (%w/w)	38 (33 -53)	56 (44 - 63)	47 (43 - 51)	40 (32 - 46)	32 (31 - 35)	30 (27 - 34)	36 (34 - 42)	38 (31 - 42)
Total Volatile Soilds (%w/w)	12 (8.2 - 14.0)	7.9 (5.5 - 9.9)	9.3 (8.6 - 11.0)	8.3 (7.4 - 10.0)	10.2 (8.9 - 11.0)	11 (9.5 - 12.0)	9.7 (7.6 - 11.0)	9.7 (8.3 - 11.0)
Chemical Oxygen Demand (mg/kg)	19000 (15000 - 22000)	12000 (7200 - 17000)	14000 (12000 - 19000)	20000 (19000 -22000)	19000 (17000 - 20000)	19000 (17000 - 21000)	18000 (16000 - 20000)	19000 (16000 - 20000)
Total Carbon (%w/w)	1.1 (0.6 - 1.2)	1.6 (0.4 - 2.2)	1.2 (0.8 - 1.3)	0.7 (0.6 - 0.8)	0.7 (0.6 - 0.9)	0.8 (0.7 - 0.9)	0.9 (0.7 - 1.2)	0.8 (0.7 - 0.9)
Ammonical Nitrogen (mg/kg)	8.3 (3.7 - 15.0)	8.2 (3.0 - 15.0)	6.7 (2.2 - 14.0)	14.7 (0.2 - 26.0)	15.6 (5.0 - 25.0)	11.9 (1.3 - 18.0)	8 (0.2 - 16.0)	4.6 (0.2 - 11.0)
Total Kjeldahl Nitrogen (mg/kg)	616 (420 - 710)	368 (270 - 510)	441 (270 - 590)	553 (270 - 760)	649 (510 - 720)	687 (630 - 780)	650 (420 - 770)	581 (380 - 700)
Total Phosphorus (mg/kg)	202 (170 -230)	157 (120 - 210)	184 (110 - 240)	194 (150 - 250)	201 (170 - 240)	199 (170 - 240)	220 (190 - 270)	201 (170 - 230)
Total Sulphide (mg/kg)	87 (44 - 270)	15 (3 - 36)	36 (14 - 59)	173 (31 - 350)	174 (100 - 340)	89 (29 -190)	68 (20 - 180)	26 (5 - 55)
Total Cyanide (mg/kg)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)	0.1 (<0.1 - 0.2)	0.2 (<0.1 - 0.2)	0.1 (<0.1 - 0.2)	0.1 (<0.1 - 0.2)	0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.1)
Arsenic (mg/kg)	6.1 (4.7 - 8.7)	4 (2.3 - 6.5)	5.9 (5.1 - 7.7)	9.4 (7.5 - 12.0)	7.4 (5.8 - 9.4)	7.1 (5.7 - 10.0)	6.6 (4.4 - 8.8)	7.1 (5.1 - 9.6)
Cadmium (mg/kg)	(<0.1) (<0.1 - <0.1)	(<0.1) (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	0.3 (0.2 - 0.5)	0.2 (0.1 - 0.3)	0.2 (0.2 - 0.3)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)
Chromium (mg/kg)	26 (20 - 30)	21 (15 - 30)	28 (23 - 30)	30 (26 - 35)	35 (28 - 40)	34 (32 - 38)	34 (25 - 41)	33 (27 - 37)
Copper (mg/kg)	24 (18 - 31)	10 (7 - 17)	13 (11 - 14)	39 (32 - 45)	22 (19 - 26)	21 (18 - 25)	16 (12 - 20)	15 (12 - 19)
Lead (mg/kg)	38 (32 - 43)	25 (20 - 37)	33 (31 - 35)	50 (38 - 55)	47 (39 - 51)	43 (36 - 49)	42 (28 - 53)	38 (32 - 42)
Mercury (mg/kg)	0.09 (0.08 - 0.12)	<0.05 (<0.05 - 0.07)	<0.05 (<0.05 - 0.06)	0.09 (0.07 - 0.15)	0.07 (<0.05 - 0.08)	0.07 (0.06 - 0.10)	0.05 (<0.05 - 0.06)	0.05 (<0.05 - 0.08)
Nickel (mg/kg)	17 (9 - 22)	15 (10 - 24)	20 (17 - 23)	18 (15 - 21)	23 (20 - 26)	23 (21 - 26)	26 (18 - 31)	23 (19 - 28)
Silver (mg/kg)	0.6 (0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	1 (0.8 - 1.4)	0.6 (0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)
Zinc (mg/kg)	97 (85 - 110)	63 (43 - 98)	79 (67 - 88)	109 (80 - 130)	103 (77 - 110)	95 (78 - 100)	93 (66 - 120)	91 (60 - 160)
Total Polychlorinated Biphenyls (PCBs) (μg/kg) [(3) (4)]	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)
Low Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (μg/kg) [(5) (6)]	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)	91 (90 - 95)	90 (90 - 94)	90 (90 - 90)	90 (90 - 90)
High Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (μg/kg) [(7) (8)]	55 (29 - 62)	27 (19 - 37)	33 (21 -49)	45 (29 - 66)	50 (24 - 75)	67 (28 - 200)	45 (29 - 74)	40 (21 - 64)

Note: 1. Data presented are arithmetic means ; data in brackets indicate ranges.

2. All data are based on the analyses of bulk (unsieved) sediment and are reported on a dry weight basis unless stated otherwise.

3. The Technical Circular 'ETWB (W) No. 34/2002 Management of Dredged / Excavated Sediment' issued in 2002 has revised the definition of 'Total PCBs' as the summation of 18 specific PCB congeners. Following the new definition, the monitoring of these 18 PCB congeners started in 2002 and the Total PCBs results only refer to 2002 - 2005.

4. Total PCBs results are derived from the summation of 18 congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

5. Low molecular weight polyaromatic hydrocarbons (PAHs) include 6 congeners of molecular weight below 200, namely : Acenaphthene, Acenaphthylene, Anthracene, Flourene, Naphthalene and Phenanthrene.

6. As the monitoring of Naphthalene only started in 2002, the Low Molecular Weight PAHs results are based on sediments samples collected in 2002 - 2005.

7. High molecular weight polyaromatic hydrocarbons (PAHs) include 10 congeners of molecular weight above 200, namely : Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene.

8. Low and high molecular weight PAHs results are derived from the summation of the corresponding congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

(Table extracted from EPD's Publication "20 Years of Marine Water Quality Monitoring in Hong Kong.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited	
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Summary Statistics for Bottom Sediment Quality in the Port Shelter and Mirs Bay WCZs, 2001 - 2005**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599	Figure No. 2.3

Parameter	Mirs Bay (North)		Long Harbour	Waglan Island	Mirs Bay (South)	Mirs Bay (Central)		
	MS4	MS5	MS6	MS8	MS13	MS14	MS15	MS16
Number of samples	10	10	10	10	10	10	10	10
Particle Size Fractionation <63μm (%w/w)	94 (85 - 99)	88 (78 - 96)	93 (85 - 98)	94 (83 - 98)	91 (83 - 95)	89 (77 - 95)	88 (81 - 92)	81 (71 - 86)
Electrochemical Potential (mV)	-202 ((-282) - (-109))	-196 ((-255) - (-95))	-228 ((-308) - (-104))	-169 ((-237) - (-103))	-149 ((-195) - (-87))	-144 ((-202) - (-77))	-142 ((-209) - (-64))	-120 ((-191) - (-39))
Total Solids (%w/w)	35 (33 - 39)	41 (37 - 44)	34 (31 - 37)	46 (45 - 49)	49 (48 - 51)	50 (46 - 54)	52 (49 - 55)	54 (49 - 57)
Total Volatile Soilds (%w/w)	9.4 (8.3 - 10.0)	8.4 (7.1 - 9.2)	11.2 (10.0 - 12.0)	7.4 (6.7 - 7.8)	6.6 (5.5 - 7.5)	6.8 (5.7 - 7.3)	6.4 (5.3 - 7.0)	6.4 (6.0 - 6.9)
Chemical Oxygen Demand (mg/kg)	16000 (15000 - 18000)	16000 (15000 - 17000)	20000 (17000 - 21000)	12000 (10000 - 14000)	11000 (9700 - 12000)	11000 (9600 - 11000)	11000 (9500 - 13000)	12000 (9600 - 13000)
Total Carbon (%w/w)	0.7 (0.6 - 0.7)	0.7 (0.6 - 0.9)	0.9 (0.8 - 1.0)	0.6 (0.5 - 0.6)	0.6 (0.5 - 0.6)	0.6 (0.5 - 0.6)	0.6 (0.5 - 0.6)	0.6 (0.5 - 0.7)
Ammonical Nitrogen (mg/kg)	9 (0.1 - 20.0)	11.7 (0.1 -23.0)	8.9 (0.4 - 21.0)	3.8 (0.3 - 9.3)	9.8 (0.3 - 48.0)	3.6 (0.1 - 9.1)	3.4 (0.3 - 9.5)	7.5 (1.2 - 37.0)
Total Kjeldahl Nitrogen (mg/kg)	616 (440 - 680)	581 (360 - 670)	731 (640 - 840)	424 (320 - 520)	431 (350 - 540)	406 (280 - 520)	388 (270 - 540)	404 (260 - 490)
Total Phosphorus (mg/kg)	204 (140 - 230)	212 (140 - 240)	241 (220 - 290)	214 (190 - 230)	234 (210 - 260)	223 (190 - 260)	220 (180 - 260)	224 (170 - 260)
Total Sulphide (mg/kg)	46 (13 - 86)	49 (5 - 180)	82 (30 - 210)	49 (11 - 180)	33 (5 - 130)	14 (8 - 20)	18 (11 - 27)	39 (7 - 210)
Total Cyanide (mg/kg)	<0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.1)	0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)
Arsenic (mg/kg)	6.8 (4.9 - 9.0)	7.3 (5.7 - 9.7)	6.5 (5.0 - 8.8)	7.4 (6.6 - 9.0)	8.3 (6.4 - 15.0)	7.6 (6.5 - 8.9)	6.6 (5.6 - 7.7)	6.3 (4.9 - 7.3)
Cadmium (mg/kg)	(<0.1) (<0.1 - 0.2)	(<0.1) (<0.1 - 0.2)	0.1 (<0.1 - 0.1)	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - <0.1)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)
Chromium (mg/kg)	36 (30 - 41)	33 (26 - 38)	32 (27 - 35)	34 (26 - 39)	34 (29 - 60)	31 (28 - 34)	30 (25 - 35)	27 (24 - 29)
Copper (mg/kg)	16 (13 - 18)	15 (11 - 18)	18 (15 - 23)	14 (11 - 20)	14 (11 - 22)	12 (10 - 16)	11 (9 - 13)	10 (8 - 13)
Lead (mg/kg)	40 (33 - 44)	41 (33 - 47)	42 (36 - 45)	34 (27 - 38)	33 (26 - 53)	31 (26 - 34)	31 (25 - 39)	30 (26 - 36)
Mercury (mg/kg)	0.05 (<0.05 - 0.07)	0.05 (<0.05 - 0.06)	0.07 (0.06 - 0.10)	0.06 (<0.05 - 0.09)	0.05 (<0.05 - 0.08)	<0.05 (<0.05 - <0.05)	0.05 (<0.05 - 0.09)	<0.05 (<0.05 - 0.05)
Nickel (mg/kg)	26 (23 - 32)	25 (20 - 26)	24 (21 - 28)	25 (20 - 31)	26 (21 - 45)	23 (20 - 26)	22 (18 - 26)	20 (17 - 24)
Silver (mg/kg)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)
Zinc (mg/kg)	91 (66 - 100)	90 (62 - 100)	101 (78 - 110)	86 (59 - 100)	85 (56 - 160)	80 (58 - 92)	75 (53 - 94)	69 (54 - 82)
Total Polychlorinated Biphenyls (PCBs) (μg/kg) (3) (4)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)
Low Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (μg/kg) (5) (6)	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)	90 (90 - 90)
High Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (μg/kg) (7) (8)	44 (28 - 70)	38 (22 - 61)	60 (35 - 83)	50 (22 - 120)	33 (21 - 47)	30 (20 - 40)	27 (19 - 42)	25 (19 - 31)

Note: 1. Data presented are arithmetic means ; data in brackets indicate ranges.

2. All data are based on the analyses of bulk (unsieved) sediment and are reported on a dry weight basis unless stated otherwise.

3. The Technical Circular 'ETWB (W) No. 34/2002 Management of Dredged / Excavated Sediment' issued in 2002 has revised the definition of 'Total PCBs' as the summation of 18 specific PCB congeners. Following the new definition, the monitoring of these 18 PCB congeners started in 2002 and the Total PCBs results only refer to 2002 – 2005.

4. Total PCBs results are derived from the summation of 18 congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

5. Low molecular weight polyaromatic hydrocarbons (PAHs) include 6 congeners of molecular weight below 200, namely : Acenaphthene, Acenaphthylene, Anthracene, Flourene, Naphthalene and Phenanthrene.

6. As the monitoring of Naphthalene only started in 2002, the Low Molecular Weight PAHs results are based on sediments samples collected in 2002 – 2005.

7. High molecular weight polyaromatic hydrocarbons (PAHs) include 10 congeners of molecular weight above 200, namely : Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene.

8. Low and high molecular weight PAHs results are derived from the summation of the corresponding congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

(Table extracted from EPD's Publication "20 Years of Marine Water Quality Monitoring in Hong Kong.)

Job Title	Figure Title	Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Summary Statistics for Bottom Sediment Quality in the Mirs Bay WCZs, 2001 - 2005**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 2.4

Parameter	Pearl Island NS2	Pillar Point NS3	Urmston Road NS4	Chek Lap Kok (North) NS6	Tsing Yi (South) WS1	Hong Kong Island (West) WS2
Number of samples	10	10	10	10	9	10
Particle Size Fractionation <63µm (%w/w)	65 (41 - 79)	59 (23 - 84)	37 (12 - 61)	46 (10 - 92)	74 (27 - 95)	83 (66 - 97)
Electrochemical Potential (mV)	-147 ((-230) - (-84))	-162 ((-236) - (-56))	-186 ((-230) - (-146))	-165 ((-205) - (-121))	-196 ((-289) - (-108))	-153 ((-216) - (-93))
Total Solids (%w/w)	55 (51 - 64)	59 (49 - 69)	63 (59 - 68)	62 (47 - 76)	49 (42 - 65)	47 (41 - 54)
Total Volatile Soilds (%w/w)	6.2 (5.4 - 7.0)	5.7 (3.1 - 7.4)	5.1 (4.6 - 5.9)	4.9 (2.2 - 8.3)	6.4 (4 - 7.5)	6.9 (5.6 - 7.5)
Chemical Oxygen Demand (mg/kg)	15000 (13000 - 17000)	15000 (8400 - 19000)	15000 (12000 - 19000)	12000 (7500 - 17000)	16000 (11000 - 19000)	14000 (9800 - 17000)
Total Carbon (%w/w)	0.7 (0.5 - 1.0)	0.6 (0.4 - 0.8)	0.6 (0.3 - 0.8)	0.5 (0.4 - 0.8)	0.7 (0.5 - 1.1)	0.6 (0.5 - 0.7)
Ammonical Nitrogen (mg/kg)	2.5 (0.1 - 8.2)	5.6 (0.1 - 16.0)	14.2 (0.2 - 30.0)	4 (0.1 - 13.0)	12.5 (5.6 - 23)	8.4 (0.9 - 30.0)
Total Kjeldahl Nitrogen (mg/kg)	277 (120 - 370)	296 (120 - 440)	258 (160 - 350)	259 (140 - 400)	382 (200 - 480)	362 (260 - 540)
Total Phosphorus (mg/kg)	172 (84 - 220)	191 (86 - 250)	157 (92 - 210)	169 (100 - 260)	180 (110 - 230)	181 (140 - 210)
Total Sulphide (mg/kg)	21 (3 - 64)	23 (5 - 65)	29 (3 - 77)	11 (2 - 38)	100 (13 - 210)	79 (39 - 200)
Total Cyanide (mg/kg)	<0.1 (<0.1 - 0.1)	0.2 (<0.1 - 0.5)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)	0.1 (<0.1 - 0.3)	0.1 (<0.1 - 0.2)
Arsenic (mg/kg)	9.6 (7.5 - 14.0)	11 (6.3 - 14.0)	10.2 (9.1 - 11.0)	11.4 (6.1 - 22.0)	8.9 (4.7 - 13.0)	11.4 (8.8 - 16.0)
Cadmium (mg/kg)	(<0.1) (<0.1 - 0.1)	(<0.1) (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)	<0.1 (<0.1 - 0.1)	0.1 (<0.1 - 0.2)	<0.1 (<0.1 - 0.1)
Chromium (mg/kg)	33 (25 - 43)	32 (18 - 42)	29 (23 - 36)	28 (15 - 45)	35 (13 - 47)	36 (32 - 40)
Copper (mg/kg)	32 (27 - 42)	31 (19 - 48)	26 (18 - 42)	19 (8 - 34)	42 (9 - 73)	25 (18 - 36)
Lead (mg/kg)	36 (32 - 50)	38 (21 - 45)	37 (29 - 46)	30 (17 - 46)	38 (15 - 53)	38 (34 - 41)
Mercury (mg/kg)	0.09 (0.06 - 0.13)	0.13 (0.06 - 0.19)	0.09 (0.06 - 0.23)	0.07 (<0.05 - 0.13)	0.11 (<0.05 - 0.15)	0.08 (<0.05 - 0.14)
Nickel (mg/kg)	20 (15 - 27)	20 (10 - 25)	18 (14 - 22)	18 (9 - 27)	21 (8 - 27)	23 (21 - 26)
Silver (mg/kg)	0.7 (0.3 - 1.0)	0.6 (0.2 - 1.0)	0.6 (<0.2 - 1.0)	0.5 (<0.2 - 1.0)	0.8 (0.5 - 1.2)	0.6 (0.2 - 1.0)
Zinc (mg/kg)	94 (73 - 130)	94 (48 - 120)	98 (67 - 110)	76 (34 - 120)	101 (31 - 130)	100 (82 - 120)
Total Polychlorinated Biphenyls (PCBs) (µg/kg) (3) (4)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)
Low Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (µg/kg) (5) (6)	91 (90 - 95)	92 (90 - 95)	92 (90 - 99)	90 (90 - 94)	92 (90 - 102)	90 (90 - 90)
High Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (µg/kg) (7) (8)	53 (27 - 124)	68 (31 - 114)	62 (32 - 117)	27 (16 - 49)	131 (22 - 422)	61 (22 - 140)

Note: 1. Data presented are arithmetic means ; data in brackets indicate ranges.

2. All data are based on the analyses of bulk (unsieved) sediment and are reported on a dry weight basis unless stated otherwise.

3. The Technical Circular 'ETWB (W) No. 34/2002 Management of Dredged / Excavated Sediment' issued in 2002 has revised the definition of 'Total PCBs' as the summation of 18 specific PCB congeners. Following the new definition, the monitoring of these 18 PCB congeners started in 2002 and the Total PCBs results only refer to 2002 – 2005.

4. Total PCBs results are derived from the summation of 18 congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

5. Low molecular weight polyaromatic hydrocarbons (PAHs) include 6 congeners of molecular weight below 200, namely : Acenaphthene, Acenaphthylene, Anthracene, Flourene, Naphthalene and Phenanthrene.

6. As the monitoring of Naphthalene only started in 2002, the Low Molecular Weight PAHs results are based on sediments samples collected in 2002 – 2005.

7. High molecular weight polyaromatic hydrocarbons (PAHs) include 10 congeners of molecular weight above 200, namely : Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene.

8. Low and high molecular weight PAHs results are derived from the summation of the corresponding congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

(Table extracted from EPD's Publication "20 Years of Marine Water Quality Monitoring in Hong Kong.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Summary Statistics for Bottom Sediment Quality in the North Western and Western Buffer WCZs, 2001 - 2005**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 2.5

Parameter	Eastern Buffer Chai Wan ES1	 Tathong Channel ES2	 ES4	Victoria Harbour (East) VS3	 (Central) VS5	 (West) VS6	Rambler Channel VS9	 VS10
Number of samples	**10**	**10**	**10**	**10**	**10**	**9**	**10**	**10**
Particle Size Fractionation <63µm (%w/w)	48 (26 - 94)	67 (15 - 92)	57 (27 - 87)	59 (10 - 91)	79 (30 - 95)	53 (43 - 69)	80 (57 - 88)	88 (73 - 97)
Electrochemical Potential (mV)	-194 ((-272) - (-65))	-173 ((-286) - (-107))	-262 ((-349) - (-187))	-329 ((-421) - (-213))	-361 ((-409) - (-244))	-330 ((-384) - (-218))	-259 ((-365) - (-137))	-265 ((-365) - (-121))
Total Solids (%w/w)	65 (51 - 71)	57 (45 - 66)	55 (47 - 70)	48 (35 - 73)	41 (31 - 66)	53 (41 - 70)	47 (40 - 53)	40 (34 - 44)
Total Volatile Soilds (%w/w)	4.8 (3.7 - 6.6)	5.7 (4.3 - 7.2)	6.2 (4.5 - 7.9)	6.6 (3.2 - 7.8)	8.5 (5.2 - 10.0)	7 (5.0 - 8.8)	7 (5.6 - 8.4)	8 (7.0 - 9.0)
Chemical Oxygen Demand (mg/kg)	12000 (9400 - 27000)	13000 (8000 - 21000)	15000 (11000 - 21000)	19000 (7300 - 25000)	27000 (15000 - 32000)	26000 (22000 - 32000)	18000 (12000 - 23000)	21000 (18000 - 27000)
Total Carbon (%w/w)	1.3 (0.4 - 1.8)	0.7 (0.5 - 0.9)	0.8 (0.3 - 1.1)	0.7 (0.5 - 0.9)	0.8 (0.7 - 1.1)	1 (0.7 - 1.6)	0.7 (0.6 - 0.8)	0.7 (0.6 - 0.8)
Ammonical Nitrogen (mg/kg)	10.1 (1.5 - 22.0)	11.4 (2.3 - 67.0)	6.4 (2.5 - 9.4)	12.2 (0.4 - 22.0)	37.9 (1.5 - 86.0)	13.8 (4.8 - 42.0)	17.6 (0.1 - 49.0)	13.5 (3.3 - 34.0)
Total Kjeldahl Nitrogen (mg/kg)	295 (190 - 430)	356 (250 - 540)	408 (290 - 500)	459 (220 - 610)	624 (360 - 710)	403 (300 - 520)	348 (160 - 460)	470 (390 - 630)
Total Phosphorus (mg/kg)	144 (100 - 200)	178 (130 - 230)	170 (110 - 240)	171 (120 - 210)	205 (130 - 240)	224 (190 - 280)	170 (120 - 200)	219 (180 - 260)
Total Sulphide (mg/kg)	58 (3 - 140)	49 (7 - 180)	171 (15 - 360)	327 (200 - 590)	766 (170 - 1700)	222 (100 - 490)	109 (3 - 460)	362 (110 - 1100)
Total Cyanide (mg/kg)	0.1 (<0.1 - 0.2)	0.1 (<0.1 - 0.2)	0.2 (<0.1 - 0.4)	0.1 (0.1 - 0.2)	0.3 (<0.1 - 0.8)	0.2 (<0.1 - 0.3)	0.2 (<0.1 - 0.3)	0.3 (<0.1 - 0.5)
Arsenic (mg/kg)	5 (3.5 - 7.0)	6.3 (4.9 - 8.2)	5.6 (3.5 - 7.9)	6.1 (0.9 - 9.4)	8.1 (6.2 - 10.0)	8.3 (6.6 - 11.0)	6.5 (4.0 - 9.3)	9.9 (8.0 - 11.0)
Cadmium (mg/kg)	0.1 (<0.1 - 0.2)	(<0.1) (<0.1 - <0.1)	0.2 (<0.1 - 0.3)	0.4 (<0.1 - 0.6)	0.8 (0.3 - 1.0)	0.4 (0.2 - 0.5)	0.5 (<0.1 - 1.3)	0.8 (0.4 - 2.4)
Chromium (mg/kg)	22 (13 - 36)	28 (20 - 38)	32 (24 - 45)	38 (12 - 60)	58 (28 - 70)	39 (30 - 52)	53 (27 - 76)	97 (56 - 190)
Copper (mg/kg)	37 (17 - 87)	24 (16 - 42)	71 (49 - 110)	112 (27 - 190)	191 (84 - 250)	116 (76 - 210)	122 (11 - 280)	266 (130 - 760)
Lead (mg/kg)	26 (18 - 48)	29 (21 - 44)	32 (23 - 40)	42 (21 - 62)	65 (50 - 84)	88 (51 - 130)	43 (21 - 81)	60 (42 - 76)
Mercury (mg/kg)	0.19 (0.06 - 1.00)	0.08 (<0.05 - 0.14)	0.17 (0.09 - 0.30)	0.32 (<0.05 - 0.72)	0.42 (0.20 - 0.52)	1.57 (0.29 - 8.00)	0.18 (<0.05 - 0.39)	0.21 (0.14 - 0.30)
Nickel (mg/kg)	13 (9 - 18)	19 (14 - 25)	16 (12 - 21)	18 (6 - 27)	26 (12 - 31)	19 (14 - 28)	29 (19 - 43)	44 (25 - 110)
Silver (mg/kg)	0.8 (0.2 - 2.0)	0.7 (<0.2 - 1.0)	1.7 (1.0 - 3.0)	3.3 (1.0 - 5.6)	8.1 (3.0 - 11.0)	3.3 (1.6 - 4.5)	3.0 (0.3 - 8.0)	7.3 (4.0 - 14.0)
Zinc (mg/kg)	63 (42 - 100)	75 (54 - 110)	94 (63 - 140)	134 (17 - 230)	256 (110 - 340)	180 (120 - 240)	124 (62 - 210)	200 (110 - 260)
Total Polychlorinated Biphenyls (PCBs) (µg/kg) [(3)(4)]	18 (18 - 18)	18 (18 - 18)	18 (18 - 18)	19 (18 - 21)	20 (18 - 23)	27 (18 - 45)	19 (18 - 23)	21 (18 - 30)
Low Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (µg/kg) [(5)(6)]	95 (90 - 126)	93 (90 - 109)	96 (90 - 115)	104 (90 - 124)	119 (90 - 181)	146 (113 - 169)	90 (90 - 90)	91 (90 - 99)
High Molecular Weight Polycylic Aromatic Hydrocarbons (PAHs) (µg/kg) [(7)(8)]	117 (21 - 391)	76 (30 - 188)	183 (75 - 402)	321 (66 - 550)	571 (279 - 985)	1572 (357 - 5780)	108 (16 - 281)	207 (119 - 339)

Note: 1. Data presented are arithmetic means ; data in brackets indicate ranges.

2. All data are based on the analyses of bulk (unsieved) sediment and are reported on a dry weight basis unless stated otherwise.

3. The Technical Circular 'ETWB (W) No. 34/2002 Management of Dredged / Excavated Sediment' issued in 2002 has revised the definition of 'Total PCBs' as the summation of 18 specific PCB congeners. Following the new definition, the monitoring of these 18 PCB congeners started in 2002 and the Total PCBs results only refer to 2002 – 2005.

4. Total PCBs results are derived from the summation of 18 congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

5. Low molecular weight polyaromatic hydrocarbons (PAHs) include 6 congeners of molecular weight below 200, namely : Acenaphthene, Acenaphthylene, Anthracene, Flourene, Naphthalene and Phenanthrene.

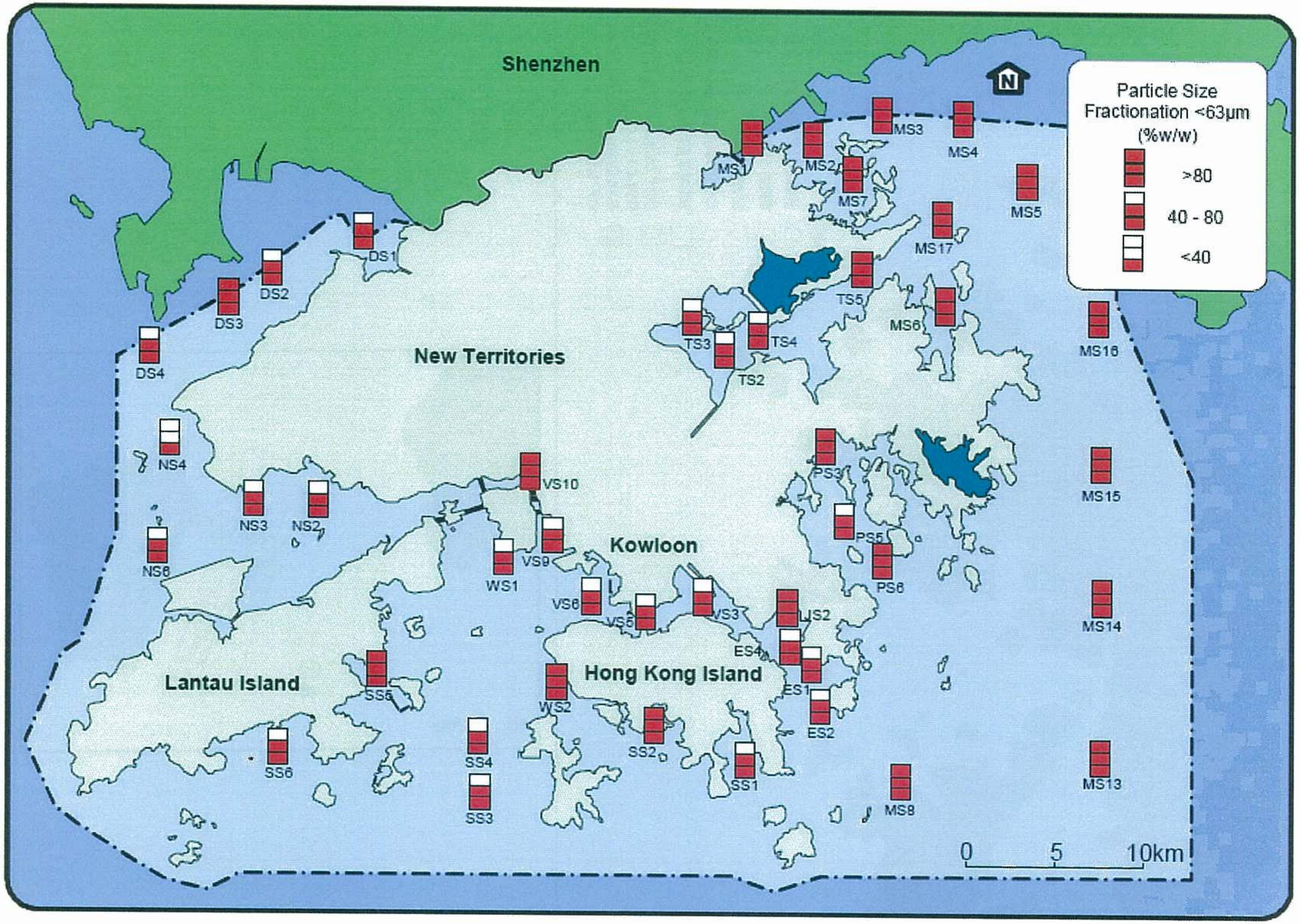
6. As the monitoring of Naphthalene only started in 2002, the Low Molecular Weight PAHs results are based on sediments samples collected in 2002 – 2005.

7. High molecular weight polyaromatic hydrocarbons (PAHs) include 10 congeners of molecular weight above 200, namely : Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene.

8. Low and high molecular weight PAHs results are derived from the summation of the corresponding congeners. If the concentration of a congener is below report limit (RL), the result will be taken as 0.5xRL in the calculation.

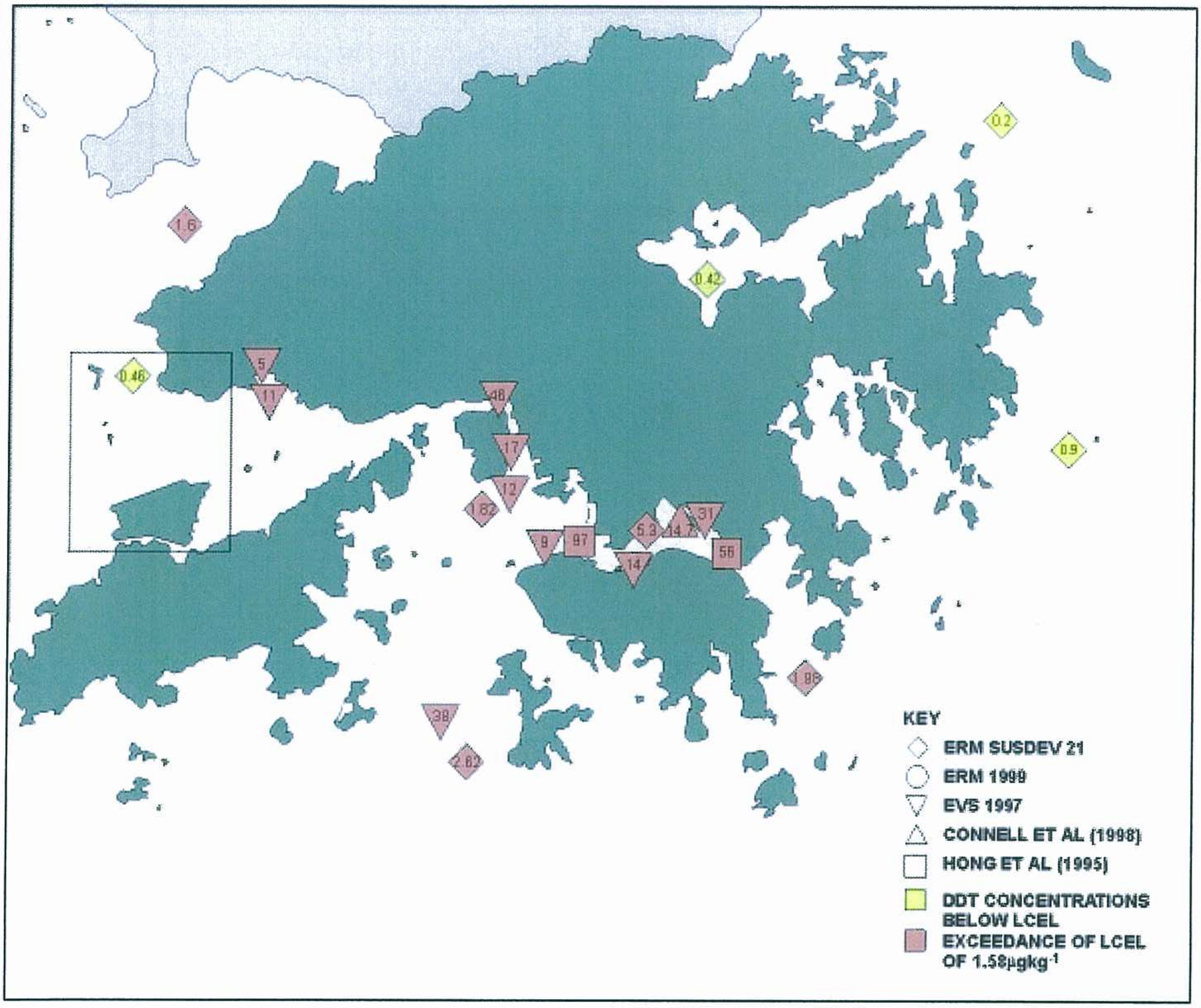
(Table extracted from EPD's Publication "20 Years of Marine Water Quality Monitoring in Hong Kong.)

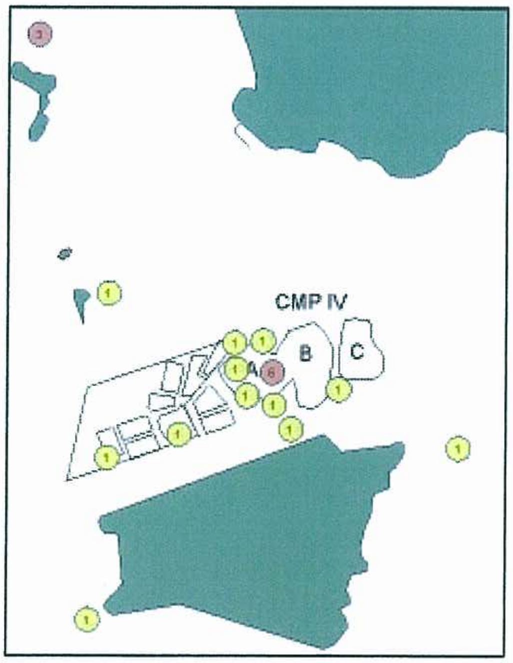
Job Title	Figure Title	ARUP — Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Summary Statistics for Bottom Sediment Quality in the Eastern Buffer and Victoria Harbour WCZs, 2001 - 2005**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 2.6



(Figures extracted from EPD's website site
http://www.epd.gov.hk/epd/english/environmentinhk/water/marine_quality/mwq_report04.html)

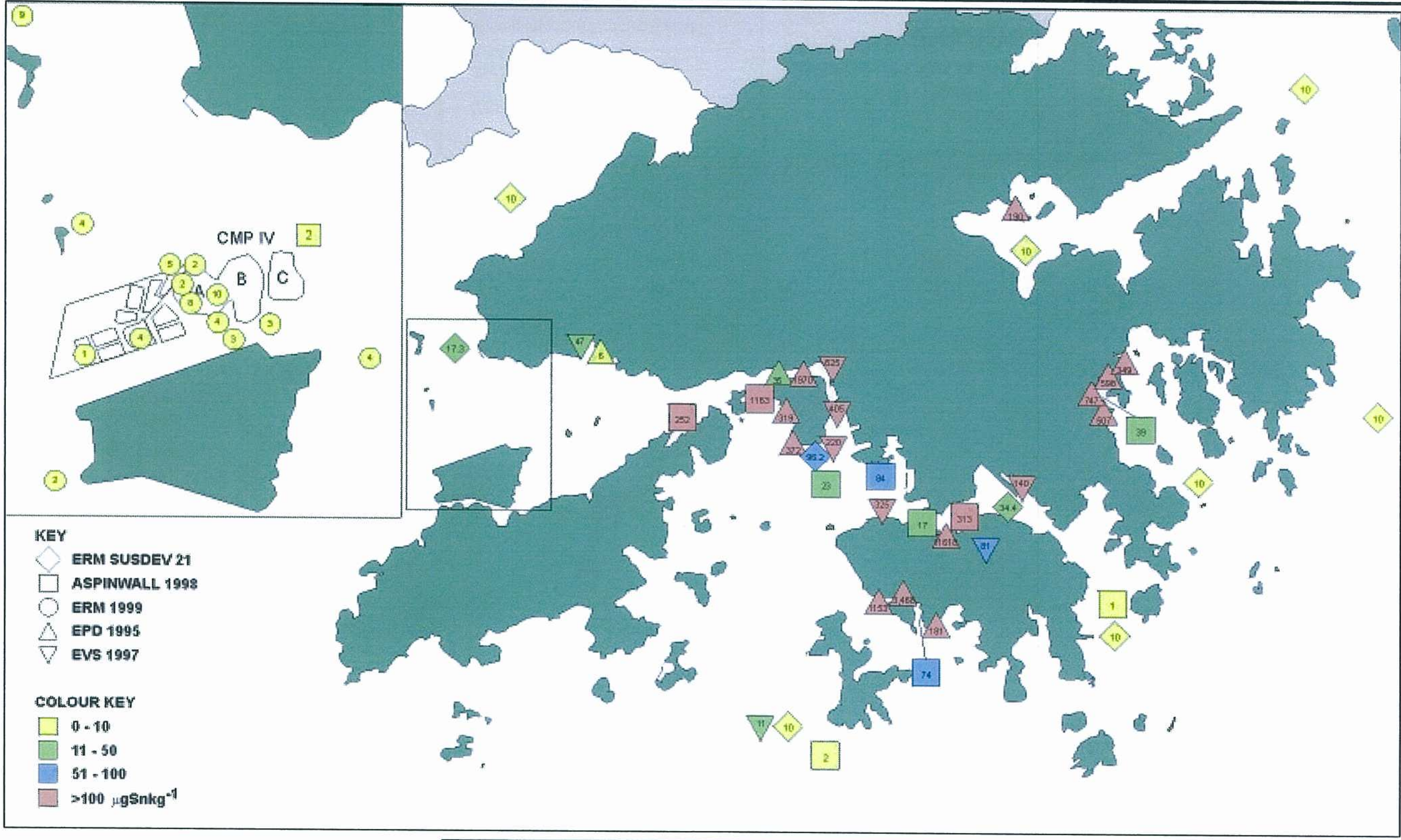
Job Title	Figure Title	
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Particle Size Fractionation <63µm in Marine Sediments in Hong Kong, 2002 - 2004**	ARUP Ove Arup & Partners Hong Kong Limited Scale NTS Drn. CL Date 04/2008 Chd. PW Passed PAT Job No. 25042 Figure No. 2.7





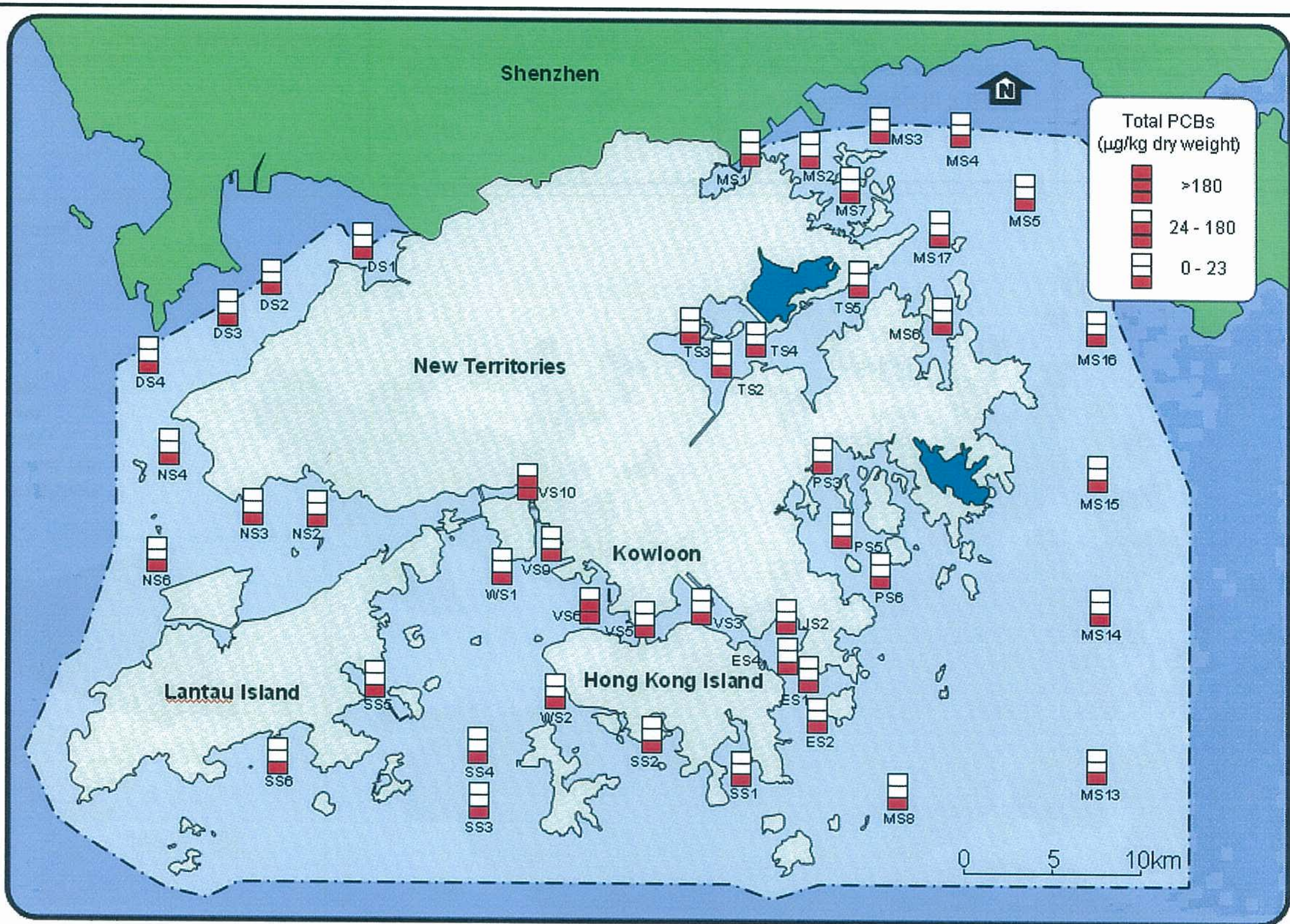
(Figures extracted from EPD's Website.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Spatial DDT Contamination Variation in Hong Kong Sediments**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 2.8



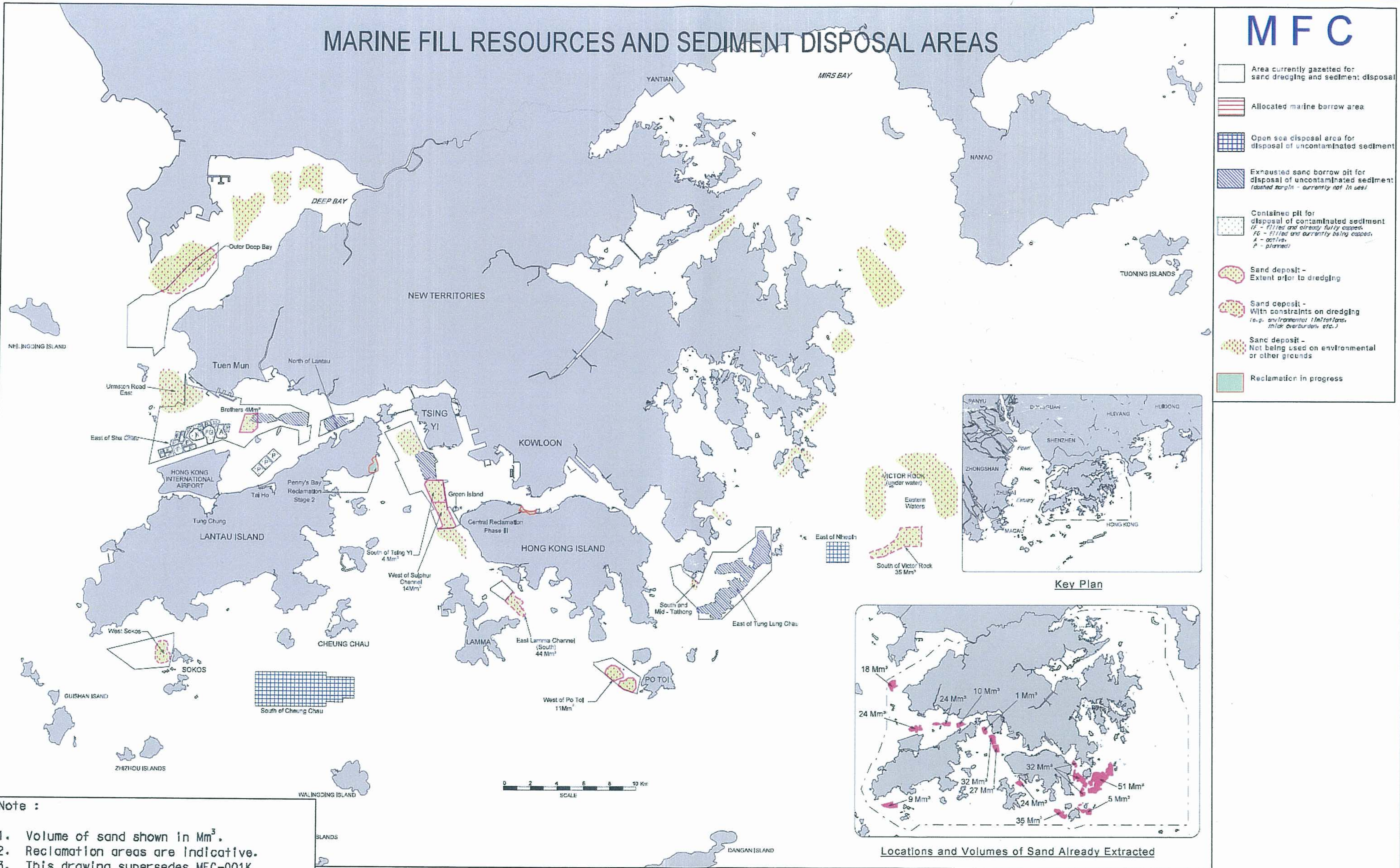
(Figures extracted from EPD's Website.)
(Data are from a ragne of studies but all values are expressed as means per station/ sampling area µgSn/kg.

Job Title CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	Figure Title **Spatial Variation in TBT Contamination in Sediments in Hong Kong**	ARUP Ove Arup & Partners Hong Kong Limited Scale NTS Drn. DN Date 10/2007 Chd. PW Passed PAT Job No. 25042 Figure No. 2.9



(Figures extracted from EPD's Website.)

Job Title	Figure Title	
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Total Polychlorinated Biphenyls (PCBs) in Marine Sediments in Hong Kong, 2002 - 2006**	ARUP Ove Arup & Partners Hong Kong Limited Scale: NTS Drn.: DN Date: 10/2007 Chd.: PW Passed: PAT Job No.: 25042 Figure No.: 2.10

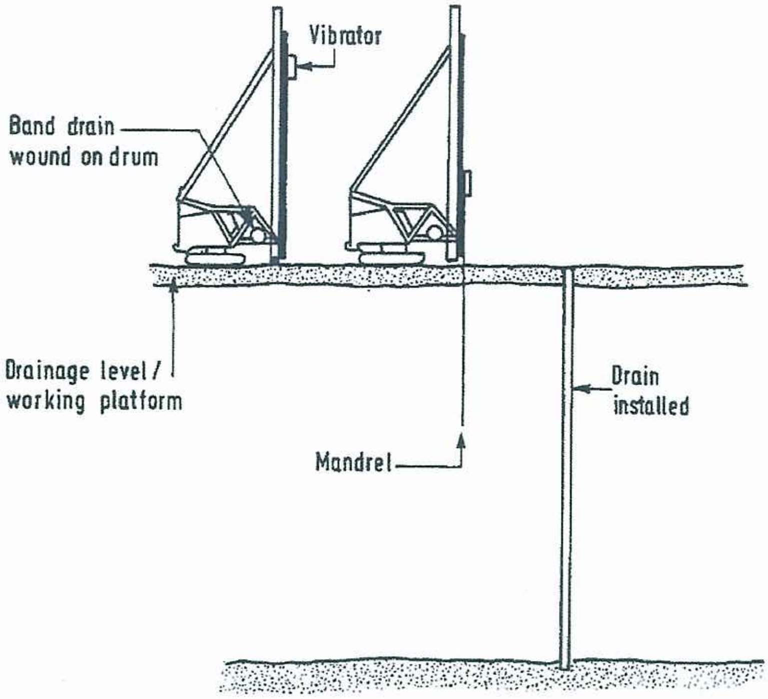


Note :

1. Volume of sand shown in Mm^3.
2. Reclamation areas are indicative.
3. This drawing supersedes MFC-001K
4. Up-to-date information is available from MFC Secretariat, CED, CEDD.
   Tel : (852) 2762 5555
   Fax : (852) 2714 0113
   E-mail : angelakhng@cedd.gov.hk
   Web Site: http://www.cedd.gov.hk/eng/services/fillmanagement/index.htm

(Figures extracted from CEDD's Website, Drawing No. MFC-001M.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Marine Fill Resources and Sediment Disposal Areas**	Scale NTS Drn. DN Date 10/2007 Chd. PW Passed PAT Job No. 25042 Figure 3.1



Schematic Diagram of Installation of Band Drain

The drain which is placed inside the mandrel with tip anchor.

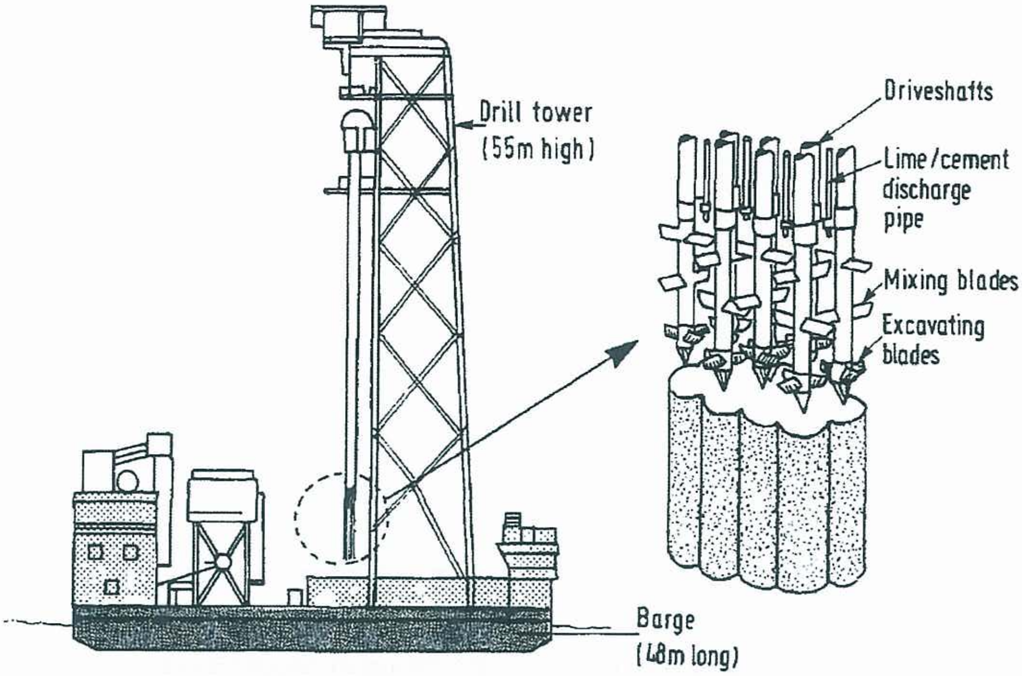
Installation of Drains on a Barge

The details of band drain and tip anchor.

Photos of Installation of Band Drain

(Figures extracted from Ciria Report C573.)
(Photos extracted from http://www.cse.polyu.edu.hk/~civcal/wwwroot/reclamation/drain/default.htm)

Job Title	Figure Title	Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Schematic Diagram and Photos of Installation of Band Drains**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 4.1

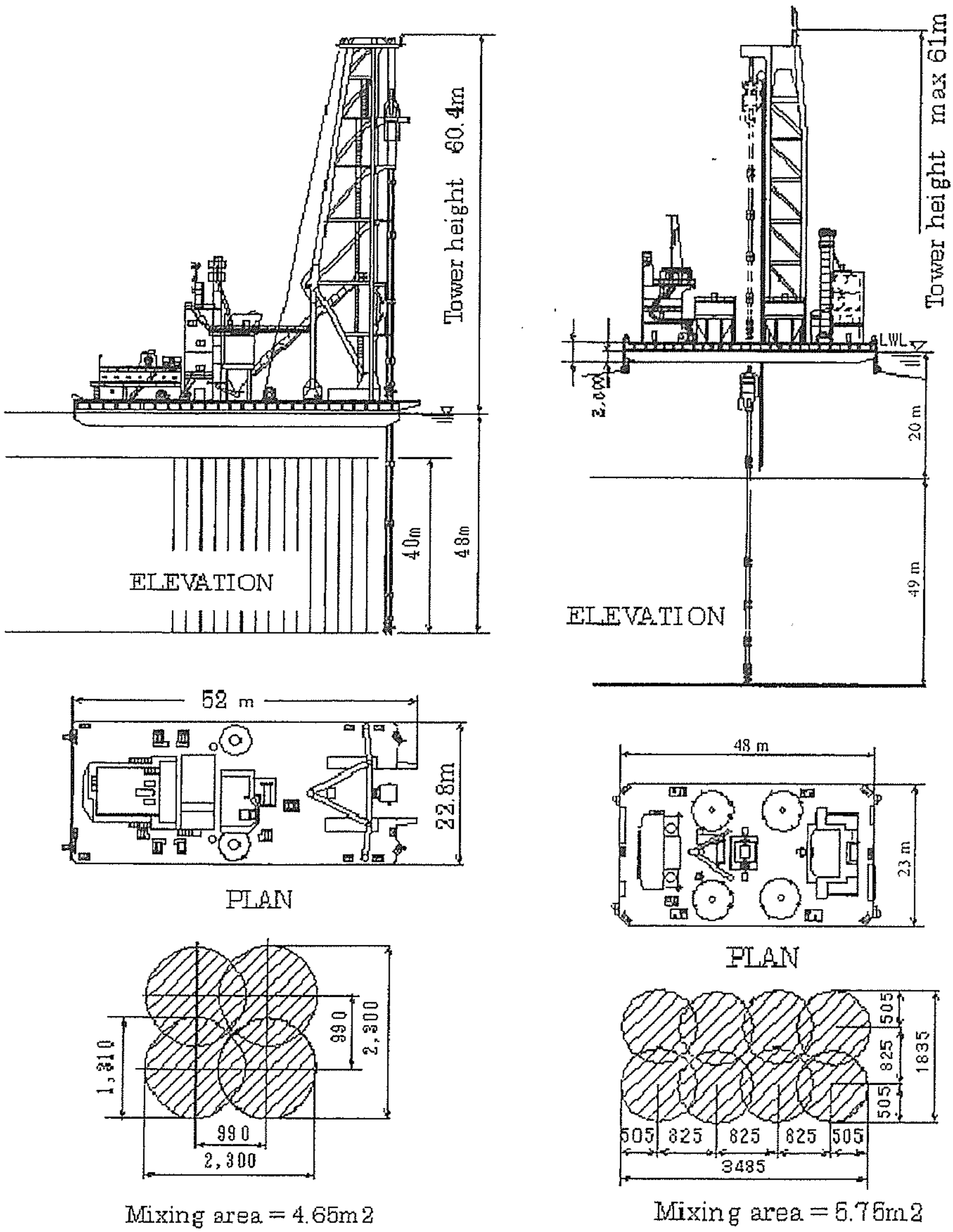


Block Formation of Deep Chemical Mixing (Marine-based)

Photos of Deep Cement Mixing (Land-based)

(Figures extracted from Ciria Report C573.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited	
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Schematic Diagram and Photos of Deep Cement Mixing**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT	
		Job No. 24599	Figure No. 4.2



(Figures extracted from the paper entitled "The Project of Off-shore CDM Soil Improvement at Deijima District in Hiroshima, Japan by Nakanishi M & Kurushima M.)

Job Title

CEDD

Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong

Figure Title

Outline of Two Soil Improvement Vessels for Deep Cement Mixing

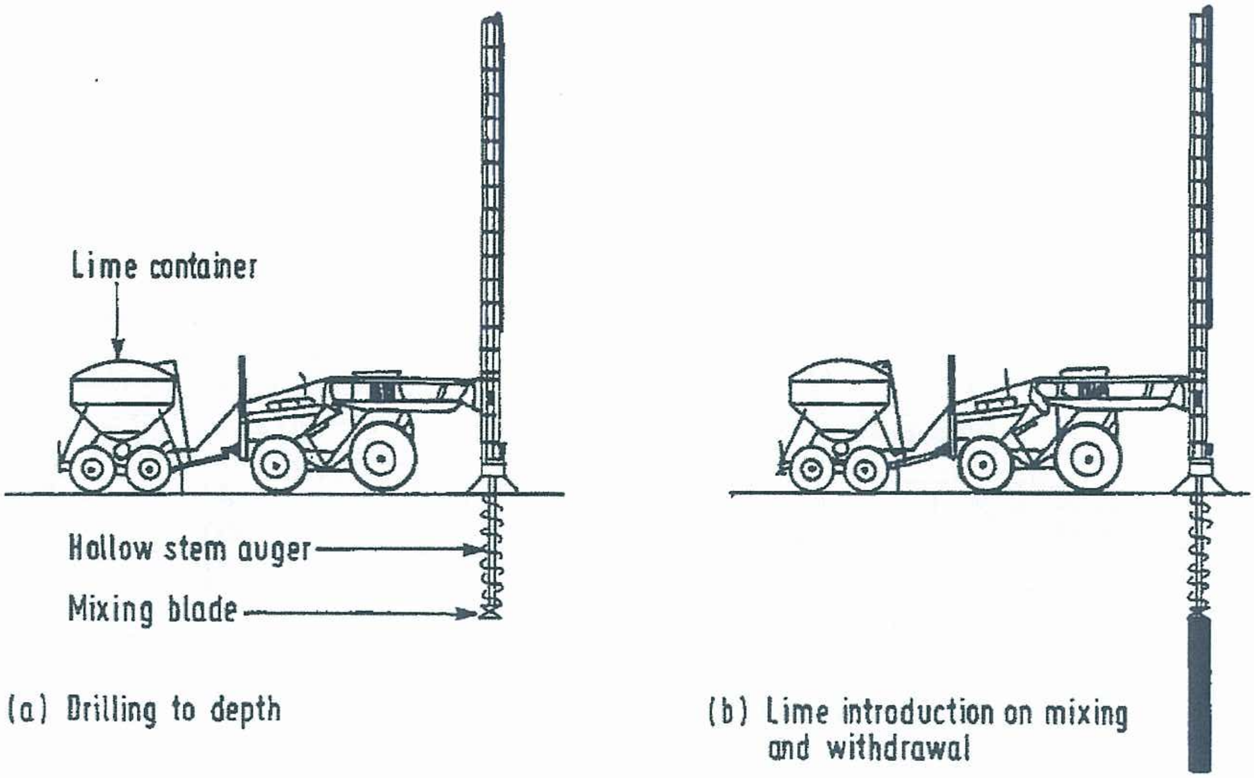
ARUP Ove Arup & Partners Hong Kong Limited

Scale N.T.S.

Drn. DN Date 10/07 Chd. PW Passed PAT

Job No. 24599

Figure No. 4.3

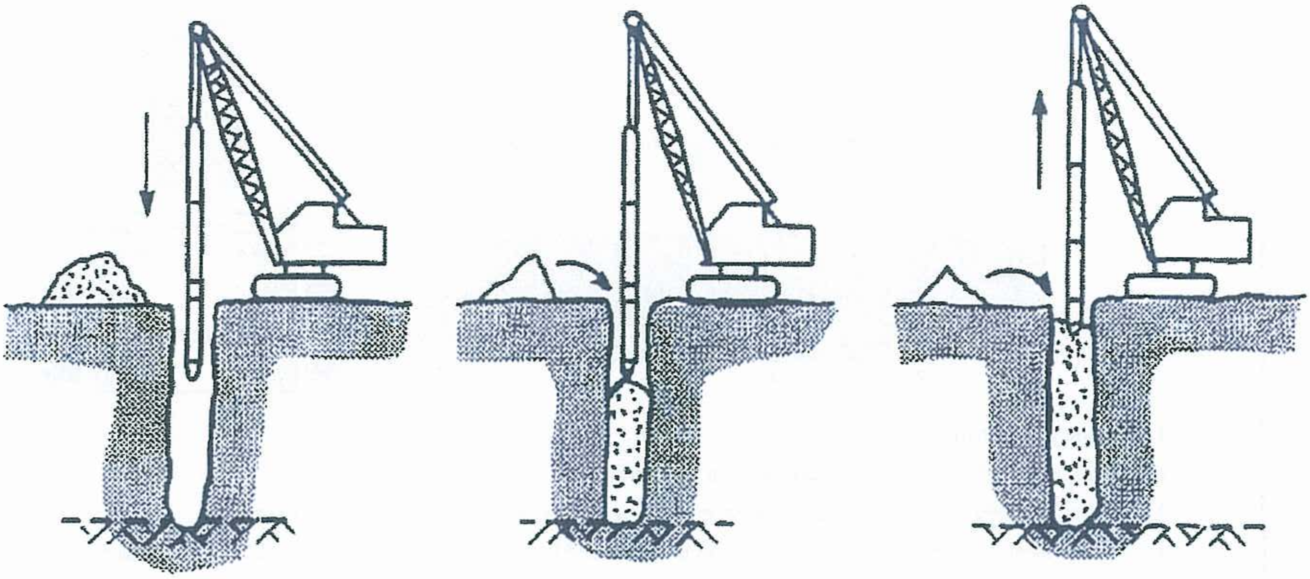


Schematic Diagram of Formation of Lime Columns

Photos of Formation of Lime Columns

(Figures extracted from Ciria Report C573.)
(Photos extracted from http://www.trevispa.com/_vti_g2_4.2.04.aspx?rpstry=20_ .)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited	
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Schematic Diagram and Photos of Formation of Lime Columns**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT	
		Job No. 24599	Figure No. 4.4



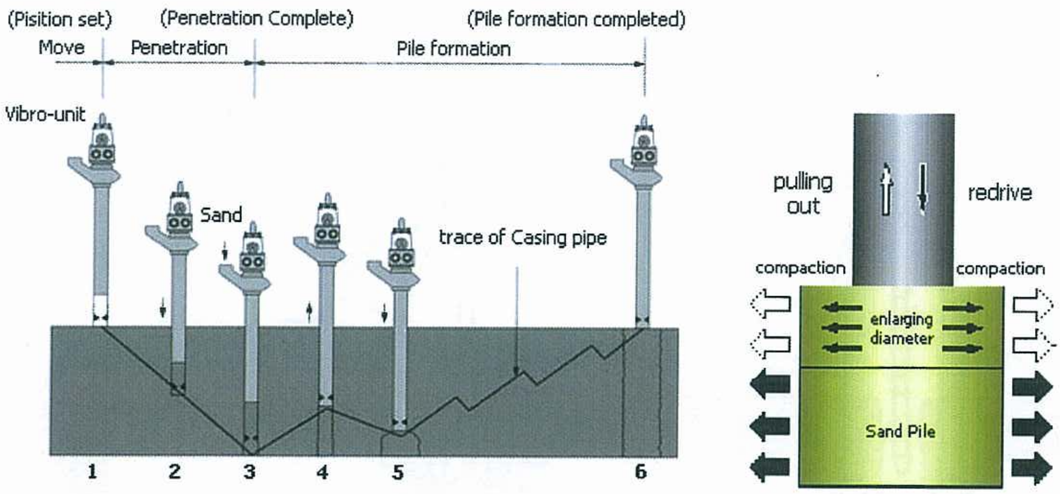
Schematic Diagram of Installation of Stone Columns

Bottom Feed Installation

Top Feed Installation

(Figures extracted from Ciria Report C573.)

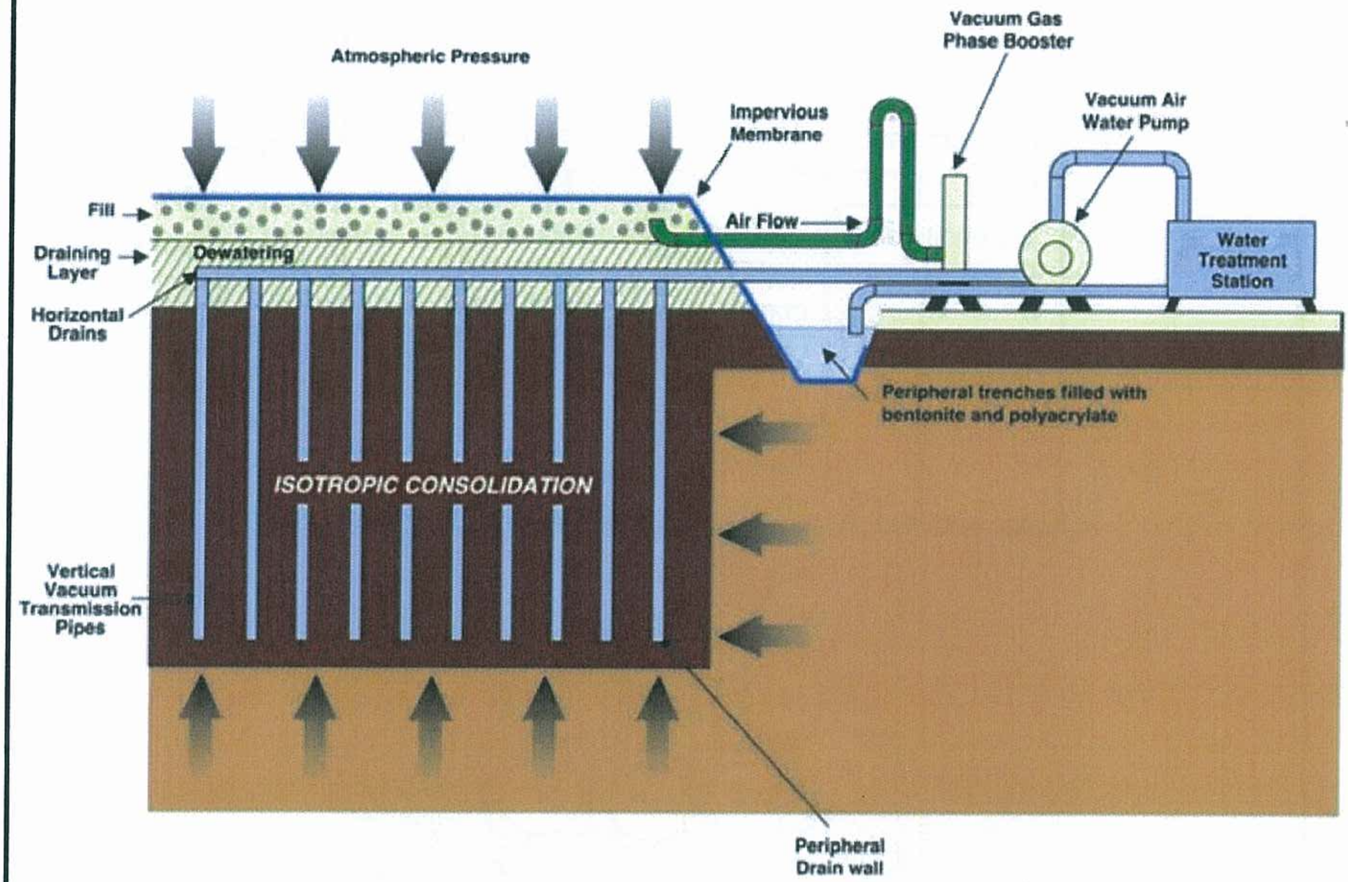
Job Title	Figure Title				
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Schematic Diagram and Photos of Installation of Stone Column Foundation**	ARUP Ove Arup & Partners Hong Kong Limited			
		Scale N.T.S.			
		Drn. DN	Date 10/07	Chd. PW	Passed PAT
		Job No. 24599		Figure No. 4.5	



1. Casing pipe is correctly positioned.
2. Casing pipe is driven into the ground using a vibro-hammer.
3. When it reaches the required depth, the casing pipe is charged with a specified volume of sand.
4. As the casing pipe is raised by a specified margin, the sand is discharged into the ground using compressed air.
5. The sand pile is compacted and enlarged by driving the pipe back down into the sand.
6. The pipe-raising, sand discharge and re-driving procedure is repeated numerous times as the pipe is gradually removed, forming a complete compacted sand pile.

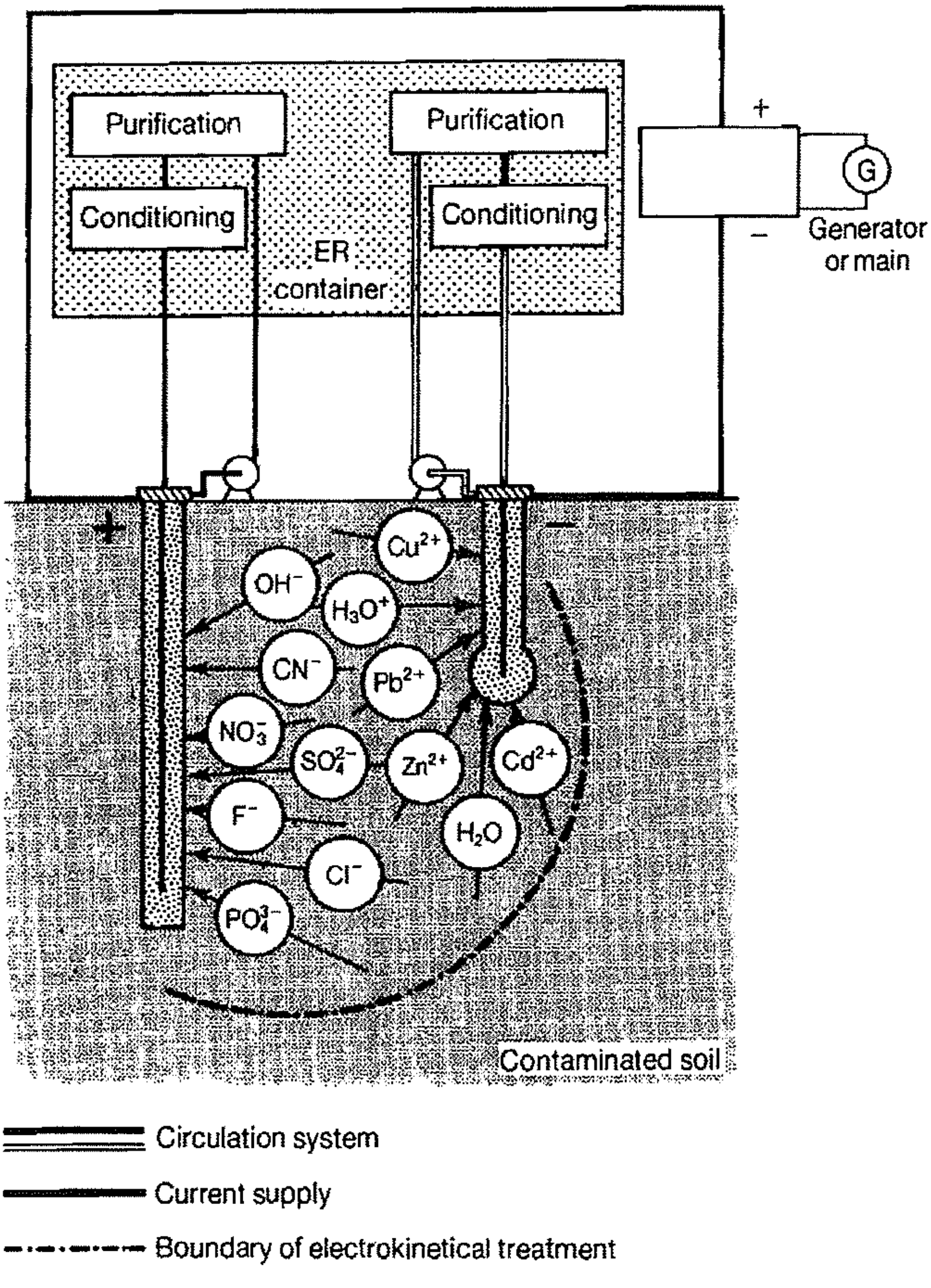
Schematic Diagram of Installation of Sand Compaction Pile

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Schematic Diagram and Photos of Installation of Sand Compaction Pile**	Scale N.T.S. Drn. CL Date 08/08 Chd. PW Passed PAT Job No. 24599 Figure No. 4.6



(Figures extracted from T. Stapelfeldt, Preloading and Vertical Drains.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Vacuum Dewatering System**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 4.7



(Figure extracted from Ciria Special Publication 109.)

Job Title CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	Figure Title **Schematic Representation of Electroremediation Field Installation and Electrokinetic Transport in Soil**	ARUP Ove Arup & Partners Hong Kong Limited Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 4.8

"Arabian Leopard" 12 – 30 inch pipeline Jet Sled (OES Equipment)

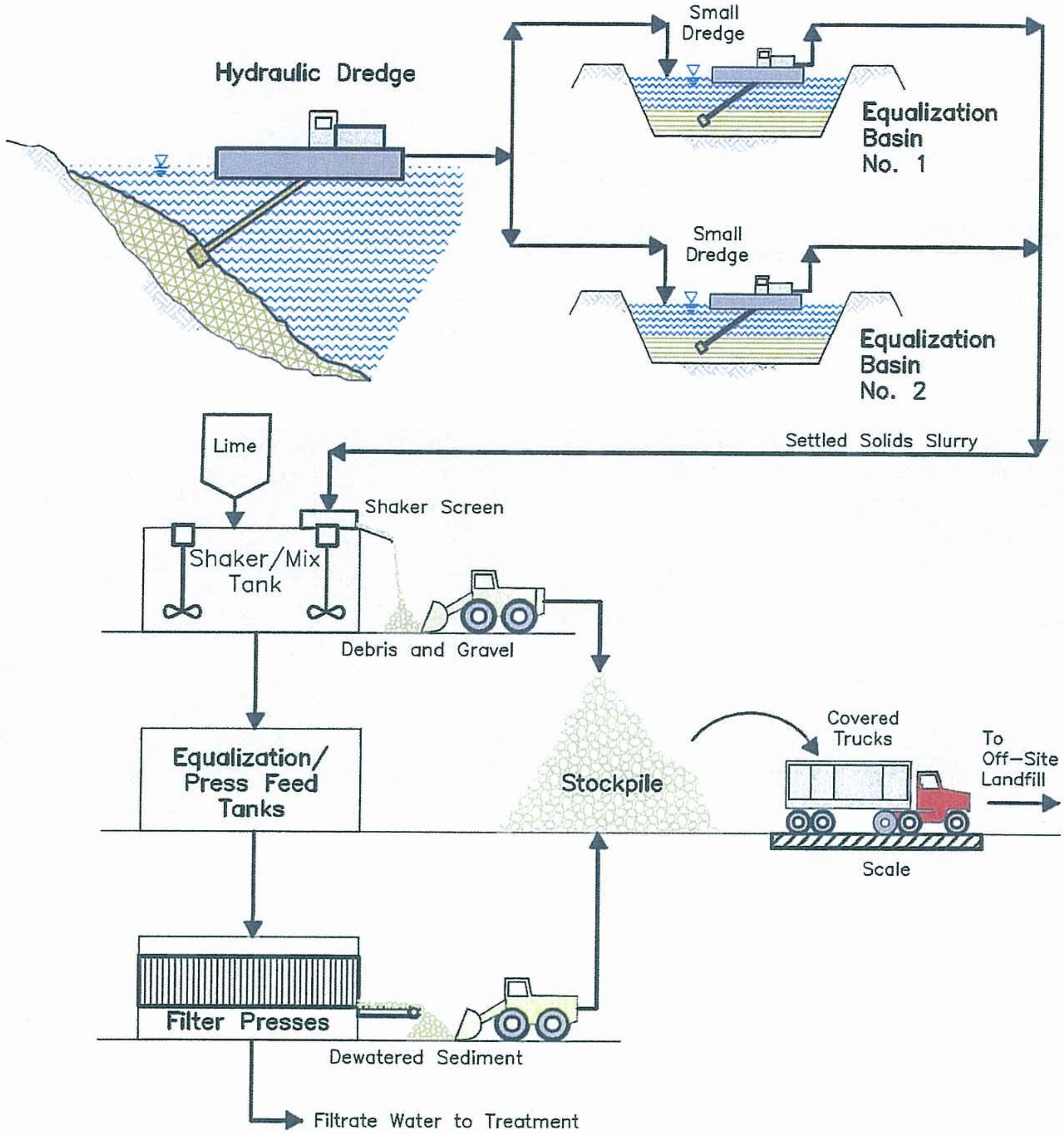
"Bengal Tiger" 30 – 60 inch pipeline Jet Sled (OES Equipment)

"Sumatran Tiger" 20 to 42 inch pipeline Jet Sled (OES Equipment)

"Canyon Horizon" Pipe Jetting Barge(Horizon Offshore equipment)

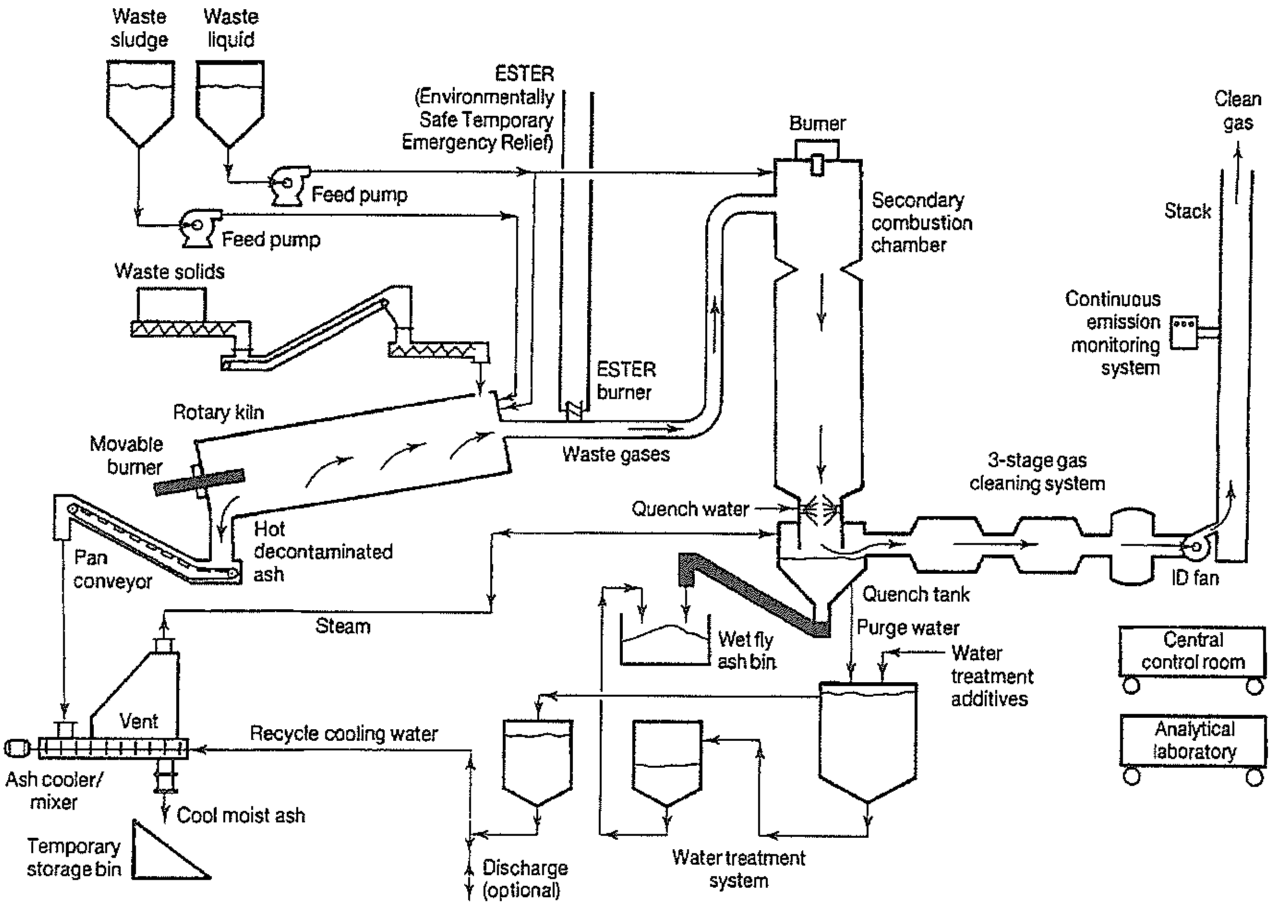
(Photos extracted from http://www.epd.gov.hk/eia/register/report/eiareport/eia_1252006/html/eiareport/Part2/Section6/Sec2_EIA%20PART%202%20S6%20Annex%206K_v3.htm)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited	
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Equipments for the Submarine Pipeline Jetting**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT	
		Job No. 24599	Figure No. 4.9



(Figures extracted from Montgomery Watson, September 2001.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Simplified Process Flow Diagram of Dewatering for Lower Fox River Project**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 5.1



(Figures extracted from Ciria Special Publication 107.)

Job Title	Figure Title	ARUP Ove Arup & Partners Hong Kong Limited
CEDD Agreement No. FM01/2007 - Review of Options for Management of Contaminated Sediment in Hong Kong	**Schematic Diagram of Direct-fired Rotary Kiln Incinerator**	Scale N.T.S. Drn. DN Date 10/07 Chd. PW Passed PAT Job No. 24599 Figure No. 5.2

APPENDIX

Appendix A

Assessment of Viable Management Options for Marine Works Involving Increase of Water Depth

Assessment of Scoring (1 to 5) to Each Parameter for the Viable Management Options

(1) Marine Works involving Increase of Water Depth

No.	Parameter	Confined Marine Disposal		Reuse as Construction Fill		Sanitary Landfill Cover	
P1	Volume of Sediment	5	Very large volume can be handled	4	Large volume can generally be handled	2	Capacity of the current landfills in Hong Kong is already limited
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	1	Existing mud pit for contaminated sediments is approaching its capacity; a new mud pit is required to cater for the ongoing demand	3	Anticipated volume in 10 years time can only be dealt with if new facilities for separation/dewatering are built	2	Significant difficulty to cope with the anticipated demand
P3	Engineering Constraints	5	Existing mud pit has been operated sucessfully	3	Technology under development all over the world; selective dredging may be necessary to obtain the right materials for intended use	3	Technology of dewatering required
P4	Operational Restrictions	4	Overall control and environmental monitoring system needed	2	High technological requirements in operation for quality control	2	Specially designed operation to suit local conditions
P5	Capital Cost	5	Cheapest	2	Very high incestment for the facilities; selective dredging may be required	3	high investment cost in undertaking mechanical dewatering for drying
P6	Recurrent Cost	4	Limited cost on management and monitoring	3	Economic benefits gained from material reuse may partially cover the costs of dredging and operation	3	moderate operation costs
P7	Programme	5	Shortest programme in both statutory requirements, construction and operation	2	long time required for facility construction and operation	2	Driven by slow progress of mechanical dewatering
P8	Impact on Water Quality	2	Dredging inevitable implying high impact; based on ongoing environmental monitoring minimal effect has been experienced	2	Dredging inevitable implying high impact	2	Dredging inevitable implying high impact
P9	Impact on Marine Ecological Habitats/Species	2	ditto	2	ditto	2	ditto
P10	Impact on Fisheries	2	high impact due to dredging and imposition of contaminated sediment	2	high impact due to dredging	2	high impact due to dredging
P11	Risks on Human Health and Safety	3	moderate risk on health and safety due to food chain	3	moderate risk on health and safety due to food chain and potential exposure	3	moderate risk on health and safety due to food chain and potential exposure
P12	Physical Properties of Sediment	5	typical physical properties of sediment in HK water can generally be dealt with sucessfully	3	Moderate flexibility in producing suitable recycled product	2	dictated by mechanical dewatering process
P13	Nature and Level of Contamination	4	typical nature and level of contamination of sediment in HK water can generally be dealt with sucessfully with various methods of confinement	3	Moderate flexibility in producing suitable recycled product	4	relatively high flexibility in dealing with the typical nature and level of contamination
P14	Sources and Locations of Contaminated Sediments	3	dumping area designated; requires marine transportation	3	transportation of sediments required for treatment	3	transportation of dredged materials to the treatment area and landfill site required
P15	Impact to the Hong Kong Construction Industry	5	Negligible impact due to past fruitful experience	3	Product treament and reuse has been in place for various industry	2	No direct application in HK; similar approach has been used for domestic and industrial waste in the sanitary landfill sites in Hong Kong
P16	Legal, Environmental and Societal Constraints	1	objection from environmental group and local residents is expected due to impact on water quality, ecology and fisheries	3	Balancing between dredging and beneficial reuse of materials	2	high impact due to dredging and high investment / operation cost
P17	Impact to Energy Footprint	5	Negligible impact	3	Treatment required (and hence energy consumption) to produce suitable reuse construction fill	3	Treatment required (and hence energy consumption) to remove contaminants
P18	Impact on Land Use	3	Moderate impact with mud pits creation	2	Treatment plant may be required; Quantities may be too large to be handled for a particular use, thus requiring land for storage facilities	1	Significant difficulty in finding suitable landfill sites

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty

Scoring and Ranking Table

(1) Marine Works involving Increase of Water Depth

No.	Parameter	Weighting	Confined Marine Disposal	Reuse as Construction Fill	Sanitary Landfill Cover
P1	Volume of Sediment	6	5	4	2
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	6	1	3	2
P3	Engineering Constraints	6	5	3	3
P4	Operational Restrictions	6	4	2	2
P5	Capital Cost	6	5	2	3
P6	Recurrent Cost	6	4	3	3
P7	Programme	6	5	2	2
P8	Impact on Water Quality	3	2	2	2
P9	Impact on Marine Ecological Habitats/Species	3	2	2	2
P10	Impact on Fisheries	3	2	2	2
P11	Risks on Human Health and Safety	3	3	3	3
P12	Physical Properties of Sediment	3	5	3	2
P13	Nature and Level of Contamination	3	4	3	4
P14	Sources and Locations of Contaminated Sediments	3	3	3	3
P15	Impact to the Hong Kong Construction Industry	3	5	3	2
P16	Legal, Environmental and Societal Constraints	3	1	3	2
P17	Impact to Energy Footprint	1	5	3	3
P18	Impact on Land Use	1	3	2	1
		Total Score	**263**	**191**	**172**
		Rank	**1**	**2**	**3**

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty

Appendix B

Assessment of Viable Management Options for Marine Works Involving Foundations and General Reclamations

Assessment of Scoring (1 to 5) to Each Parameter for the Viable Management Options

(2) Marine Works involving Foundations and General Reclamations (1 of 2)

No.	Parameter	Band Drains with Surcharging		Deep Cement Mixing		Vibro-replacement / Vibro-displacment Lime Piles		Granular Pile (Stone Column and Sand Compaction Pile)		In-situ Capping	
P1	Volume of Sediment	5	Basically independent of the volume of sediment	4	Large volume can be handled	4	Large volume can be handled	4	Large volume can be handled	5	Maximal volume can be handled
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	5	basically independent of the volume of sediment	5	Anticipated volume in 10 years time can generally be dealt with	5	Anticipated volume in 10 years time can generally be dealt with	5	Anticipated volume in 10 years time can generally be dealt with	5	Anticipated volume in 10 years time can generally be dealt with
P3	Engineering Constraints	5	This has been the most common ground improvement method applied in HK	3	No full scale application in HK; Stringent quality control required during mixing; not used for ground with obstructions; field trials normally needed	2	Technique basically identical to Deep Cement Mixing but with even less applications worldwide	4	Relatively more applications in HK, particularly for stone column; more flexible in application in adjusting diameter and spacing of granular piles	3	A relatively new remediation method; more researches needed to determine better capping alternatives with field and lab validation; a poorly executed capping placement would result in non-unifor / insufficient coverage
P4	Operational Restrictions	4	Long term settlement can generally be catered for upon operation	4	low impact to operation; soil bearing capacity and seismic stability enhanced	4	low impact to operation; soil bearing capacity and seismic stability enhanced	4	low impact to operation	1	Sediments are isolated but not treated; long term settlement and low strength of sediment would be issues for future developments
P5	Capital Cost	4	low cost	3	substantial investment cost	3	substantial investment cost	3	substantial investment cost	4	quite simplicity of use with low cost
P6	Recurrent Cost	5	Very low	3	minimal monitoring on performance	3	minimal monitoring on performance	4	minimal monitoring on performance	3	Performance monitoring with sediments basically not treated
P7	Programme	3	moderate time	4	A fast programme can be achieved with skillful workers	3	moderate time	3	moderate time	3	moderate time
P8	Impact on Water Quality	5	Negligible impact to water quality	3	Moderate impact associated with marine application of DCM; mitigation measures may be necessary	3	Moderate impact with addition of lime; mitigation measures may be necessary	4	Low impact to water quality by introducing sands or gravels	4	Low impact with controlled sequence and method of capping
P9	Impact on Marine Ecological Habitats/Species	5	ditto	3	ditto	3	ditto	4	ditto	4	ditto
P10	Impact on Fisheries	5	ditto	3	moderate impact due to cement placing	3	moderate impact due to lime placing	4	low impact	4	low impact
P11	Risks on Human Health and Safety	5	ditto; low risk on health and safety	3	ditto; moderate risk on health and safety due to food chain	3	ditto; moderate risk on health and safety due to food chain	4	ditto; low risk on health and safety	3	moderate risk on health and safety due to possible exposure to contaminated sediment with improper capping
P12	Physical Properties of Sediment	4	relatively high flexibility	3	rely on chemical reaction with sediment	3	rely on chemical reaction with sediment	3	may not be feasible for low strength sediment (stone column) or soils with SPT-N >15 to 35 (sand compaction pile)	4	relatively high flexibility
P13	Nature and Level of Contamination	4	relatively high flexibility	3	does not work well with soils having a high organic content and acidic	4	It can be used to treat with almost the entire range of soil types	4	relatively high flexibility in dealing with the typical nature and level of	3	may not be appropriate for sediments containing large accumulations of
P14	Sources and Locations of Contaminated Sediments	5	application generally independent of sources and locations of sediments	5	application generally independent of sources and locations of sediments	5	application generally independent of sources and locations of sediments	5	application generally independent of sources and locations of sediments	2	Not appropriate at sites that must be dredged to facilitate navigation; are subject to erosion and strong currents; and have steeply sloped bottoms
P15	Impact to the Hong Kong Construction Industry	5	Negligible impact due to fruitful applications	3	Overseas experience and technologies may be referenced	2	Less applications than DCM; Overseas experience and technologies may be referenced	4	Sufficient local knowledge	3	Overseas experience and technologies may be referenced
P16	Legal, Environmental and Societal Constraints	5	Negligible risk to the environment and public	3	moderate objection is expected due to impact on water quality, ecology and fisheries	3	moderate objection is expected due to impact on water quality, ecology and fisheries	4	Low risk to the environment and public	3	moderate objection due to impact on human health and safety
P17	Impact to Energy Footprint	5	negligible impact	4	low impact with minimal energy generation/transfer	4	low impact with minimal energy generation/transfer	4	low impact with minimal energy generation/transfer	4	low impact with minimal energy generation/transfer
P18	Impact on Land Use	5	Negligible impact with in-situ construction and operation	5	Negligible impact with in-situ construction and operation	5	Negligible impact with in-situ construction and operation	5	Negligible impact with in-situ construction and operation	5	Negligible impact with in-situ construction and operation

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty

Assessment of Scoring (1 to 5) to Each Parameter for the Viable Management Options

(3) Submarine Utilities Installation (1 of 2)

No.	Parameter		Pipe Jacking		Pipe Jetting		Horizontal Directional Drilling		Confined Marine Disposal
P1	Volume of Sediment	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	5	Very Large volume can be handled
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	1	Existing mud pit for contaminated sediments is approaching its capacity; a new mud pit is required to cater for the ongoing demand
P3	Engineering Constraints	3	Technology applied commonly in HK for land based work only; need for modification to suit marine applications; technical constrainsts on ground conditions, pipe size, and working length etc.	3	Technology has been developed and applied in few marine-based projects in HK; technical constraints on ground conditions, trendh depth, water depth, and measure to control pollutants from spreading into water etc.	4	Technology has been developed and applied in a number of marine-based projects in HK; techncial constraints on ground conditions, pipe size and type, and working length etc.	5	Existing mud pit has been operated sucessfully
P4	Operational Restrictions	4	routine maintenance required	4	routine maintenance required	4	routine maintenance required	4	Overall control and environmental monitoring system needed
P5	Capital Cost	3	Cost required in establishing temporary works, launch shafts	3	mobilization cost for jetting machine	4	Cost required in establishing temporary works, launch shafts, land-based equipment	5	Cheapest
P6	Recurrent Cost	5	Low maintenance cost	4	Low maintenance cost	4	Low maintenance cost	3	moderate cost on management and monitoring
P7	Programme	4	fast in construction	4	fast in construction	4	fast in construction	5	Shortest programme in both statutory requirements, construction and operation
P8	Impact on Water Quality	5	Negligible impact with no dredging	3	sediments at the top portion of the existing seabed is liquefied by the jetting machine and will mix with water; appropriate measures have to be exercised to minimize impact	5	Negligible impact with no dredging	2	Dredging inevitable implying high impact; based on ongoing environmental monitoring minimal effect has been experienced
P9	Impact on Marine Ecological Habitats/Species	5	ditto	3	ditto	5	ditto	2	ditto
P10	Impact on Fisheries	5	ditto	3	ditto	5	ditto	2	high impact due to dredging and imposition of contaminated sediment
P11	Risks on Human Health and Safety	5	Negligible	3	moderate risk on health and safety due to food chain	5	Negligible	3	moderate risk on health and safety due to food chain
P12	Physical Properties of Sediment	5	Almost independent of the physical properties of sediment	5	Almost independent of the physical properties of sediment	5	Almost independent of the physical properties of sediment	5	typical physical properties of sediment in HK water can generally be dealt with sucessfully
P13	Nature and Level of Contamination	5	Almost independent of the nature and level of contamination	5	Almost independent of the nature and level of contamination	5	Almost independent of the nature and level of contamination	4	typical nature and level of contamination of sediment in HK water can generally be dealt with sucessfully with various methods of confinement
P14	Sources and Locations of Contaminated Sediments	5	no impact	5	no impact	5	no impact	3	dumping area designated; requires marine transportation
P15	Impact to the Hong Kong Construction Industry	4	low impact due to mature technology developed and experience gained	4	low impact due to mature technology developed and experience gained	4	low impact due to mature technology developed and experience gained	5	Negligible impact due to past fruitful experience
P16	Legal, Environmental and Societal Constraints	5	Insignificant constraints	3	environmental impact may pose moderate constraints	5	Insignificant constraints	1	objection from environmental group and local residents is expected due to impact on water quality, ecology and fisheries
P17	Impact to Energy Footprint	5	Negligible impact	5	Negligible impact	5	Negligible impact	5	Negligible impact
P18	Impact on Land Use	5	Negligible impact	5	Negligible impact	5	Negligible impact	3	Moderate impact with mud pits creation

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty

Scoring and Ranking Table

(2) Marine Works involving Foundations and General Reclamations

No.	Parameter	Weighting	Band Drains with Surcharging	Deep Cement Mixing	Vibro-replacment/ Vibro-displacement Lime Piles	Granular Piles (Stone Column and Sand Compaction Pile)	In-situ Capping	Vacuum Dewatering System	Suction Can	Confined Marine Disposal	Reuse as Construction Fill	Sanitary Landfill Cover
P1	Volume of Sediment	6	5	4	4	4	5	4	5	5	4	2
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	6	5	5	5	5	5	5	5	1	3	2
P3	Engineering Constraints	6	5	3	2	4	3	3	2	5	3	2
P4	Operational Restrictions	6	4	4	4	4	1	4	3	4	1	2
P5	Capital Cost	6	4	3	3	3	4	3	3	5	1	2
P6	Recurrent Cost	6	5	3	3	4	3	4	3	3	2	1
P7	Programme	6	3	4	3	3	3	4	3	5	1	2
P8	Impact on Water Quality	3	5	3	3	4	4	5	4	2	2	2
P9	Impact on Marine Ecological Habitats/Species	3	5	3	3	4	4	5	4	2	2	2
P10	Impact on Fisheries	3	5	3	3	4	4	5	4	2	2	2
P11	Risks on Human Health and Safety	3	5	3	3	4	3	5	3	3	3	3
P12	Physical Properties of Sediment	3	4	3	3	3	4	4	4	5	3	2
P13	Nature and Level of Contamination	3	4	3	4	4	3	4	4	4	3	4
P14	Sources and Locations of Contaminated Sediments	3	5	5	5	5	2	5	5	2	2	2
P15	Impact to the Hong Kong Construction Industry	3	5	3	2	4	3	3	3	5	3	2
P16	Legal, Environmental and Societal Constraints	3	5	3	3	4	3	5	4	1	3	2
P17	Impact to Energy Footprint	1	5	4	4	4	4	5	4	5	2	2
P18	Impact on Land Use	1	5	5	5	5	5	5	5	3	2	1
		Total Score	**325**	**252**	**240**	**279**	**243**	**295**	**258**	**254**	**163**	**144**
		Rank	**1**	**6**	**8**	**3**	**7**	**2**	**4**	**5**	**9**	**10**

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty

Appendix C

Assessment of Viable Management Options for Submarine Utilities Installation

Assessment of Scoring (1 to 5) to Each Parameter for the Viable Management Options

(3) Submarine Utilities Installation (1 of 2)

No.	Parameter	Pipe Jacking		Pipe Jetting		Horizontal Directional Drilling		Confined Marine Disposal	
P1	Volume of Sediment	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	5	Very Large volume can be handled
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	5	Generally not a concern without the need of dredging	1	Existing mud pit for contaminated sediments is approaching its capacity; a new mud pit is required to cater for the ongoing demand
P3	Engineering Constraints	3	Technology applied commonly in HK for land based work only; need for modification to suit marine applications; technical constrainsts on ground conditions, pipe size, and working length etc.	3	Technology has been developed and applied in few marine-based projects in HK; technical constraints on ground conditions, trendh depth, water depth, and measure to control pollutants from spreading into water etc.	4	Technology has been developed and applied in a number of marine-based projects in HK; techncial constraints on ground conditions, pipe size and type, and working length etc.	5	Existing mud pit has been operated sucessfully
P4	Operational Restrictions	4	routine maintenance required	4	routine maintenance required	4	routine maintenance required	4	Overall control and environmental monitoring system needed
P5	Capital Cost	3	Cost required in establishing temporary works, launch shafts	3	mobilization cost for jetting machine	4	Cost required in establishing temporary works, launch shafts, land-based equipment	5	Cheapest
P6	Recurrent Cost	5	Low maintenance cost	4	Low maintenance cost	4	Low maintenance cost	3	moderate cost on management and monitoring
P7	Programme	4	fast in construction	4	fast in construction	4	fast in construction	5	Shortest programme in both statutory requirements, construction and operation
P8	Impact on Water Quality	5	Negligible impact with no dredging	3	sediments at the top portion of the existing seabed is liquefied by the jetting machine and will mix with water; appropriate measures have to be exercised to minimize impact	5	Negligible impact with no dredging	2	Dredging inevitable implying high impact; based on ongoing environmental monitoring minimal effect has been experienced
P9	Impact on Marine Ecological Habitats/Species	5	ditto	3	ditto	5	ditto	2	ditto
P10	Impact on Fisheries	5	ditto	3	ditto	5	ditto	2	high impact due to dredging and imposition of contaminated sediment
P11	Risks on Human Health and Safety	5	Negligible	3	moderate risk on health and safety due to food chain	5	Negligible	3	moderate risk on health and safety due to food chain
P12	Physical Properties of Sediment	5	Almost independent of the physical properties of sediment	5	Almost independent of the physical properties of sediment	5	Almost independent of the physical properties of sediment	5	typical physical properties of sediment in HK water can generally be dealt with sucessfully
P13	Nature and Level of Contamination	5	Almost independent of the nature and level of contamination	5	Almost independent of the nature and level of contamination	5	Almost independent of the nature and level of contamination	4	typical nature and level of contamination of sediment in HK water can generally be dealt with sucessfully with various methods of confinement
P14	Sources and Locations of Contaminated Sediments	5	no impact	5	no impact	5	no impact	3	dumping area designated; requires marine transportation
P15	Impact to the Hong Kong Construction Industry	4	low impact due to mature technology developed and experience gained	4	low impact due to mature technology developed and experience gained	4	low impact due to mature technology developed and experience gained	5	Negligible impact due to past fruitful experience
P16	Legal, Environmental and Societal Constraints	5	Insignificant constraints	3	environmental impact may pose moderate constraints	5	Insignificant constraints	1	objection from environmental group and local residents is expected due to impact on water quality, ecology and fisheries
P17	Impact to Energy Footprint	5	Negligible impact	5	Negligible impact	5	Negligible impact	5	Negligible impact
P18	Impact on Land Use	5	Negligible impact	5	Negligible impact	5	Negligible impact	3	Moderate impact with mud pits creation

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty

Assessment of Scoring (1 to 5) to Each Parameter for the Viable Management Options

(3) Submarine Utilities Installation (2 of 2)

No.	Parameter	Reuse as Construction Fill		Sanitary Landfill Cover	
P1	Volume of Sediment	4	Large volume can generally be handled	2	Capacity of the current landfills in Hong Kong is already limited
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	3	Anticipated volume in 10 years time can only be dealt with if new facilities are built	2	Significant difficulty to cope with the anticipated demand
P3	Engineering Constraints	3	Technology under development all over the world; selective dredging may be necessary to obtain the right materials for intended use	3	Technology of dewatering required
P4	Operational Restrictions	2	High technological requirements in operation for quality control	2	Specially designed operation to suit local conditions
P5	Capital Cost	1	Relatively high investiment cost for the facilities; selective dredging may be required	2	high investment cost in undertaking mechanical dewatering for drying
P6	Recurrent Cost	2	Economic benefits gained from material reuse may partially cover the costs of dredging and operation	1	relatively high operation costs for running the landfills
P7	Programme	1	long time required for facility construction and operation	2	Driven by slow progress of mechanical dewatering
P8	Impact on Water Quality	2	Dredging inevitable implying high impact	2	Dredging inevitable implying high impact
P9	Impact on Marine Ecological Habitats/Species	2	ditto	2	ditto
P10	Impact on Fisheries	2	high impact due to dredging	2	high impact due to dredging
P11	Risks on Human Health and Safety	3	moderate risk on health and safety due to food chain and potential	3	moderate risk on health and safety due to food chain and potential
P12	Physical Properties of Sediment	3	Moderate flexibility in producing suitable recycled product	2	dictated by mechanical dewatering process
P13	Nature and Level of Contamination	3	Moderate flexibility in producing suitable recycled product	4	relatively high flexibility in dealing with the typical nature and level of contamination
P14	Sources and Locations of Contaminated Sediments	3	transportation of sediments required for treatment	3	transportation of dredged materials to the treatment area and landfill site required
P15	Impact to the Hong Kong Construction Industry	3	Product treament and reuse has been in place for various industry	2	No direct application in HK; similar approach has been used for domestic and industrial waste in the sanitary landfill sites in Hong Kong
P16	Legal, Environmental and Societal Constraints	3	Balancing between dredging and beneficial reuse of materials	2	high impact due to dredging and high investment / operation cost
P17	Impact to Energy Footprint	3	Treatment required (and hence energy consumption) to produce suitable reuse construction fill	3	Treatment required (and hence energy consumption) to remove contaminants
P18	Impact on Land Use	2	Treatment plant may be required; Quantities may be too large to be handled for a particular use, thus requiring land for storage facilities	1	Significant difficulty in finding suitable landfill sites

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty

Scoring and Ranking Table

(3) Submarine Utilities Installation

No.	Parameter	Weighting	Pipe Jacking	Pipe Jetting	Horizontal Directional Drilling	Confined Marine Disposal	Reuse as Construction Fill	Sanitary Landfill Cover
P1	Volume of Sediment	6	5	5	5	5	4	2
P2	Anticipated Annual Rate of Contaminated Sediment Disposal	6	5	5	5	1	3	2
P3	Engineering Constraints	6	3	3	4	5	3	3
P4	Operational Restrictions	6	4	4	4	4	2	2
P5	Capital Cost	6	3	3	4	5	1	2
P6	Recurrent Cost	6	5	4	4	3	2	1
P7	Programme	6	4	4	4	5	1	2
P8	Impact on Water Quality	3	5	3	5	2	2	2
P9	Impact on Marine Ecological Habitats/Species	3	5	3	5	2	2	2
P10	Impact on Fisheries	3	5	3	5	2	2	2
P11	Risks on Human Health and Safety	3	5	3	5	3	3	3
P12	Physical Properties of Sediment	3	5	5	5	5	3	2
P13	Nature and Level of Contamination	3	5	5	5	4	3	4
P14	Sources and Locations of Contaminated Sediments	3	5	5	5	3	3	3
P15	Impact to the Hong Kong Construction Industry	3	4	4	4	5	3	2
P16	Legal, Environmental and Societal Constraints	3	5	3	5	1	3	2
P17	Impact to Energy Footprint	1	5	5	5	5	3	3
P18	Impact on Land Use	1	5	5	5	3	2	1
		Total Score	**316**	**280**	**322**	**257**	**173**	**154**
		Rank	**2**	**3**	**1**	**4**	**5**	**6**

Note - Impacts on parameters P5, P6 and P7 highlighted in yellow are those with great uncertainty